Monsters in the making

Design of the Nike Dual Transmission Line Loudspeakers by Hein Lass 2007

Design aims of the Nikes

- To have Dianna Krall oozing her huskiness in my living room
- Hear kick drums make a thwack rather than a bong
- Hear the sound made by Keb Mo's fingers on the frets as he changes chords
- Feel the couch shake to the low down grunt of Audio Slave's bass guitar
- Have Ricky Lee Jones sing without any sibilance
- Headbang with the audience at an Opeth gig
- Count the layers of musicians playing Mahler's 2nd

The main aim was to hear the music and not the speakers. For that one needs drivers that respond very fast with no cone break-up, an enclosure that can go down low without colouring the sound, and a crossover that do not induce phase shifts and differences in the crossover area to ensure holographic precise placement of instruments. The baffle had to prevent interference between the drivers, between the drivers and the baffle edges, and the enclosure sides had to be totally silent and vibration free even at high volumes and pumping low frequencies.

The above requirements dictated every design decision made in creating the Nikes.

First off the mid/bass clarity and kick drum thwack suggested a transmission line enclosure. No other enclosure design can get close to the bass and midrange response of transmission lines. This, coupled to the requirement to go low without a sub, will make for big enclosures, and I mean huge.

Driver Selection

There are literally thousands of drivers available to the serious hobbyist to choose from. I have tried a host of different drivers in my transmission lines over the years and have developed some preferences. Yes, I did manage to make polypropylene mid/woofers sound good, but not half as good and efficient as a cheap pair of Philips 8” paper cones used in one transmission line system (that was promptly bought by a serious hi-fi connoisseur to partner some rather expensive valve amps).

Many designs later I finally gave up on plastic cones. In my view plastic is much better suited for Tupperware bowls and one should not mount expensive magnets onto plastic bowls. They are too heavy and slow for my liking and the mids lack clarity. Oh woe, a host of commercial designs mate plastic cone mid/woofers to metal dome tweeters. Most of these are so shrill that they make my hair stand on end. If you suffer from listening fatigue after just one CD and your ears ring for the next half hour, something is seriously wrong. The boom/tish sound of plastic and metal is best left for youngsters in their mobile discos.

The search was thus on for a decent paper cone mid/woofer with a fairly low resonance frequency and a clean and fast midrange reaching some way beyond the tweeter’s roll off frequency. I have been happy with most of the cloth type tweeters that I have used over the years. I was sufficiently impressed once with a pair of metal dome tweeters used in the now defunct TDL transmission lines (made for them by Elac) that I did try some Seas metal domes in a later design. Sorry Seas, but I ripped them out and gave them away after a week to an elder with high frequency hearing problems. So back to old and trusted technology it was, a paper cone mid /woofer and a cloth tweeter.

Mid/Woofer

There is one paper cone mid/woofer that has been consistently used in many esoteric high-end designs. This is the famed 18W/8545k made by Scan-Speak. It has very good resolution in the bass and midrange, low colouration, precise imaging and the “open” sound that I prefer. In addition it has all the right characteristics to suit a transmission line enclosure. Agreed, they are not pretty and have been around for a while, but who cares?

You simply can not slap any old driver into a transmission line. Transmission lines prefer drivers with a fairly high Qms (3 to 6) and a fairly low Qes (0.3 to 0.4). The 8454k weighs in at a Qms of 5.2 and Qes of 0.3, right on target.

The resonance frequency is a low 28 Hz which is no mean feet for a 7” paper cone but one look at the magnet size explains all.

Tweeter

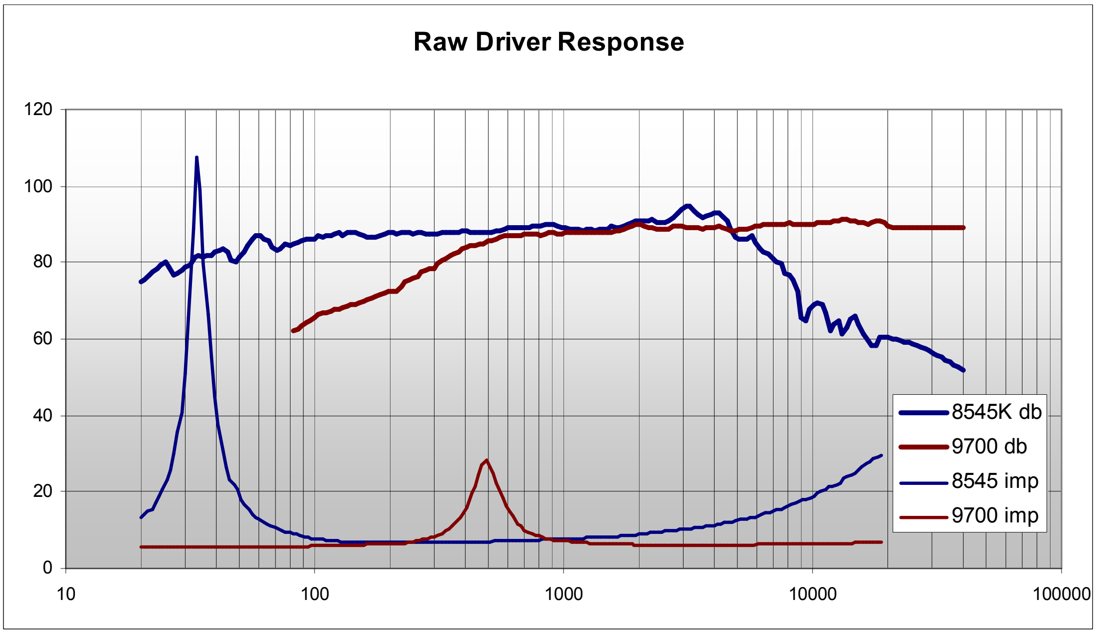
Top end without sibilance dictated a soft dome tweeter. Although I am quite happy with an upper end pair of Vifa cloth tweeters in my Halo Desktop Monitors, I was mightily impressed with some Scan-Speak 9700s in a commercial design at a hi-fi fair once. The choice was thus fairly easy and it will be the D2905/9700s for the Nikes. At the upper end they go well beyond what I am able hear, but more impressive is a low natural resonance at 500 Hz (making a fairly wide overlapping frequency range available for the crossover point). They have excellent dynamics with oodles of detail. The response curve can not be described as ruler flat, but it is good enough and the proof is in the hearing.

I thus chose the 9700 from ScanSpeak. The low resonance frequency allows for experimentation with the crossover point.

Raw Driver Response

The raw driver response curves show some lift in the upper end of the 8454k (between 3000 and 5000 Hz) and cone brake-up from around 9000 Hz.

The large overlapping area between it and the fairly linear tweeter should enable us to easily stay clear of any nasties.



Designing the Lines

When I designed my first transmission line speaker many years ago it felt like dabbling in the black arts. Theory was scarce and my first design was a copy of the famous TDLs. From then on I was hooked to the sound and I read whatever I could find and developed my own design spreadsheets.

Some of my systems had amazing bass and some had none. I learned about the humps and dips in line response and how to handle these. If you get it right, the back wave escapes from the port in phase with the directly projected sound of the driver. If you get it wrong, the waves are out of phase with a lack of bass. It can be quite disconcerting when you listen to a jazz bassist running up and down the scales and the sound disappears and then reappears further down. Thanks to excellent work done by Augspurger and King we now have a much clearer mathematical understanding of what happens inside transmission lines.

All my previous designs where of MTM configuration with the two mid/woofers in parallel sharing a single line. This works quite well and is used in most commercial designs, but the ripples in the response are always present. You can control their magnitude by tapering the lines, positioning the drivers some way from the closed line end and playing around with the stuffing to eat away some of the frequencies in the form of heat. Martin King's MathCAD model makes predicting these things a lot easier but I have always thought that there should be a better way of controlling the ripple. Then Eureka, what if two separate lines are used and you tune them so that the ripples are out of sync? In theory the peaks and dips should add to a flat response. This is not entirely my idea. I read article once on the Net speculation on the viability of such a double transmission line, but the author did not actually build it.

Although I have not seen this route pursued by other designers, this formed the basis of the Nike transmission line design.

Designing the lines took a bit of to and fro between MathCAD and AutoCAD. The end is a happy medium between the best response from MathCAD and what was possible in terms of folding these into a practical enclosure. The Scan-Speak's low Fs meant rather long lines making the enclosures fairly tall. To me this not an issue at all as you have to mount small box speakers on stands to get them to ear level anyway and the space underneath the boxes then become wasted space. One should see transmission line enclosures as speakers with built in stands and a as a bonus the stands are doing something useful to boot.

Most designers use a constant taper through the line and this is good practise to tame the ripples. However I had some success before with stepped tapered lines. This means whenever you fold the line you end the previous line slightly smaller than the theory predicts, you then open the next line slightly bigger than the constant taper theory predicts for this point and so on until you reach the port with the correct tapered down dimensions. Martin's model seems to handle this OK and both lines were thus designed in this fashion. The end result is better loading of the line and lower ripples in the response curves.

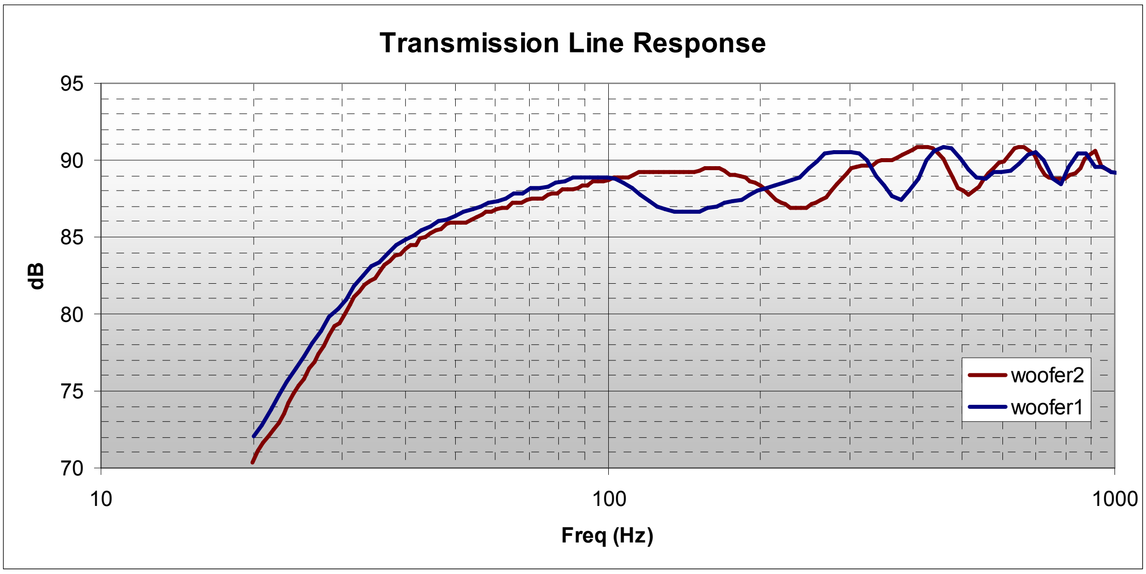
The end results are given in the following table and the picture shows how the lines are folded into the enclosure:

Nike line dimensions

	Line 1	**Line 2**
Line Length (mm)	2063.4	1813.4
Taper Ratio overall	2	3.57
Port Area Si (cm^2)	288	145
Closed End Area So (cm^2)	580	518
Line inside width (mm)	288	288
Port Height (mm)	100	50
Driver distance from closed end (mm)	412	664

The response from MathCAD is shown in the graph below.

Mmm, the ripples are mostly out of phase as required, except at 800 Hz where both have a dip. Playing around with the stuffing should address this but we will also see later that the baffle edge diffraction throws a 1.5 dB peak at 800 Hz. I love it when a plan comes together. The two lines have also lowered and shifted the impedance peaks.



Baffle Design and background waffle

The Baffle has a definite and major effect on the tonal characteristics of the sound from the loudspeakers. This is quite evident if one compares high-end loudspeakers with run of the mill speakers that clutters discount and appliance stores. At the bottom of the price scale, the drivers are simply slapped into (or even worse, onto) a squarish baffle in a rather symmetrical layout. High-end designs sport recessed drivers, non symmetrical layouts and rounded baffle edges. All of these are for good reasons and might need some explanation to the lay person.

Although, visual observation will make the casual observer believe that loudspeakers and everything around them are stationary. Nothing can be further from the truth as sound waves travel at the speed of sound (about 1195 km/h), albeit that the waves are invisible to the eye, but not true for the ear though. Not even the fastest racing cars travel close to the speed of sound, and the amount of work put into making their shapes more aerodynamic to lessen the effects of vacuums, eddy current break-aways etc. are legendary. Let’s consider modern fighter jets as these are actually capable of operating at the speed of sound and megabucks are spent to optimize the shapes and curves to keep things smooth and to reduce drag and other nasty effects when waves break away and behave erratically.

Sound waves emit from the loudspeaker drivers at high speed and anything (expected or unexpected) that it encounters on the way will severely influence the wave shape and direction, this include baffle and box edges and corners, and also the interaction of the various drivers’ waves with each other. The major factors that should be considered in baffle design are thus; the shape and size of the baffle, the edge shapes of the baffle, the distances between drivers and between drivers and baffle edges.

Baffle size and shape

The sound emitting from the drivers are projected into the 3D space of the listening room. The higher frequency waves have short wavelengths and bounces off the baffle and into the listening space. Low frequencies have longer wave lengths and when the ¼ wave length is longer than the width (or length) of the baffle, it does not encounter any baffle surface to bounce off and thus continues past the baffle edge and into the space behind the loudspeaker.

This causes the infamous “baffle step” with a 6db drop in the sound levels of the low frequencies. However, this is a rather simplistic view of the issue as there is not infinite space behind the speaker boxes in normal listening rooms (maybe in Buckingham Palace and thus not of concern to us). The waves that travel past the baffle edges might encounter other parts of the speaker enclosure (depending on the box shape) or continue on their journey until encountering other furniture or most likely the wall behind speakers. It bounces off these surfaces in complex directions and most often eventually reaches the listener to interact with the directly projected sound. Owing to the longer paths taken and the obstacles encountered, these waves reach the listener after the directly reflected waves with heavily changed shapes. These waves then interfere with the direct waves and the ear hears the sum total of this mix.

Not all is bad though as this “room effect” as it is known, tends to compensate somewhat for the “baffle step” loss and reduces the 6db loss. In practical listening rooms we thus get some lost bass back, albeit delayed and with unpredictable peaks and dips. Some furniture will reflect sound waves and some will absorb waves depending on its surface finish, density and shape, so experiment.

In a simplistic baffle that is rectangular with all the drivers mounted on the centre line, this “baffle step” will happen at the same frequency for all the drivers and results in a very audible and defined step. I know that this is a very simplistic analysis so far, but bear with me as things are getting a little more exciting from here on.

Baffle Layout

If one now staggers the driver positions so that we have unequal distances from the driver centres to the baffle edges things become more complex. Some waves now see a shorter distance say to the left of the driver than to the right. The “baffle step” now occurs at different frequencies and the 6db loss occurs over a wider frequency range (less pronounced step). If all the drivers are unequally spaced, we have several steps and the combined effect has been spread over wide frequency range. It should be appreciated that the same happens in all directions radially from the driver centre. At 90 degrees to the one side of the driver the distance to the baffle edge is x. At a few degrees more, we move slightly down and the distance to the edge is slightly longer etc. Unequal driver positioning thus spreads the step over a wider frequency range and makes it less pronounced.

Now you know why designers of rectangular box shapes stagger their drivers on the baffle and why some others prefer to use tapered or pyramid shaped boxes. All that they are trying to do is to spread things around a little. The real gung-ho designers even design oval enclosures to limit the baffle step.

Edge Diffraction

But this is only part of the picture. We now know that at higher than a specific frequency, the waves are reflected off the baffle. We also know that lower than a specific frequency, the waves travel past the edge into the space behind the speaker enclosure. But what happens to the unlucky wave that hits the edge and how does that influence what we hear?

It is time to go back to racing cars and aircraft. When air flows over a surface at speed interesting things happen. Let’s divide the air stream into several layers. The layer closest to the surface is slowed down by the friction between it and the stationary surface (the logic is the same for stationary air and a fast moving surface as all things are relative after all). The next air layer up moves slightly faster and this continuous away from the surface until we have moved far enough away from the surface for the friction effect to become negligible. This is known in engineering terms as the “boundary layer” effect.

The faster travelling upper layers thus bend down towards the slower layers. The net effect is that the air flow bends towards the surface to hug it as it travels past.

If we now curve the surface slightly the flow will still try and hug the surface and as we bend the surface more and more, a kind of rolling motion occurs at the front of the flow path towards the surface. If the bend becomes too sharp the rolling motion can not fill the void fast enough. This is where the flow actually brakes away from the surface and is sent spinning into space in vortexes known as Eddy currents. At this point uniformity goes for a loop and things get very complex and unpredictable.

Now, what has this got to do with loudspeakers and edge diffraction? Actually quite a lot. If our baffle has a large curved edge, several waves will bounce off the edge curve surface in a predictable manner. If the edge curve becomes small, the wave range that can bounce of the edge surface become narrower and the bounce angles more unpredictable. When the edge is sharp, it is similar to the vortex break-aways described above. A mess of interference patterns and shock waves are hurtled into the listening room and is commonly referred to as distortion.

Another way of looking at this is to consider the waves as a sandwich of sound frequencies going around the sharp edge. The shorter wavelengths hug the surface closely and the longer waves less closely. The wave that just makes it past the edge is torn away from its buddy on the inside causing shock waves, turbulence and other nasties. Aerodynamic principles can thus be applied to loudspeaker and baffle design (in my mind at least).

Soundstage

Let's forget about sound systems in the home and consider live musicians on stage for a moment. Whether it is a symphonic orchestra in a cathedral or a jazz band in smoky club, the principal stays the same. Individual performers and instruments are positioned in 3D space with width, depth and height (to a lesser extend) positioning information.

Your poor loudspeakers have to try and emulate all of this information and create something as close to the original as possible. Logic dictates a multitude of channels and a clutter of speakers all around your room. OK, so we all agree that this is not practical and designers have settled on stereo to try and simulate 3D spatial sound. By the way, if you are using a home theatre system to listen to music, please switch of the surround mode when listening to normal stereo CDs. If you can not hear the improvement in the bass and soundstage definition something is seriously wrong somewhere (this is obviously not applicable to surround recordings such as SACD).

Two point sources probably have the best hope of achieving this rather daunting task. This is the argument followed by single driver affectionate who are quite happy to sacrifice the bottom end in an effort to have a single driver producing the entire frequency range.

Our quest for a flatter and wider frequency range have resulted in purpose designed drivers such as woofers, mids and tweeters. However, the more drivers the more complex the crossover to separate the frequency range into separate and defined ranges. Crossovers make use of capacitors and inductors and these causes serious phase shifts. The more drivers used, the more complex the crossover and its side effects. This is why designers of complex speakers tend to prefer active crossovers as it makes for easier handling of the phase shifts.

Why are phase shifts important you might ask? In wave theory there is a phenomenon known as interference. Interference theory dictates that if two waves are in phase, they combine with a summed response. However, if two waves are out of phase, they combine and cancel each other out. This is used by car designers such as Lotus to reduce noise in their cabins. They pick up the road, engine and wind noise, invert the phase of the signals and amplify this via speakers into the cabin. The out of phase noise signals cancel each other out and thus a quieter car, neat.

Anyway, back to loudspeakers. If the frequency range is broken into discrete bands and fed to multiple speaker drivers, we have interference at the transfer points. These overlapping waves might be in or out of phase or somewhere in between and thus cause humps or dips in the frequency response, and might even shift the position of a specific instrument around on the sound stage as it is transferred from one driver to the other. Even if rock performers move around on stage, their amps stay stationary (except Jimmy Hendricks of course pushing and pulling his speakers around and Keith Emerson doing similar things to his organ). So mostly we expect instruments and their positions to be well defined.

This is why I prefer two-way designs with fairly simple and minimalist crossovers. However, two way designs have problems of their own. A large driver that can produce sufficient bass might not be able to reach the roll off point of the tweeter, or even if it does, the cone might start breaking up causing horrible interference and distortion. Cone break up is simply where the cone stops acting as a piston and standing waves form in the speaker cone (again simply a matter of wave lengths short enough to form standing waves in the cones owing to the cone diameter).

In essence mid/woofers are thus smaller in diameter to woofers so that they can reach the tweeter roll-off. In general, the smaller the cone diameter the less bass it can produce. The short and sweet is that most high-end two way speakers thus make use of two mid/woofers to emulate one larger driver with more bass response. Interference theory also results in the summation of the sound pressure levels (louder) and making matching to the tweeter sound levels easier. Most tweeters are light and more efficient than larger and heavier speaker cones. At worst, if you use a single mid/woofer that is less efficient than the tweeter you might have to burn away some tweeter signal in the form of heat with resistors in the tweeter circuit (but this is a waste of energy).

Back to my favourite practise of using two mid/woofers in parallel and one tweeter. The drivers can be positioned in various ways on the baffle and specific designers (and manufacturers) prefer specific layouts. Proponents of point source emulation prefer the tweeter in the middle with the mid/woofers above and below. This is either called MTM (mid/tweeter/mid) of D'Appolito after it’s, by now famous, designer. The idea is to emulate a point source with its centre at the tweeter position and a large bass driver with its centre at the same point.

I rather prefer this kind of layout but it has some pitfalls to consider. If all the drivers are in line we have some serious lobbing effects projected into the listening space. This is owing to interference patterns between the drivers and the symmetrical edge effect problems previously discussed. Cheaper manufacturers happily slap all the drivers in line and on the centre of the baffle. High end designers tend to stagger the drivers to improve dispersion and lessen the lobbing and edge effects.

Nike Baffle Design (finally)

So how is all of this incorporated into the Nike baffle?

Transmission line enclosures are complex to build and one way of keeping it simpler is to have parallel sides. The advantages of pyramidal shapes and constantly changing edge distances can be employed but makes building the boxes very difficult. On the positive side, transmission line enclosures tend to be tall and at least the distance to the bottom edge of the enclosure is long. If the baffle is mounted flush into the enclosure, the entire box height can be considered as baffle height. In addition, beneath the bottom edge is the floor and not empty space as would be the case with smaller boxes on stands. The waves that would have bent around the edge into empty space are now reflected off the floor and towards the listener. The amount of reflected sound is determined by what you have as a floor and what it is covered with (you thus have some measure of control by changing and moving carpets around).

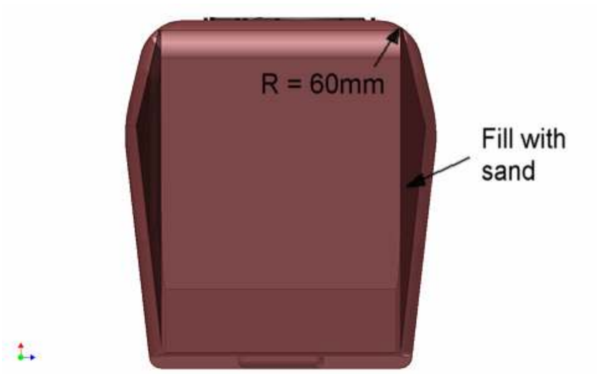
The main culprits will thus be the two sides and the top edge. I made use of the biggest edge radii that the design and wood thickness allowed. In practise this turned out to be around 16mm radius for the side edges and 30mm for the top edge radius. OK, it was a lot better than a sharp edge but I still did not like it much. The smoother things are the better and I thus do not employ any form of grill or cover over the drivers (grill frames mostly negate all your efforts to reduce edge interference). The Watts employ an open foam type cover without any frame and I think that this is a move in the right direction (although some traditionalists think it is cheap and flimsy).

I used my own spreadsheets to get some rough driver positions. The idea is to stagger them such that no distance to the edge is the same as for any other driver/edge. In addition, the spacing is also such that no multiples of standing waves can happen (i.e. it is of no use to have the one distance exactly double the wavelength of another edge distance).

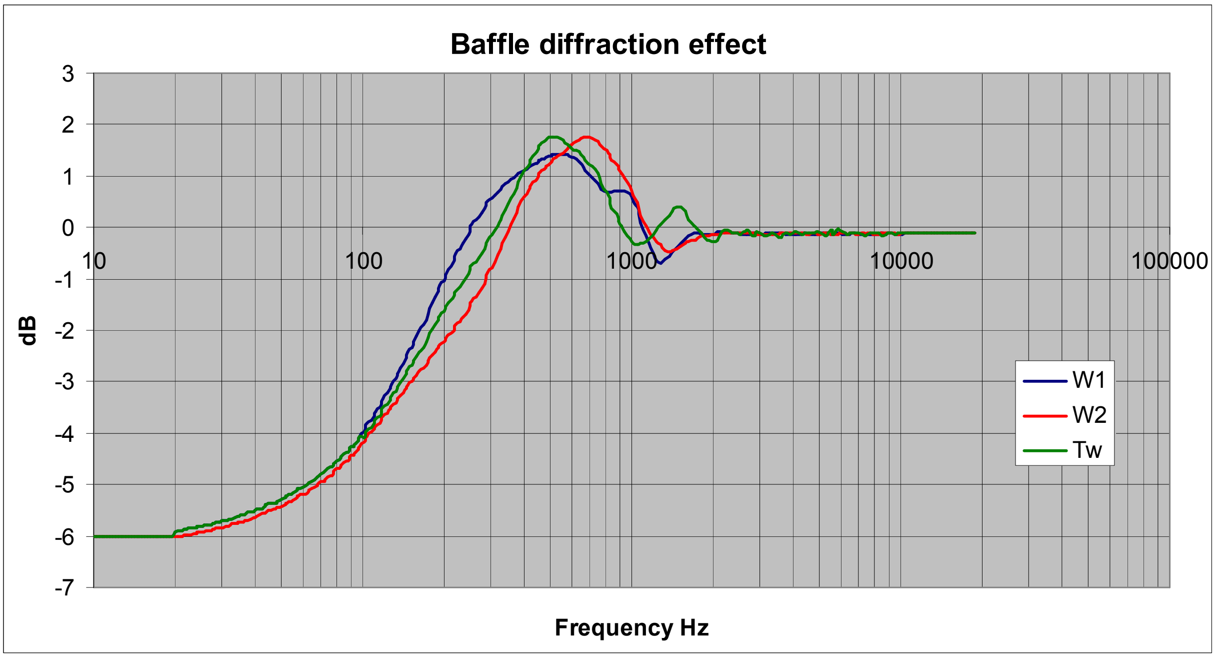
In order to best emulate a point source, the drivers are positioned as close to each other in the vertical plane. These positions then served as input for the excellent Baffle Diffraction Simulator spreadsheet developed by Paul Verdone available on the Net. I did some fine tuning moving the drivers around until I had the smoothest frequency response. I am happy to say that my simplistic calculations where very close to the final result.

The 320mm baffle with 16mm radius edges causes peaks of up to 1.8dB between 600 and 800 Hz and a -1.3dB dip in the tweeter response at 3000 Hz with some other smaller peaks and dips distorting the response. The graph shows the baffle edge effect after I have added false sides to the box. These are filled with sand to dampen any box vibrations and allowed for a much bigger radius to be used for the box edges.

The end result was effectively a wider baffle with 60mm edge radii. The biggest hump is now 1.6 dB shifted lower to 700 Hz and the tweeter dip at 3000 Hz disappeared completely. The curves are a lot smoother in general and the diffraction far more under control and predictable. An additional benefit is that the roughness in the response in the area where we will be crossing over (1000 Hz to 3000 Hz) has disappeared; this will make the design of the cross over somewhat easier.



Although the result is impressive there is still a slight hump in each driver's response (550, 600 and 700 Hz). I could not get rid off this with layout tweaking. Remember when we designed the transmission lines there was a slight dip at 800 Hz and only the summed response will dictate if this should be addressed with the crossover design when room effects have been taken into account.

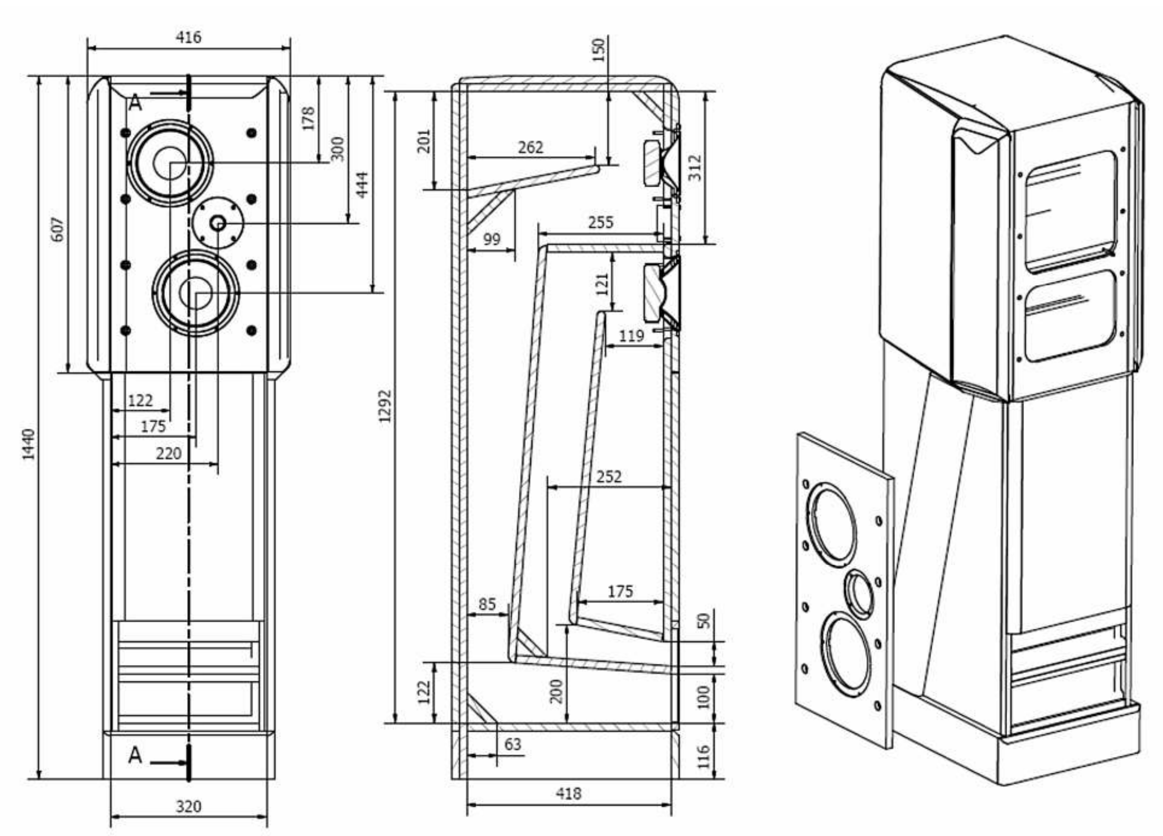


The response rolls off smoothly from 350 Hz down. Not good but the room effects will compensate for this as we will see.

If you think this graph is a bit rough for high-end sound, you should see what the diffraction curves of some very expensive loudspeakers look like. The Nike's baffle diffraction actually looks good and at least it is well defined and something that we can address and tame with the crossover.

Note the rounded edges on the inside of the driver cut-outs to prevent standing waves and interference with the driver cones.

The final enclosures



The Nikes are big, they are 416 mm wide and nearly 1.5 m tall. The box consists of two independent folded transmission lines for reasons as explained previously. The lines are tapered to eliminate standing waves and improve the loading of the drivers. All corners are filled and rounded with silicon sealant and all internal surfaces are lined with thick carpet underfelt.

The lines are partly filled with batting (synthetic fibre filling used for cushions and upholstery). The fillings are from behind the drivers to the closed ends only and are very loosely packed, less than normal as usually recommended for more traditional single lines (owing the line ripple cancellation achieved with the two differing line lengths).

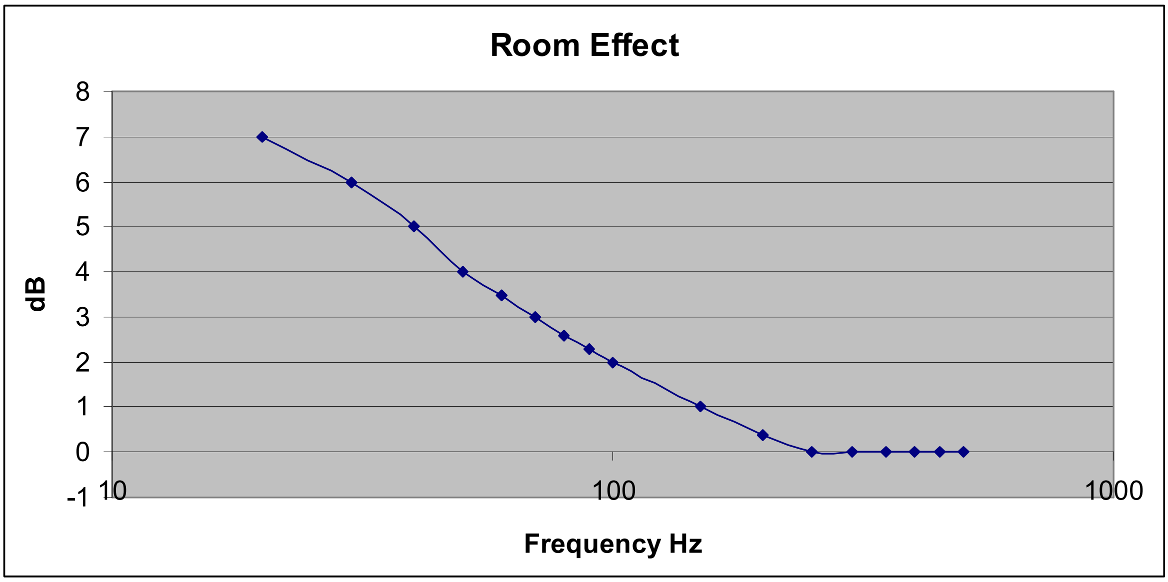
The boxes have false bottoms for mounting the crossovers outside of the lines. The upper half of the boxes have double walled with sand filling (swimming pool sand) to dampen panel vibrations. Slanted braces are glued to the lower half of the side panels for stiffening.

All woodwork is Superwood (a South African branded fibre board similar to MDF). The boxes are sturdy and heavy and needs at least to people to lift or carry. The ports are covered with speaker cloth to keep mice and insects out but the baffles are currently bare. I do not want grill frames to interfere with the sound and will only add grills if I can get hold of the right acoustically transparent foam. The baffle outside surface is covered with felt to dampen higher frequency reflection slightly.

Room effect

As discussed extensively before, the baffle edge effect predictions consider the speaker to be in the middle of a very large room and thus the 6 dB drop. Real rooms do not behave like this as the sound waves that bend around the enclosure is reflected back to the listening position by the rear wall, the floor, ceiling, sidewalls and hard furniture.

Martin Colloms have done some good work on room effects and has developed some curves for room effects in typical rooms.

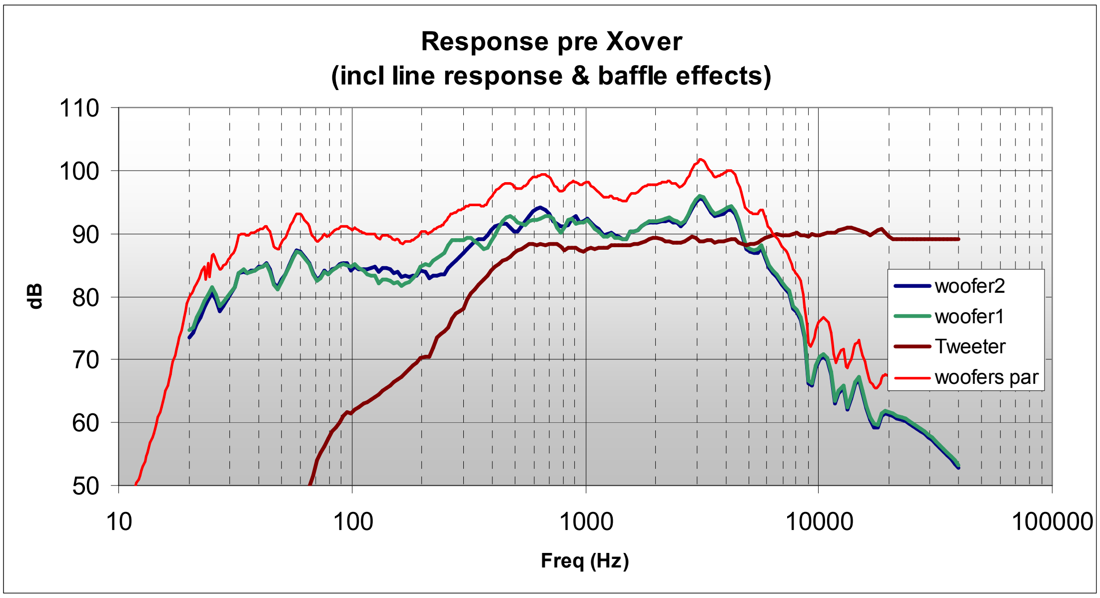


In essence it means that we do not loose as much bass in the typical room as predicted for a loudspeaker in the middle of the desert.

The Nike Crossover

Crossovers are necessary evils in multi driver speaker designs. We need to limit the amount of low frequency signal send to the tweeter as tweeters are quite delicate little creatures with voice coils that can be fried fairly easily. We also need to limit the amount of high frequency signal sent to the mid/woofer to avoid cone break-up and the resultant distortion (quite evident at the high end of the woofer if one looks at the raw driver response).

Just to put things in perspective lets have a look at the response graph that we have so far with all the effects incorporated that we previously discussed.



With the two woofers in parallel it is clear that there is a massive problematic hump between 230Hz and 6600Hz. One option is to filter one of the woofers out at about 250Hz and only allow one of the woofers to cover the midrange. This sounded like a good idea until modelling in the Passive XOver design spreadsheet showed some problematic phase shifts between the two woofers.

I thus decided to stick to my original parallel woofer design (with one crossover controlling both) and to correct the midrange hump with a more complex cross over.

First off, we will follow the usual practise and notch the woofer impedance hump down somewhat. This is done by connecting a series resistor and capacitor in parallel with the woofers. This also levels out the impedance rise at higher frequencies and makes the high pass filter design a tad easier. Secondly we will add a RLC circuit in parallel to the tweeter to get rid of the hump in the tweeter impedance at 500 Hz. This will also increase the roll off slope of the tweeter when combined with the high pass filter. Not a bad thing as it ads protection to the tweeter's voice coil and allows us to use a fairly low crossover point if we so wish.

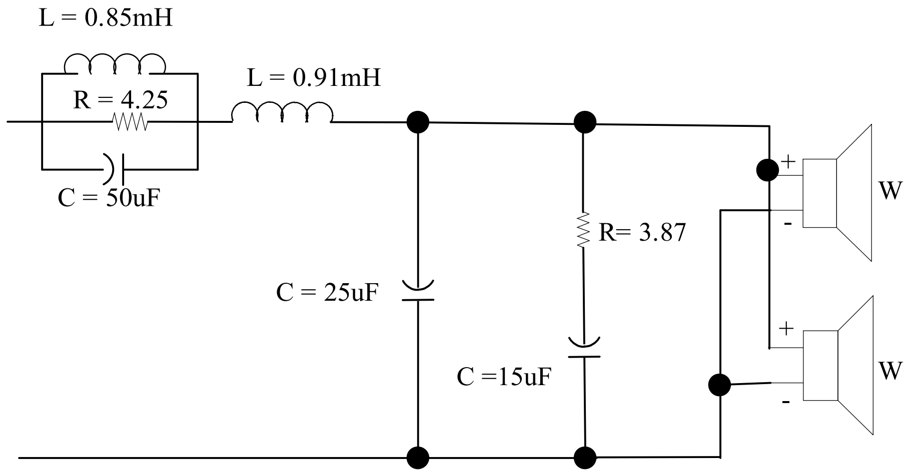
The next question is what slopes to use for the filters? There are two camps in crossover design. The adherents of steep slopes believe that they can reduce the amount of driver overlap and supposedly also address some other frequency humps and dips caused by bad baffle design, phase differences etc. Steep sloping filters requires lots of electronic components and component interaction can become rather complex (and come at a monetary price). Then there are the minimalists that prefer less components and gentler slopes.

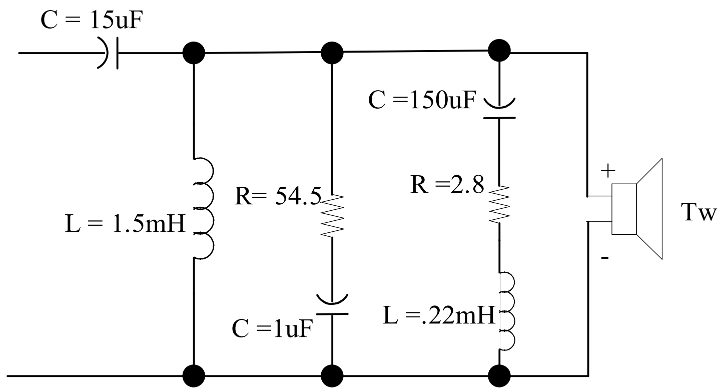
Both arguments carry some value and I was led here by my own experience. I have tried various filter slopes in previous designs. The best result I have ever achieved was with the Philips paper cones previously mentioned using first order filters with 6db slopes. The worst result was with my current PC transmission lines using 24 dB slopes. I had headaches for weeks trying to get to the source of some serious ringing, until I ripped out half the crossover components in desperation and changed them to 12 db slopes. I could not believe the improvement in the sound and this exercise cured me from complex filters for life.

I originally wanted the cross over point to be below 2000 Hz as cone beaming starts around there for the woofers, but phasing problems between the woofer and tweeter drove the cross over point slightly up to 2360 Hz.

The woofer has a RLC contour network in series before the cross over to flatten the midrange hump.

The final crossover circuit (after lots and lots of tweaking) is as follows:

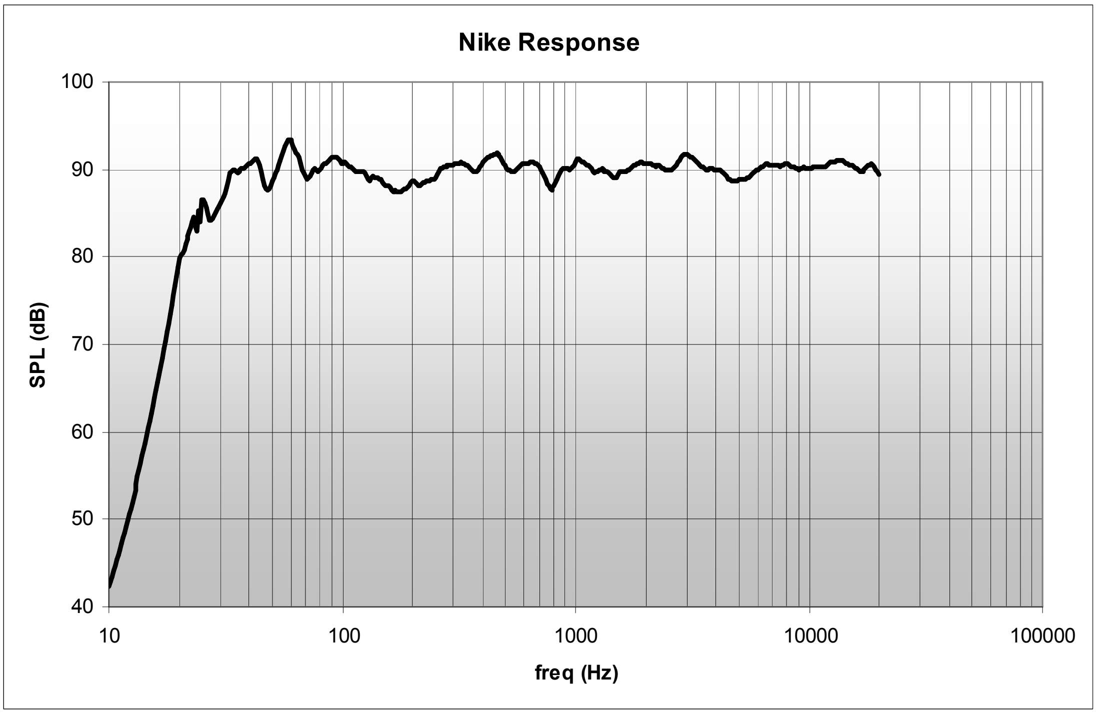




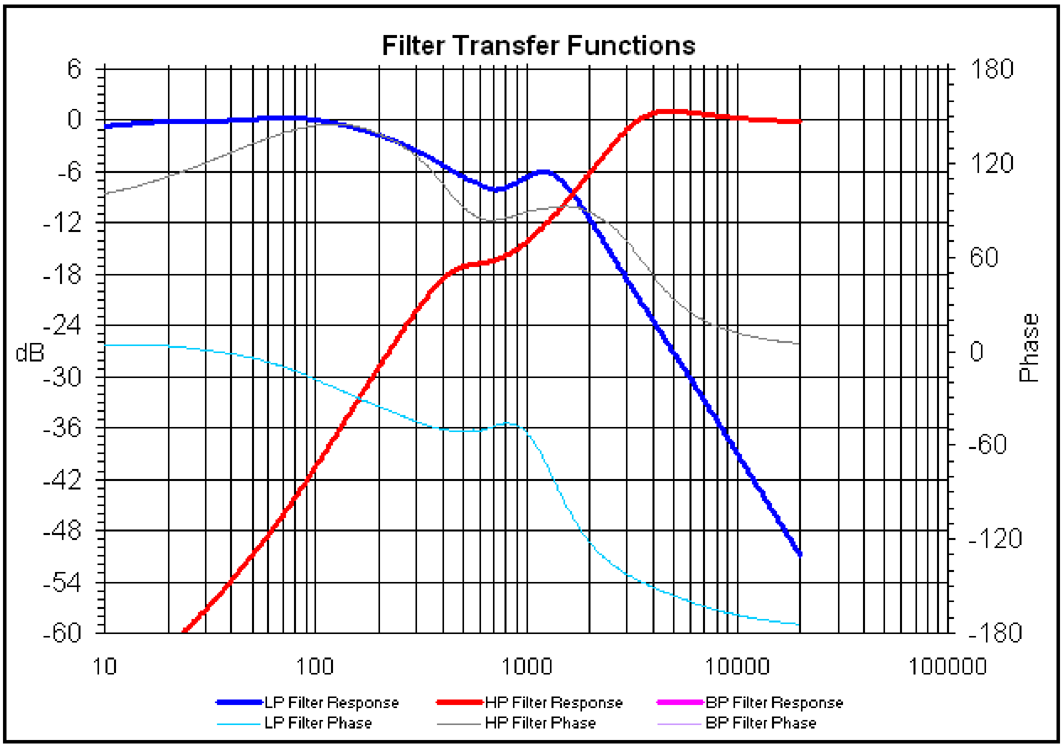
None of the crossover component values are text book values as this resulted in phase discrepancies between the woofers and the tweeter. Lots of tweaking resulted in values that took care of the baffle step and the radiation centre distance difference between the tweeter and the woofers (I used a flat baffle to limit diffractions caused by surface step changes and the listening distance to the tweeter's acoustic centre is thus slightly shorter than to the woofers).

The woofers and tweeter is virtually in phase at the crossover point, with the woofers at 111 degrees and the tweeter at 105 degrees. The response curve is not entirely ripple free but all are within a 3 db band and I am quite happy with results.

Nike frequency response



The filter transfer functions show the sound shaping that I had achieved by tweaking the component values. It is far from text book stuff, but suites the drivers, box and baffle layout rather well. Note that the transfer functions suggest a cross over point of 1750 Hz, but with the drivers in the Nike boxes it actually results in a 2360 Hz cross over point.



The Proof of the Pudding

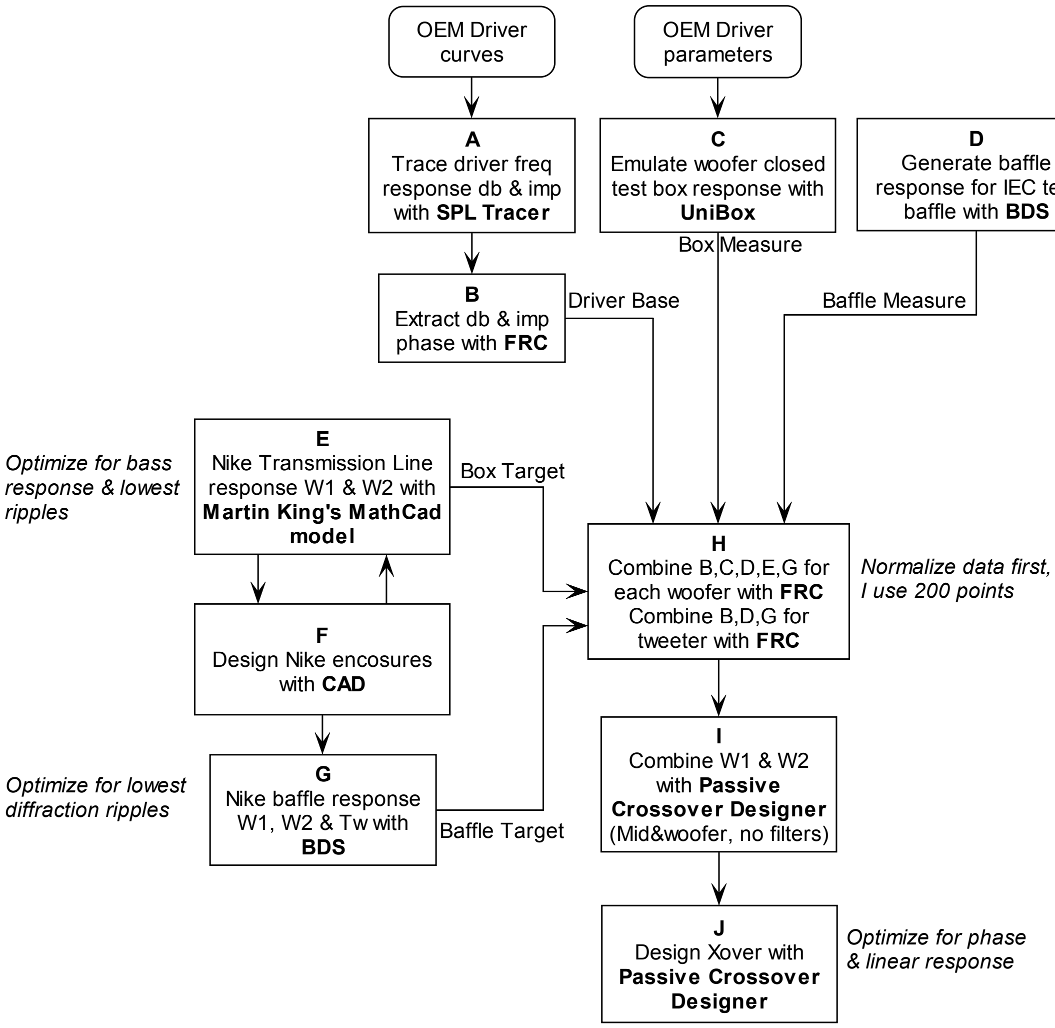
The proof of all my labour is in the hearing. The Nikes are totally awesome and everything that I have ever dreamed off to own in terms of high fidelity sound reproduction. What more can I say?

I certainly do not have the most expensive music system in the world, but if you close your eyes you won't be able to tell that Keb Mo is not right there in the room with you. For those interested, the rest of the system is a rather dated Marantz CD player, Harman Kardon DVD/SACD player, Rotel surround processor and Rotel power amplifiers.

The AV speaker setup is completed by a Vifa/Seas based centre speaker and two rear Vifa based surround speakers. Although the centre and rear speakers are also of my own design, they are of more conventional design. Note the absence of a subwoofer (definitely not required by the Nikes) as they will do more harm than good.

Design Logic

The following flow diagram sums up the design process of the Nikes. Extensive use was made of the excellent tools from the FRD Consortium website. Acronyms are used for the various FRD spreadsheets. Output data from the each spreadsheet is exported as FRD (response) or ZMA files (impedance) to be used in other spreadsheets. Descriptive naming of the files is paramount as one can easily get confused between the various output files.



A Last Word

After many years of experimentation, I finally produced a pair of loudspeakers that I am overawed by. You can throw absolutely any music style at it and it will handle it with aplomb. The Nikes were 3 years in the making but worth every minute I spent on designing and building them.

I finally own a pair of loudspeakers that I do not want to start upgrading after a few weeks of listening. Well, there are the 9700 tweeters that I might want to upgrade. I am not entirely convinced that they are worth their cost and reputation. Don't get me wrong, the Nike's sound is almost perfect but I do feel that I should be able to improve the top end. Any suggestions?