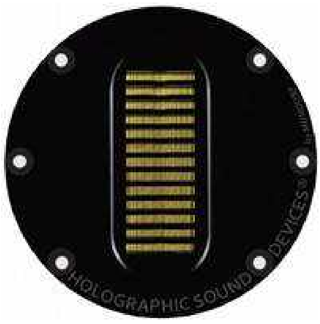
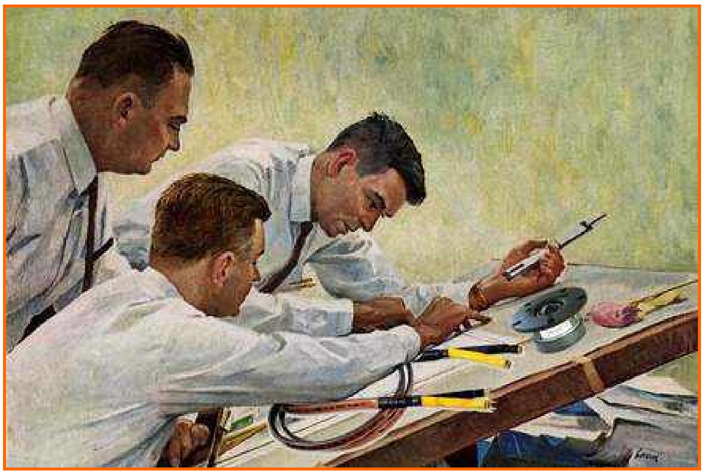
L' Orfeo - design concept

The L'Orfeo loudspeaker is designed to be a reference grade, two-way speaker kit based on very high quality components in a cleverly thought out and easy to build enclosure. The relatively compact and slim shape of this floorstander should integrate into many an interior, especailly when you consider that the finishing options are nearly endless if you build them yourself. The main ingredients are an 18cm Scanspeak Illuminator midwoofer combined with a large Mundorf Air Motion Transformer tweeter. Both were chosen for their high resolution, low distortion and wide usable bandwidth. Furthermore the final system should have a healthy 8 ohm nominal impedance so that the choise of a partnering amplifier is made easier. And last but not least, the overall tonal balance must be extremely neutral so that this loudspeaker can be used as a tool as well as a means to listen to a large, varied repetoire of music.

This Illuminator midwoofer from the Danish company Scanspeak is in every aspect an unusual design with it's open construction, the extremely long linear excursion and patented under-hung SD-3 (Symmetrical Drive) neodymium motor system, which due to copper caps and its construction ensures very low distortion, adding the unique patented cones, low-loss linear suspension the result is (if we are to believe Scanspeak): “The Very Best Money Can Buy”! The L'Orfeo uses the Scanspeak 18WU8741T-00 paper cone version which produces a remarkable combination of deep bass and midrange neutrality - ideal if you're looking for wide bandwidth from a relatively small enclosure. I have found this driver to be very flexible and can be used in many cabinet types ranging from small, well damped closed boxes of about 15 litres up to large bass-reflex systems getting close to 40 litres and with only a small amount of damping material inside. The L' Orfeo bass-reflex cabinet has an internal volume of 35 litres but if your space is limited or the speakers have to be placed very close to a wall, it is possible to build the L' Orfeo as a (smaller) closed box without any alterations to the crossover. More about the cabinet design in the next chapter.



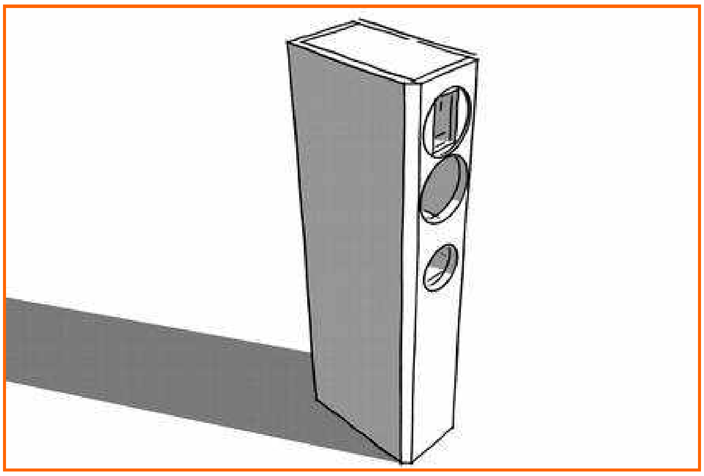
The Mundorf AMT (Air Motion Transformer) Concert Model 2510c has very strong neodymium magnets and a low mass diaphragm foil that together give high efficiency and fine microdynamics combined with remarkably high SPL while maintaining a very low distortion ratio. According to the german magazine Hobby-Hifi the AMT 2510c has some of the lowest distortion levels they have ever measured! This tweeter is "holographically" precise in its depth, clarity, and transparent performance - very dynamic! Finally it has a low-resonance chamber that is damped with multiple layers of felt. Internally the AMT is constructed with Mundorf's Silver-Gold wire and terminated in gold-plated banana sockets for easy connection with the supplied plugs. Basically this all boils down to an excellent tweeter with extremely high resolution without ever getting "edgy" or harsh.

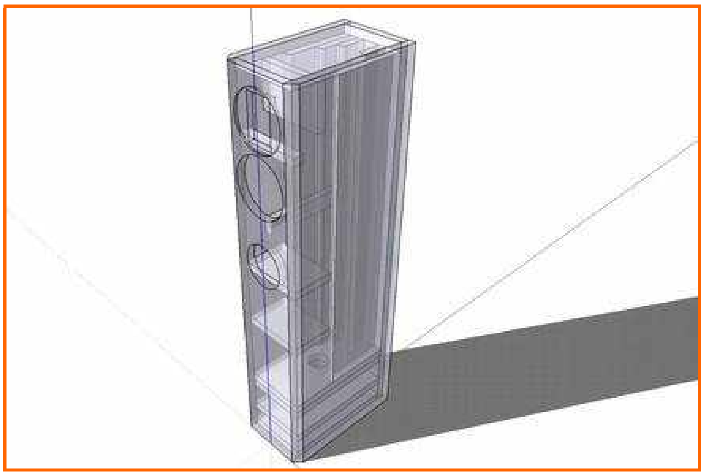


So the L'Orfeo loudspeaker uses one of the best midwoofers and one of the best tweeters available today. The art is to combine these two, using high-grade crossover components, very pure internal wiring and a clever cabinet concept, to a seamless and coherent unity in a package that should please a large potential audience. As mentioned earlier, the choise of cabinet finish will give you the possibility to match them to your personal budget and interior. The L'Orfeo is available as a complete DIY kit including every part down to the last screw except for the cabinets. Seeing as labour is the most expensive part of any product, you can save a lot of money if you build the cabinets yourself. The loudspeaker is designed in such a way that all the panels are rectangular and can be glued together with butted joints - so there are no difficult angles to cut and only the tweeter is recessed.

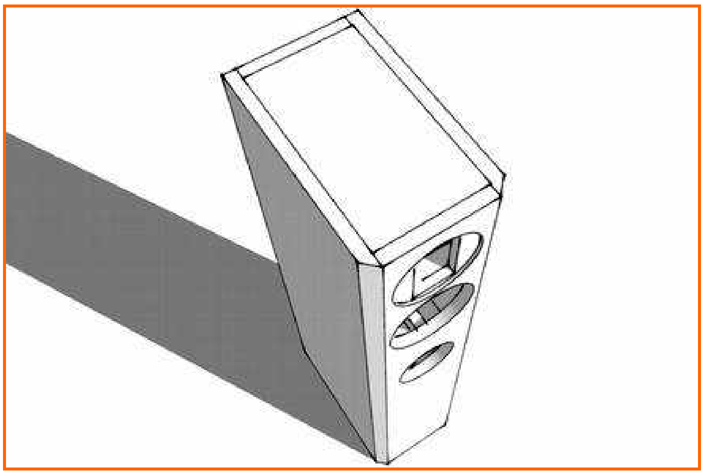
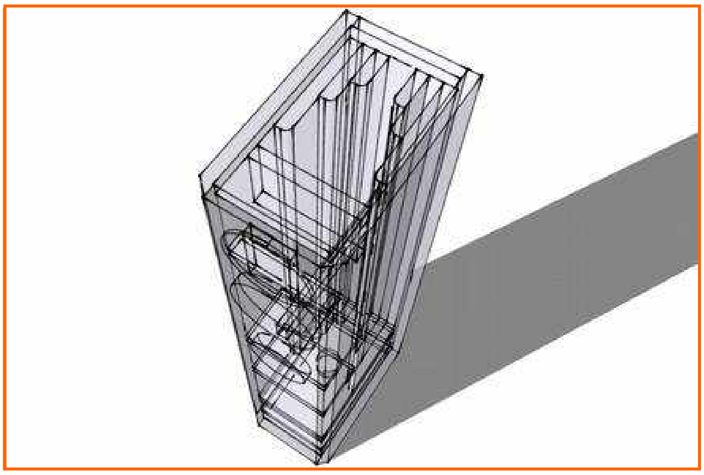
L' Orfeo - cabinet construction

From the outside, the cabinet of the L'Orfeo looks rather standard issue, but inside it is a totally different story. Instead of a normal cross-braced rectangular enclosure, this loudspeaker uses a unique diffusor type of woofer loading. This internal diffusor has several major advantages: first of all it creates an irregular shape that breakes the back wave produced by the woofer. This minimizes the amount of delayed energy that (in more coventional designs) is reflected back off the rear wall and travels through the thin paper cone of the midwoofer, "smearing" the original clean signal that is fed to the woofer. The second advantage is that the cabinet width and depth vary internally so the strong standing waves that you usually get between two parallel surfaces are broken down into several smaller and therefore less harmfull ones. Third item is that the varying panel thickness (minimum 22mm / maximum 88mm) and density (constrained-layers) helps reduce panel-borne resonances, flexing and vibrating energy that travel through a panel of constant thickness. Advantage number four: all these extra panels help to make the whole construction "dead" and heavy, again reducing unwanted excess energy radiating from the cabinet. All these advantages together result in a very quiet cabinet that also needs only a minimum of damping material inside and therefore adds to a "live" and dynamic approach to music. To my knownledge this type of *Internal Cabinet Diffusor* is a world premiere has not been used before, so if you see it popping up in other loudspeakers in the future, be sure to remember that you saw it first at Humble Homemade Hifi! :-) The only damping material inside these loudspeakers is some bonded acetate fibre that is placed in the *Internal Helmholtz Absorber* that is positioned near the bottom of the cabinet, between the main volume and the crossover compartment. This absorber volume works like a reflex-port in reverse. The volume, port diameter and length are tuned to act like a sort of "black hole" for a defined frequency - namely that of the standing wave between the top and bottom panels of the cabinet. The main volume is completly free from any type of damping material!

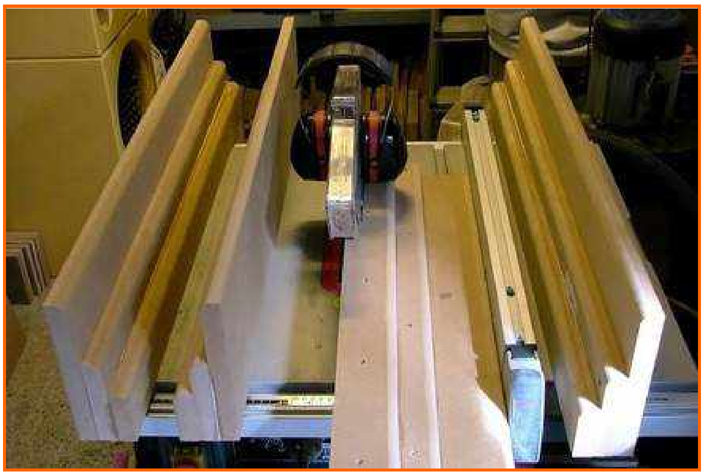
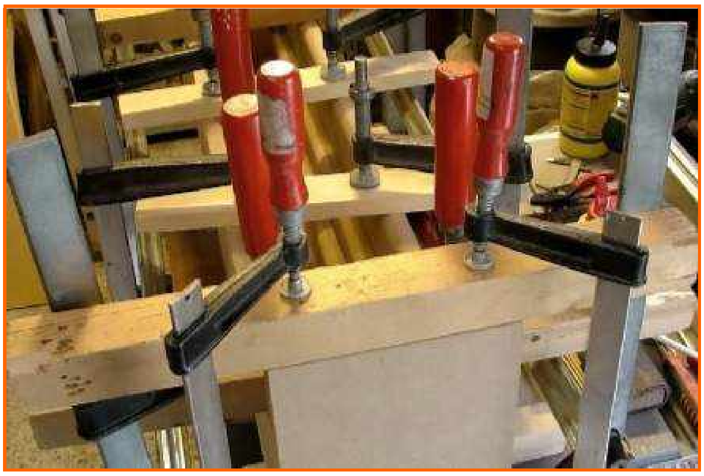




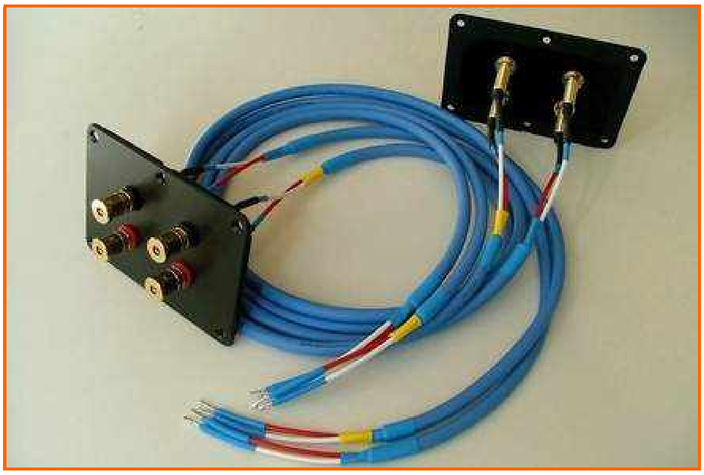
One last important thing about this design: all the panel dimensions and positioning of the panels are based on the Fibonacci sequence of numbers. Fibonacci numbers are intimately connected with the Golden ratio that is found to be aesthetically pleasing. They also appear in biological settings such as branching in trees, arrangement of leaves on a stem, the flowering of artichoke, an uncurling fern and the arrangement of a pine cone. In music, Fibonacci numbers are sometimes used to determine tunings, and, as in visual art, to determine the length or size of content or formal elements. It is commonly thought that the third movement of Béla Bartók's Music for Strings, Percussion, and Celesta was structured using the Fibonacci sequence of numbers. (source: http://en.wikipedia.org/wiki/Fibonacci_number)

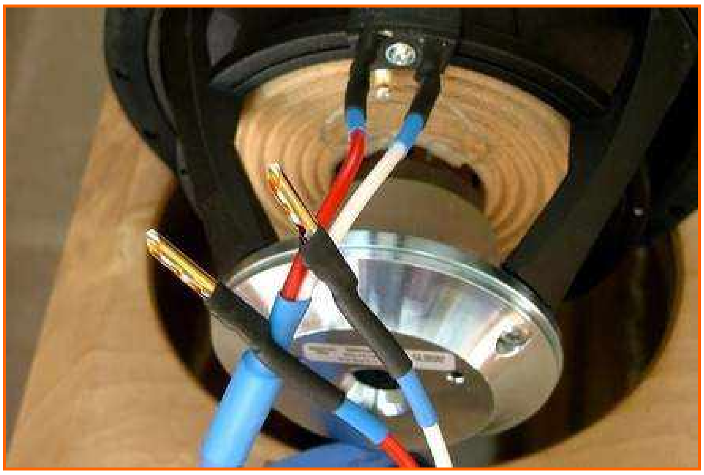
The various sketches show how all the panels and supports are posistioned inside the cabinet. It may look a little complicated at first, but all the necessary mdf is just cut into straight forward rectangular panels. Also many panels have the same dimensions. You can find a high resolution drawing including a full parts list at our download page. Besides the 22mm thick mdf panels there are only two other pieces of wood: one is a small support glued horizontaly to the inside of the baffle inbetween the tweeter and the midwoofer. This gives extra strength to the baffle where it is at it's narrowest. The other support connects the baffle to the rear wall just below the midwoofer. Again adding extra strength to the baffle between two cut-outs (port and woofer) and forming a rigid connection between the front and back panels.

This photo on the left shows how the diffusor panels are made. The three panels of different width have one edge rounded-off with a 12mm radius using a router. They are then glued and screwed together to form a solid block. On the table saw the end where they all come together is trimmed so that it will make a perfect fit when glued to the rear wall of the cabinet. On the right you can see that it is always handy to have lots of clamps! Note how I use pieces of wood to spread the force applied by the clamps. This gives a more even distribution of the pressure and protects the mdf from getting dented.

The photo on the left explains the internal structure of the diffusor, absorber, crossover compartment and other panels. Don't forget to put the damping material inside the Internal Helmholtz Absorber (second compartment from the bottom) before the final side panel is glued into place! On the photo the bottom panel still has to have the cut-out made for mounting the crossover. On the right we see a detail of the base of this loudspeaker. It is made from three 22mm thick mdf panels glued together, the top panel being smaller than the other two. The matte black finish is obtained by applying two layers of water-based "black-board paint" with a fine foam roller. Sand the first coat with 400-type sandpaper before the final coat is applied. The height adjustable "spikes" are made from M6 black hex-head bolts that go through the base-plate and are secured with normal M6 washers and nuts. Finally capped-nuts are used for the height adjustment / levelling of the speakers.



All internal wiring in the standard kit is very pure Jantzen Audio 6N Solid Core Copper wire for the woofers and tweeters and is connected to premium grade gold-plated bi-wire binding posts. As an option the kit is also available with Furutech Alpha S-14 internal wiring and any Furutech binding posts of your choise. The photo shows the premium grade bi-wire binding posts with Furutech Alpha S-14 wiring - a nice combination! The Mundorf AMT2510c tweeters come standard with mounting screws and gold plated beryllium copper banana plugs for connecting the internal wiring to the tweeters. Note how all wire ends are terminated with heat-shrink tubing to assure long-term stability and nice looks!

Photo's of the rear with the bi-wiring terminals connected for single-wiring. The cables are by Dyrholm Design Audio from Denmark.

L' Orfeo - crossover design

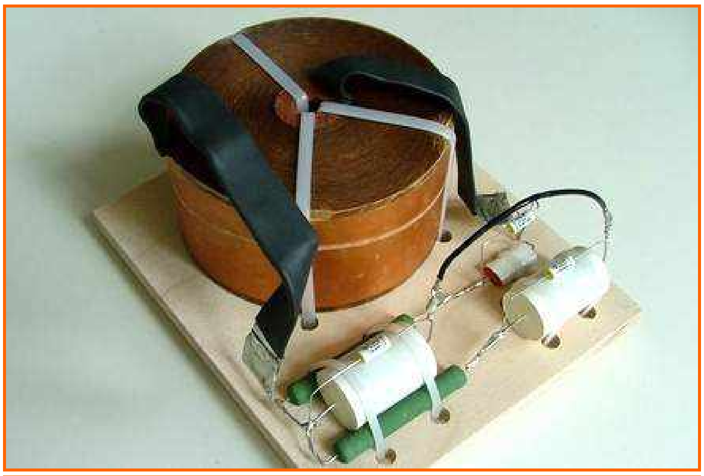
First some information about crossover design in general followed by how I go about designing a loudspeaker filter. The crossover is the heart and soul of any loudspeaker. Even the best drivers in the world mounted in a well built cabinet can sound terrible if the crossover typology and quality of the crossover components used are not well designed and implemented. A loudspeaker filter has several functions, the main one being to devide the frequency spectrum into pieces (in this case two) that the corresponding drivers can cope with. The woofer must be attenuated before it starts beaming at high frequencies, the tweeter must have protection from low frequencies so you don't blow it up! Now this may seem easy, you just look at the datasheets of each driver, see in which region they overlap, choose a crossover-point somewhere in the middle of that region, feed the data into one of the many online crossover calculators - and bingo! Unfortunatly, as with most things in life, it isn't quite that simple. First of all loudspeaker drivers don't have ruler flat frequency and impedance curves. The load that a driver presents to an amplifier consists of a complex electrical impedance, a combination of resistance and both capacitive and inductive reactance. A loudspeaker driver does not have a constant resistance across its frequency range. Instead, the voice coil is inductive, the driver has mechanical resonances, the enclosure changes the driver's electrical and mechanical characteristics, etc. (source: http://en.wikipedia.org /wiki/Loudspeaker). For example a nominal 8 ohm midwoofer can have an impedance curve with peaks of over 50 ohms and a dip down to 6 ohms. So that makes all static charts, tables and online calculators completely useless.

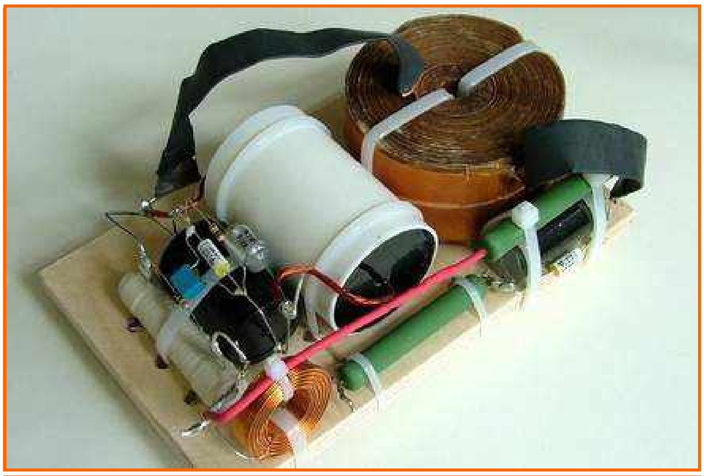
So the only way to design a loudspeaker crossover correctly is to take very accurate measurements of each of the driver's frequency and impedance curves with their corresponding acoustic and electrical phase response, in their final enclosures and after they are fully burnt-in. Also waterfall plots must be made to see if there are any parts of the frequency spectrum that take a little too long to decay. And add in a few off-axis frequency measurements to check baffle edge diffraction problems and some distortion measurements for spotting any other nasties. And don't forget to measure the output from the port either - especially with a two-way system, there can be quite some midrange energy radiating from the bass reflex port!

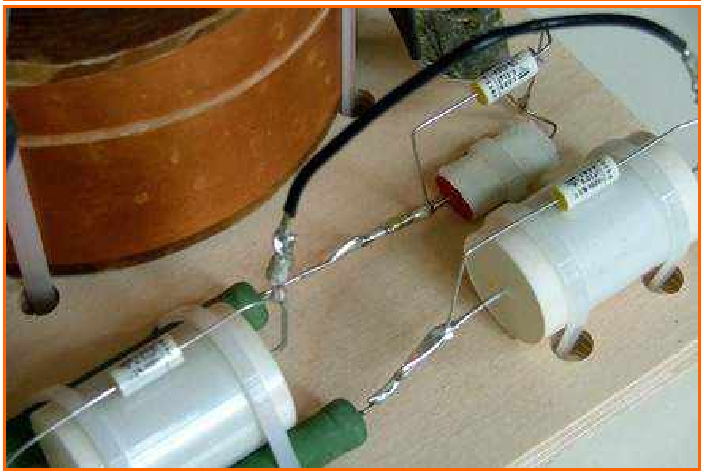
After thorough interpretation of all this data, the relevant sections are fead into accurate and versatile simulation software and several crossover typologies and options are modelled. This is where over 30 years of experience comes in handy to know what has potential and what is a complete waste of time. This modelling results in about 5 or 6 different crossover schematics that all seem to produce a more or less flat summed frequency plot, an amplifier friendly impedance curve and are kind enough to the driver / cabinet combination used. They may vary in steepness of the slopes, crossover-point, have lots of additional correction correction-networks or be relatively simple, etc, etc. Each of these 5 or 6 different crossovers are then built in real-life with standard quality components and listened to exstensively. This part of the crossover design is quite interesting as it lets you hear how the various driver / crossover combinations work (or don't work) together. Some combinations "harmonise" better than others but they all have their own sonic signatures. After this lengthly period of evaluation you are left with about half the amount of crossover schematics that still seem to sound okay. Then it is time to measure again. These measurements will show any potential "problem area's" and together with their sonic characters help narrow down the options. Just to keep things simple: say you are left with two filter possibilties that both sound quite good. With the recent measurements in the back of your head, further modelling of these crossovers and even more listening sessions, you try to "tune" the two options until you have the feeling that you can "squeeze" them no further. Let them both compete with each other, like a sort of speaker "shoot-out". When crossover A seems to be the winner soundwise and concerning measurements, then "tune" crossover B even more until it seems to be on top. Keep this process going as long as possible combining constant measuring with listening to all types of music, from string quartet to big-band, from electronic dance to large orchestrial and choir works (see my Music Page for inspiration). Don't make the mistake of **only** using these so called *audiophile* recordings of jazz-trio's you often hear at hifi-shows. They always sound good, even on a crappy system. Give them something healthy to eat like a nice helping of Johann Sebastian Bach's *Weihnachtsoratorium*. This part of the design has nothing to do with personal taste nor is it part of any "voicing" stage. All that should be on your mind during this stage are things like balance, neutrality, sound-stage and coherence.

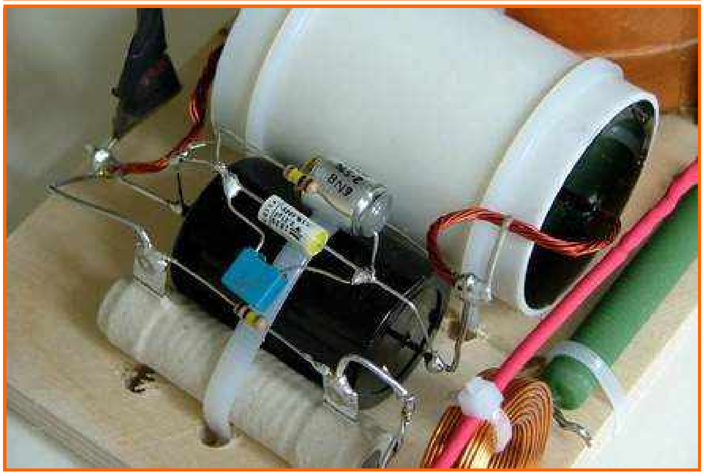
After a while you should be left with a crossover schematic that measures very well and sounds very good. This one will serve as the basis for the final design stage. Now it's time for fine-tweaking, system matching and a little bit of personal taste. The crossover is now built with high-grade crossover components on the more critical positions. This can get a bit tricky because you have to take into account the signature of the loudspeaker drivers, etc and the signature of the crossover components. They all have to blend together well to form a synergy that takes the system to a much higher level. There is no point in just buying "the best" components money can buy, the chance that you will get a perfect "match" that way is rather remote. What I usually do first with a two-way system, is to start with the midwoofers low-pass inductor (L1 in the schematic further down this page) because the choise here is limited: air-core's of various wire diameters or AWG's, round wire, flat wire, hexagonal wire, litze wire, copper foil with polypropylene or copper foil with impregnated paper - that's it! When you have decided on your favourite inductor then it's time for the tweeters main high-pass capacitor (C7+C9 in the schematic). In this case I mixed two flavours roughly in a 1:7 ratio to obtain the taste I like. From experience I know these two go together well like salt & pepper, peanut butter and jelly, fish & chips, gin & tonic, etc, etc. Another sonically critical component is the resistor that is directly in the tweeters signal path (R3 in the schematic). I put may favourite resistor here: the Mundorf M-Resist Supreme, very affordable, reliable, spatious, detailled and smooth. This substituting process is repeated for all the components throughout the crossover, obviously some positions are more critical than others. For example, to obtain a maximum in coherency, I chose the same brand and type of inductor (just a smaller gauge) for the high-pass inductor parallel to the tweeter. But the inductor in the correction network also parallel to the tweeter, is a normal small gauge baked wire air-core (L3 in the schematic).

The final icing on the cake are the bypasses. These are components with a very small capacitance compared to the main value. You don't see any difference to the standard measurements when they are in place, but they do make small audible enhancements in things like smoothness, micro-detail and imaging. These parts are so cheap that you can use them in all positons and blend multiple types till you obtain your favourite blend.



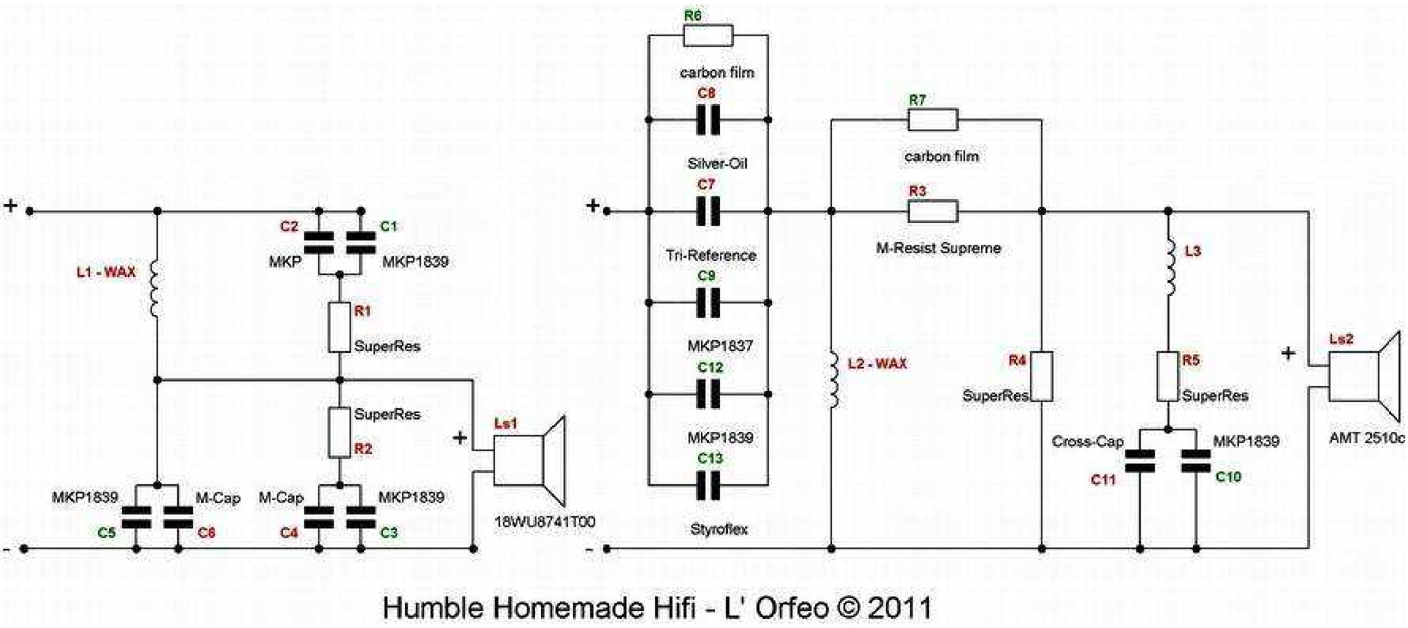






For the first version, I built the woofer low-pass section and the tweeter high-pass section on two seperate boards made from 9mm Baltic Birch plywood so that they are a bit easier to mount inside the cabinets. Also it makes the photo's easier to explain. The crossover boards have holes drilled at the necessary posistions and the components are held into place by strong, high quality Hellermann Tyton tie-raps. All connections are first crimped together to ensure good mechanical contact. Then the connections are soldered with RoHS compliant lead-free solder with 3% silver content. The crossovers supplied with the kit are built the same way except they come on one board as shown at the bottom of this page.

The photo's on the left show the woofer low-pass section with the large Wax Coil dominating the other corrective elements. Basically it is a 2nd-order filter with a Zobel network to flatten the woofers impedance due to inductive rise caused by the voice-coil. A small RC-network parallel to the Wax-Coil tames the woofers peaking in the octave from 2500 to 5000Hz. The Wax Coil's copper foil leads are insulated with shrink tubing to avoid short circuit should they accidentily come into contact with other conductive parts. Note the little Vishay MKP1839 bypass capacitors across all the capacitors in the woofers parallel circuits. The two photo's on the right show the tweeter 2nd-order high-pass section. The tweeter series capacitor is an example of hifi "Haute Cuisine" and consists of a blend of Intertechnik Tri-Reference and Mundorf Supreme Silver-Oil, garnished with some Vishay MKP1837 and MKP1839 bypass capacitors with a 100K carbonfilm resistor and Styroflex capacitor for topping. Parallel to the tweeter we see an LCR-network that tames some excess energy in the lower treble. The capacitor in this network is also bypassed by a Vishay MKP1839. The green resistors in the parallel sections are Jantzen Audio SuperRes Non-inductive.

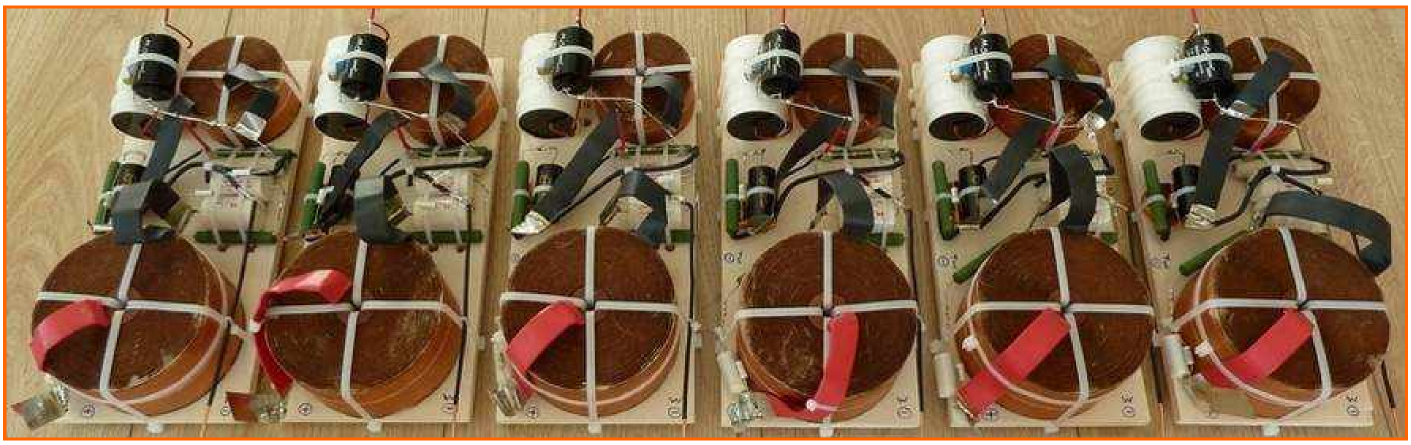


Inductors
L1 = Jantzen Audio Wax Coil / 12AWG
L2 = Jantzen Audio Wax Coil / 14AWG
L3 = Jantzen Audio baked air-core / 0,70mm wire

Resistors
R1 = Jantzen Audio SuperRes Non-Inductive / 10 watts
R2 = Jantzen Audio SuperRes Non-Inductive / 10 watts
R3 = Mundorf M-Resist Supreme / 20 watts MOX
R4 = Jantzen Audio SuperRes Non-Inductive / 10 watts
R5 = Jantzen Audio SuperRes Non-Inductive / 10 watts
R6 = Carbonfilm resistor / 0,25 watts
R7 = Carbonfilm resistor / 0,25 watts

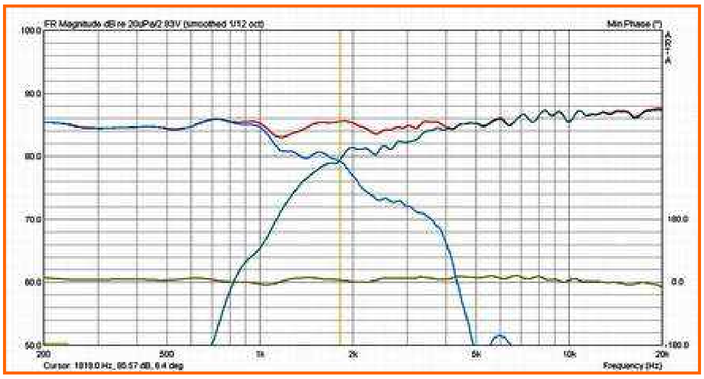
Capacitors
C1 = Vishay MKP1839 / 400VDC
C2 = Mundorf M-Cap / 250VDC
C3 = Vishay MKP1839 / 400VDC
C4 = Mundorf M-Cap / 250VDC
C5 = Vishay MKP1839 / 400VDC
C6 = Mundorf M-Cap / 250VDC
C7 = Intertechnik Tri-Reference / 600VDC
C8 = Mundorf M-Cap Supreme Silver-Oil / 1200VDC
C9 = Vishay MKP1837 / 160VDC
C10 = Vishay MKP1839 / 400VDC
C11 = Jantzen Audio Cross-Cap / 400VDC
C12 = Vishay MKP1839 / 400VDC
C13 = Styroflex / 160VDC

The schematic shows the main filtering components in red and the fine-tuning bypass elements in green. The tweeter high-pass capacitor consists of the parallel connection of C7 + C8 + C9 + C12 + C13 + R6. The carbonfilm resistor's capacitance of a few hundred picofarads works the same way as a bypass capacitor. Both drivers are connected in positive phase. The crossovers are only supplied in matched pairs, fully assembled and tested as part of the L' Orfeo kit as shown on the photo below - the cd is not included, it is just there for scale reference!

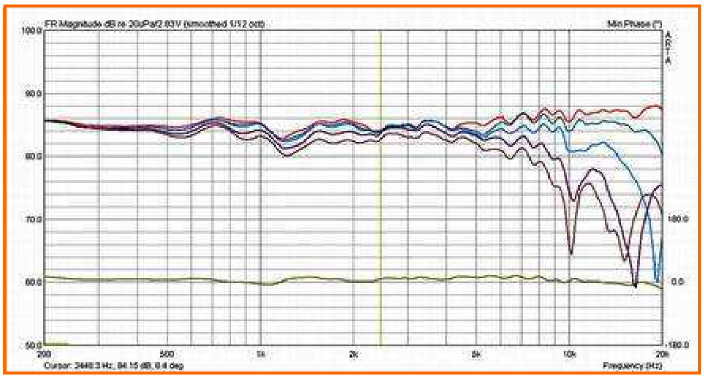


L' Orfeo - measurements and listening

Looking at the measurements of the various frequency curves we can see a very smooth overall response with an efficiency of about 85dB / 1 watt / 1 meter with a fluctuation through nearly the whole range of only +/- 1dB. Only above about 7kHz does the curve have a gradual rise towards the top where at 20kHz it is a couple of dB's louder than the rest of the spectrum. The crossoverpoint between the midwoofer and the tweeter is situated at a 1800Hz. The off-axis response curves show a very even polar response.

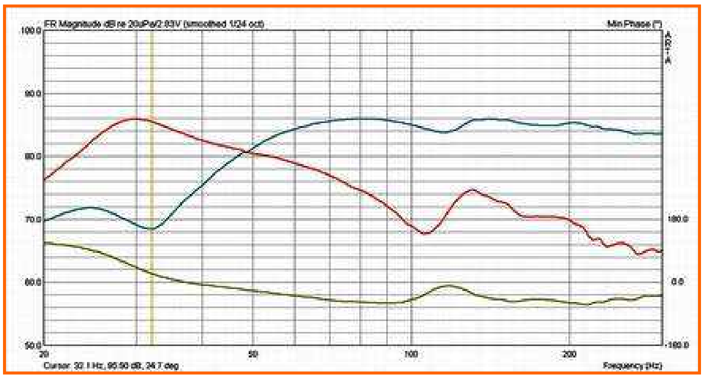


Above left: individual frequency curves of the midwoofer (blue) and tweeter (green) and the summed response of the finished system (red) with corresponding acoustic minimum phase; frequency range 200Hz - 20kHz; horizontal range 50dB - 100dB, subdivision 2dB's.

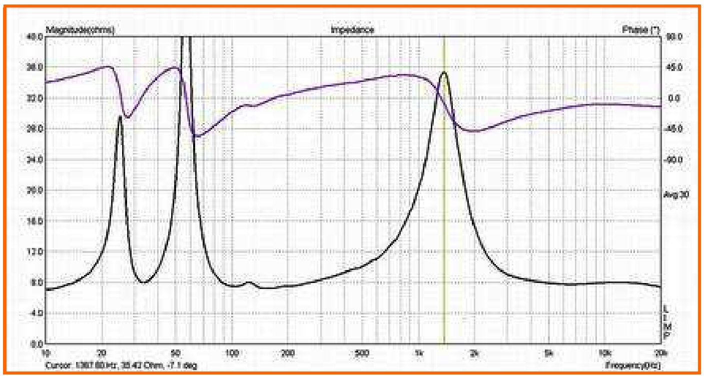


Above right: on axis and off-axis frequency curves of the summed system response: on-axis (red); 15 degrees off-axis (green); 30 degrees off-axis (blue); 45 degrees off-axis (purple); 60 degrees off-axis (brown) frequency range 200Hz - 20kHz; horizontal range 50dB - 100dB, subdivision 2dB's.

Zooming in on the low frequency response we see that the port has it's strongest output level centered around 30Hz. There is a slight ripple in both the woofers output and the ports output near 125Hz where they interact with each other. This also corresponds with a ripple in the impedance plot at the same frequency, indicating some sort of standing wave inside the cabinet - most likely a residual of the standing wave between the parallel top and bottom panels. With more damping material inside the cabinet I was able to smooth out these irregularities, but subjectively speaking, also robbed the loudspeaker of a little of it's lively, dynamic character. The overall system impedance is a healthy and amplifier friendly 8 ohms with an impedance minimum of 6,9 ohms at 150Hz. The two impedance peaks in the bass are centered around the port tuning frequency of 33,5Hz.

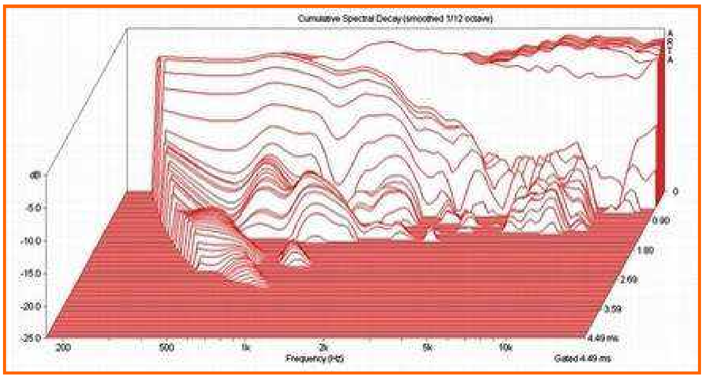


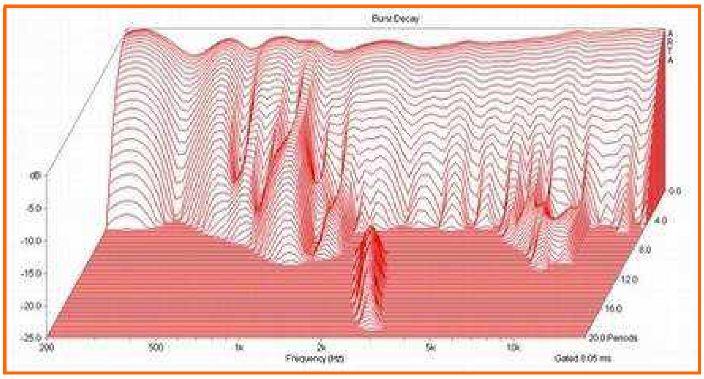
Above left: individual near-field frequency curves of the midwoofers bass response (green) and the reflex-ports output (red) with corresponding phase; frequency range 20Hz - 300Hz; horizontal range 50dB - 100dB, subdivision 2dB's.



Above right: impedance curve of the finished system (black) with corresponding electrical phase (purple); frequency range 10Hz - 20kHz; horizontal range 40 ohms, subdivision 4 ohms.

Finally the two decay plots that show the energy storage versus frequency of the L'Orfeo loudspeaker. The cumulative spectral decay plot (or waterfall plot) shows a rapid and even decay over the whole spectrum. There is some delayed energy in the 700Hz to 1kHz range that corresponds with a slight hump in the frequency curve at the same frequencies. This can also been seen in the burst decay plot. This is delayed energy that radiates from the bass-reflex port and can be found in any two-way ported enclosure. Again, with a light fill of damping material inside the cabinet I was able to lower the level of the "bump" in this range, but subjectively speaking, I preferred the lively, dynamic character of the loudspeaker without any damping material in the main volume. With the port closed, transforming the loudspeaker into a closed box, the overall frequency response throughout the whole midrange can be made even smoother and the decay plot even shorter. This at the cost of some depth in the bass and some dynamics in the upper bass and lower midrange. So here you have some room to experiment and tune the cabinet to your personal taste and / or match it to the rest of your system and room acoustics.





Above left: cumulative spectral decay of the finished system; frequency range 200Hz - 20kHz; horizontal range -25dB, time window 4,49ms.

Above right: burst decay of the finished system; frequency range 200Hz - 20kHz; horizontal range -25dB, time window 20 periods.

So what does all this effort of building your own high-end loudspeakers give you in the end? Well, if you are looking for a loudspeaker with built-in effects, look elsewhere. If you are looking for a loudspeaker that can be used a neutral reference, read on. The L' Orfeo is a loudspeaker that is extremely neutral, will do any type of music and just plays the recording as it is. Besides neutrality you also get lots of detail without it ever being fatiguing - good for long term listening. This loudspeaker lets you look really deep into the recording but does it so smoothly, that it just seems natural. Nothing is emphasized at all, the overal balance is very coherent. Spatial information is very realistic with good image size. Vocals are placed at the front of the band with the individual instruments positioned with space around the rest of the sound-stage. The bass is relatively deep considering how small the woofer is but don't expect miracles from an 18cm midwoofer - if you want to rattle the windows druing movies, buy a subwoofer. The richly textured midrange is extremely neutral, the transition from woofer to tweeter is seemless and the treble is clear with a nice dynamic "snap" to it. Authentic ride cymbal stick definition. Overall there is a nice coherent balance between detail and smoothness.

The Humble Homemade Hifi reference grade, two-way loudspeaker kit L' Orfeo is sold with all components except the cabinets. The kit comes with the Scanspeak and Mundorf drivers in matched pairs, Jantzen Audio 6N internal-wring, bi-wiring bindingposts (you can choose between gold-pated or nickel-plated), damping material, reflex-ports, black mounting screws and a pair of ready assembled, matched and tested crossovers. See our shop for pricing. Furutech internal wiring and Furutech binding-posts of your choise are available as an option.