GWM4 Build Guide

A design by Gerhard Westphalen

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Introduction

This guide describes in detail how to build a speaker system similar to the GWM4. Several modifications must be made compared to the GWM4 as those use parts that are not publicly available. These parts include the amplifiers and DSP board. Unfortunately there aren't many options on the market available to end users that suit the needs for these speakers. Several suggestions will be made but ultimately it will be the responsibility of anyone interested in building these to find suitable parts and modify the design accordingly.

This guide is intended for anyone interested in building these speakers for themselves or simply to learn how a system like this is put together. Looking at a system like this and all of the parts involved can help professionals such as mixing engineers better understand the speakers that are currently on the market and better judge whether the price tag on a specific model is justifiable. This guide is not meant for anyone looking to profit by selling this speaker system or anything similar. This guide also does not provide any guarantee that the system will work and anyone who attempts to put a system like this together must do so at their own risk. Having said that, I'm happy to answer any questions and help with basic troubleshooting. Please email me or contact me through social media. Any suggestions for updates to this guide are also encouraged.

It's worth pointing out that this guide is not an in-depth look at speaker design. It is primarily intended for engineers and audiophiles who don't have any previous knowledge about speaker design. The most difficult part is building the cabinets so basic woodworking skills are a requirement (or the cabinet construction can be outsourced). Knowledge of basic audio related terminology is assumed.

Background

The GWM4 was designed as a way to share the experience of high quality sound as well as to show that great sound does not have to cost a fortune. This meant that it had to be a compact system that could easily be shipped for anyone to demo at no cost. It was specifically designed as a system for mastering. The GWM4 was only released as a prototype with 4 pairs sold. Each pair also included a calibration session to get the speakers tuned to the user's room using the onboard DSP.

There were several design criteria that had to be met. Due to wanting a compact and affordable price, this design was limited to being 2-way. Speaker design is all about compromise and these are no different. Some of the elements that need to be juggled include the frequency response, size of cabinets, and max SPL. As this was designed for mastering, the max SPL could be somewhat sacrificed. This contrasts a speaker designed for tracking where uncompressed transients can easily exceed 120dBSPL at 1m even when monitoring at only 1 - 2m away from the speakers. The max SPL of the GWM4 allows for adequate mastering levels at 1 - 2m away. Mixing at loud levels can easily hit their limits (although that limit is beyond most similarly sized 2-way speakers).

Although this system was meant to be affordable, only the highest quality components were used. The listed price of the prototypes was $3300 USD. Compared to similar speakers on the market, the closest speakers are from Jones-Scanlon (the only major difference is in the high frequency driver used) and cost $5000. In terms of speakers from larger speaker companies, the price is closer to $10,000 and even then many speakers at that price still use much cheaper components than the GWM4.

The total parts cost for the GWM4 is around $2600 USD per pair. Of course that doesn't include any labor (>20 hours to build one pair) or R&D costs as well as the investment into a number of tools and equipment required to design and build these speakers. The modifications required to allow anyone to build these speakers does increase the price. Anyone interested in building a pair of these speakers should expect to pay closer to $3000 not including the price of any tools or equipment required.

Additional design criteria include an extended frequency response which is not found in similar 2-way speakers of this size, the lowest distortion possible, and good dispersion characteristics. In these regards, the GWM4 outperforms any similar speaker on the market. The main reasons for this are the quality of parts used and designing the speakers around the use of DSP which will be covered later on.

One of the "special" parts of the GWM4 is the use of phase correction which is rarely found in speakers. Systems that use similar phase correction include Trinnov, DEQX, and Dirac. The phase correction adds an incredible amount of detail by correcting nonlinearities that every speaker has. There are many who are opposed to phase correction citing issues such as preringing. As the measurements will show in later sections, there is essentially no preringing on these speakers and the transient response is better than without phase correction (the "traditional" speaker design approach). The biggest issue with systems that offer phase correction and why so many are opposed to it is that they are rarely set up properly. Any system with automatic setup capabilities will most likely not work well. The DEQX system, for example, requires a setup session that lasts over 6 hours and costs $500. Unless you are very experienced setting these kinds of systems up, it'll likely do more harm than good to try to set it up yourself.

System Overview

The GWM4 consists of only a few parts. The main components include the cabinet, woofer, tweeter assembly, amplifiers, and DSP section. There are a number of smaller parts such as the back plate, power switch, and screws which must also be considered. Each of these parts will be discussed in the following sections. Where relevant, images and digital files will be provided.

At the end of this guide an alternative version of the system will be described. This version greatly simplifies the modifications and design work required to build these speakers based on the parts that you decide to use for the amplification and DSP by using external units that are prebuilt. The drawbacks are that the cost of undertaking this project would be much greater ($1000 - $2000 above the price mentioned earlier) and there would be a number of units (and cables) sitting outside of the speaker which take up space in the room. The advantages are that troubleshooting is much easier and any component could easily be swapped out for an upgrade.

Woofer

The woofer used is the Purifi PTT6.5W04-01B. The 8 ohm version of this woofer could also be used. Purifi has recently released slightly different versions of this woofer and any should be adequate as long as the cabinet is adapted to have the right woofer cutout size.

Purifi was co-founded by Bruno Putzeys who is the man behind companies like Hypex, Kii, and Grimm. Needless to say, these woofers are outstanding. The GWM4 would simply not exist if it weren't for this woofer which offers essentially every quality required for these speakers. This includes high xmax (maximum linear excursion), a fairly high sensitivity, high power handling, and incredibly low distortion. The combination of these factors allow these woofers to reach very low frequencies (for a 6.5” woofer), play at high SPL levels, and have low distortion.

The biggest drawback to this woofer is that it is one of the most expensive 6.5” drivers on the market costing $369 USD. Woofers of similar size used in most studio monitors generally cost around $30. There are very few speakers that use a woofer of this size costing more than $100.

Tweeter Assembly

The high frequency section consists of several parts. A number of tweeters were tested on both flat baffles and in a waveguide while developing the GWM4. When measuring the off-axis response it was clear that using the waveguide was going to give the best results. The winner was the ScanSpeaker Illuminator R3004/6020-10. On a flat baffle it is far from flat but once in the waveguide with proper frequency response correction it sounds great and has a very consistent off-axis response. It's certainly not the most expensive tweeter around costing $185 but this level of tweeter is pretty much reserved for higher end speakers such as with Barefoot where their cheapest speaker which uses this tweeter costs $6245.

The waveguide is a Visaton WG148 R. Unfortunately there aren't very many waveguides on the market unless you want to 3D print or CNC your own. Mounting the tweeter to this waveguide is a bit of a challenge. The first step is to remove the protective grill off of the tweeter which can be easily done by using a screwdriver to carefully pry it off and then removing any residual glue.

The tweeter is held onto the waveguide using a 3D printed bracket. The STL file for the bracket is included in the files which accompany this guide. If you do not have your own 3D printer there are a number of services which you can order prints from.

Between the tweeter and waveguide there is a piece of felt which helps seal everything. It can be a bit of a challenge to cut the felt so that the opening for the tweeter is large enough but the felt does not extend past the edges of the tweeter frame. Around the frame of the bracket and tweeter silicone glue is used to ensure that it is sealed.

Due to the tweeter having tiny contact pins, soldering a larger gauge wire is difficult as either the plastic that holds the pins melts or a proper soldered connection is not created which can easily break afterwards (speaking from experience). A faston connector of the right size should be used.

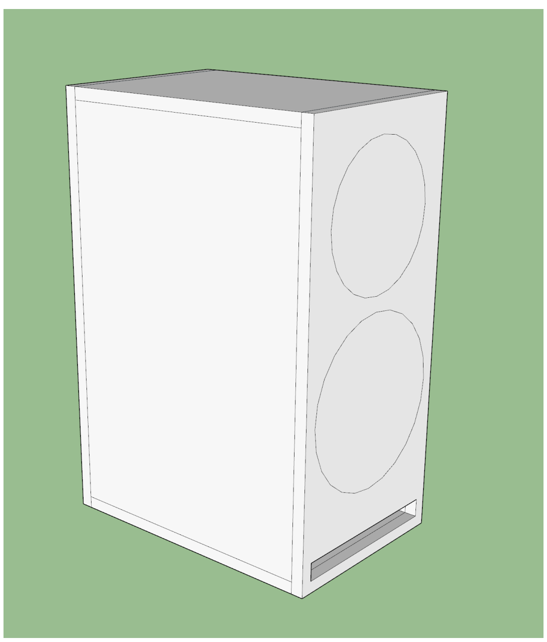
While these speakers don't use a passive crossover, a protection capacitor is used on the tweeter in case there are any low frequency bumps from the amp or DSP boards. A 24mfd Solen PB2400 is used. It starts filtering just below the crossover point and offers decent performance for the price. This capacitor is added inline between the amp and tweeter. Some sort of foam wrapping around that is suggested to stop it from rattling inside the enclosure.

Cabinet Design

The cabinet is designed to be 0.57ft³ tuned to 37Hz. In reality the built cabinet is a little smaller than that with a moderate amount of polyester stuffing. This tuning puts the -6dB point down at around 32Hz which is quite impressive for a 2-way speaker this size. At power levels that don't exceed xmax this puts the max SPL levels at 105dBSPL at 1m. Technically at the max power levels that the woofer is rated at the speaker is capable of 109dBSPL at 1m. Of course this exceeds the xmax at certain frequencies (below 75Hz).

The port is 7" x 0.75". This puts the port length at 16" which is a bit of a challenge to fit in a box this size. At the highest power levels without exceeding xmax this keeps the port air velocity below 30m/s. Even then, that velocity peak is at 35Hz where it's unlikely that these speakers would be playing content with that much material at those low frequencies. This low air velocity ensures that there isn't any port "chuffing" and that the air can move through the port without causing nonlinear issues.

Cabinet Construction



Basic cabinet model in SketchUp

Building the cabinets is by far the most difficult part of building a pair of these speakers (or any speaker for that matter). It doesn't require much knowledge as far as woodworking goes. The basic tools required are a table saw, a router, a circle jig for the router, a drill, an orbital sander, and clamps. All of the tools required to build these speakers can be purchased for under $500 from brands like Ryobi which are perfectly adequate for an ameature woodworker. Having a CNC router or ordering CNC'd parts from a company that offers those services can make the process a lot easier with better looking cabinets. The router bits required are a flush trim bit, a roundover bit (with your preferred radius), and a rabbet bit. Using a router table can greatly help avoid accidentally creating imperfections which can be a lot of work to fix before painting.

The cabinets are built using MDF. The front baffle uses ¾" while the rest uses ½". Ideally it would all be made with ¾" although that makes them more expensive to ship. When sending these speakers out to demo I was usually covering the shipping costs which were around $150 to ship a pair from Canada to the US so ½" was used to help bring down this cost.

The cabinet baffle is 8" x 17.5" and the cabinets are 11.75" deep. The port is 0.5" away from the bottom edge of the front baffle. The center of the woofer is 6.5" away from the bottom edge and the center of the waveguide 13.5". The back panel on the back is as high as possible so that the electronics don't interfere with the port inside. When using a circle jig to cut the woofer hole there may be some experimentation required to find the right hole size. Adding 1mm to the diameter of the listed size on the spec sheet for the woofer and waveguide will give a decent fit but will have edges around. 0.5mm is perhaps a good clearance amount. One factor to keep in mind is that the paint used will add some amount of thickness which needs to be accounted for.

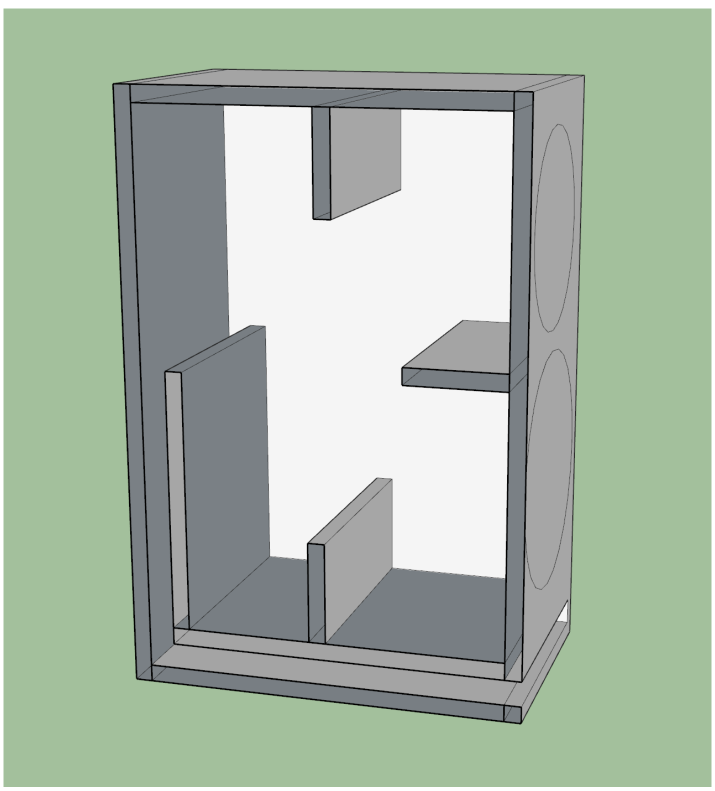
Since the woofer and waveguide need to be flush with the baffle, a rabbet must be made at the correct depth. The important thing to keep in mind is the size of the rabbet needed so that the woofer and waveguide can still screw into but is also large enough so the the rest of these parts can fit into the holes. First the circle jig is used to router a hole that's the size of the inner edge of the rabbet. The rabbet bit is then used to make a larger hole (the correct diameter of the woofer and waveguide) that's the depth to recess those parts.

The port starts off as 2 pieces of MDF that are glued together in an L shape. The width of that is the inner width of the cabinet. The L should stay a constant 0.5" away from where the bottom and back baffle will be. Technically an additional piece should be used across the corner of the L to make the corner have a more consistent size but in the prototypes built the 90 degree bend there was left. When glueing the speakers together some sort of 0.5" spacers should be used between the port L and the bottom panels with clamps then pushing them together. Care must also be taken to make sure that the front of the L piece lines up with the front baffle so that once the front baffle is glued in there will be an airtight seal all around the connection between the baffle and the rest of the cabinet around the port.

When cutting the pieces of MDF for the front and back baffles it can be helpful to add some extra material that will hang off the edge once they are glued to the sides, top, and bottom. A flush trim bit can then be used around the perimeter of the baffles to make them perfectly match the other dimensions. ¼" of extra material is a lot of sawdust to create when flush trimming so ⅛" or less should be used. Spacers should be used when glueing the baffles onto the rest of the speakers to make sure that the excess material is accounted for. The port is created in a similar fashion. First a hole is drilled (measured out to the center of where the port should be sitting behind the front baffle. Then a flush trim bit is used to follow the perimeter of the port hole and create that cutout shape on the front baffle.

The port hole on the baffle should be rounded over using a roundover bit. All of the other edges of the speaker can be rounded over to taste. Technically the larger the radius, the less diffraction off of the edges of the baffle.

There are 3 braces in the speaker in addition to the L piece which adds additional bracing. All of the braces are 3” in one dimension and the inner dimension of the cabinet on the other dimension. The first brace is placed behind the woofer perpendicular to the bottom. It is glued to the L piece and the sides. The second brace sits between the woofer and waveguide perpendicular to the front baffle. It is glued to the front baffle and sides. The last brace sits behind the tweeter perpendicular to the top of the speaker. It is glued to the top and sides.



Cross section showing L piece and bracing

The cutout for the back plate would ideally also be rabbeted so that the plate sits flush with the rear baffle. This isn’t a requirement and was not done on the GWM4 prototypes. Some sort of foam gasket should be used around the edge of the plate to avoid air leaking. The effects of a small air leak is minimal in terms of the tuning of the cabinet but it can lead to annoying sounds coming from the back of the speaker.

Once the cabinet is all glued and flush trimmed there may be some edges that have gaps in them. Some sort of wood filler should be used. Because this will require additional sanding, it’s preferably done before rounding over the corners.

Painting

There are countless different ways to paint the speakers. Duratex was used on the GWM4 as it is by far the easiest way to get great looking and durable results. It can also easily be fixed if there are ever any chips or scratches in the paint. The application method of Duratex can result in very different end results. Using the roller that can be purchased with Duratex results in having a large round lumpy texture. Using a foam trim roller will give a finer and pointier texture that’s more similar to coarse sandpaper. Watering it down and using an HVLP will give the smoothest finish although any imperfections will telegraph through the paint. Extra attention must be paid when preparing the cabinets if spraying. The edges should all be sealed and everything must be sanded past 300 grit. If rolling Duratex, then the thicker coats will hide most imperfections under the paint.

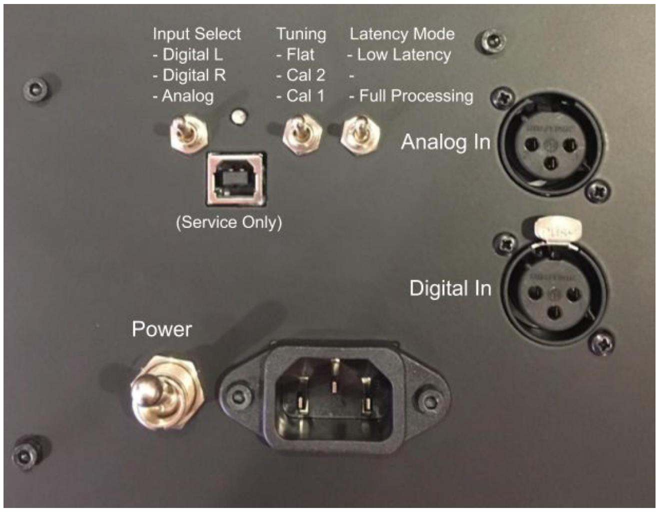
If you’re using Duratex, it’s important to note that while it will dry in a few hours, it takes many weeks to fully cure. During that time it can easily stick to anything that the speakers are placed on. I have had 20lb pieces of concrete get stuck to speakers which then had to be chiseled off and the speaker repainted.

Back Plate

The plates used on the GWM4 are made of 16g steel and are powder coated. The DXF file used for that has been included in the accompanying files although this should only be used as a guide since it will not account for the different amps and DSP boards used.

The DXF file was created using Sketchup and Fusion 360. The plates were made at a local fab shop but there are online services that will make these. It’s important to keep in mind that powder coating has a minimum cost. $100 is pretty typical and that cost won’t change regardless of if you’re ordering 2 plates or 20. The steel plate itself cost $25 each.

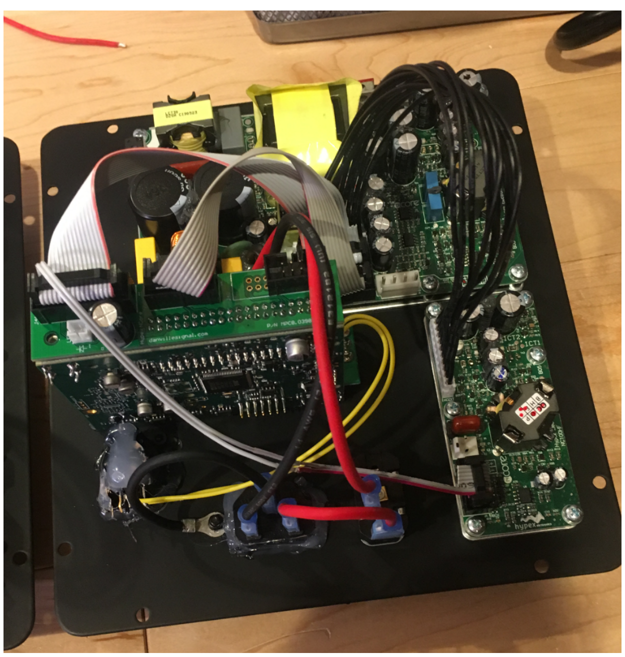
The plates on the GWM4 were not labelled as there was no affordable way to do that. The cheapest service with labelling cost around $80 per plate. If you care to have labels then a small good quality transparent sticker with white text (if using black powder coating) is a good option.



I/O and switch descriptions on back plate

It's important to seal any ports on the plate to prevent air leaks. As with sealing the plate using a gasket, leaks around the ports can result in annoying sounds. If the ports used aren't already sealed then silicone can be used to seal them internally and/or externally.

The various holes on the GWM4 plates are used for the following purposes - mounting to the cabinet, IEC connector, power switch, DSP board mounting (via the switches and analog input XLR), digital input XLR, and mounting for the 2 Hypex amp boards. The plate was grounded with one of the screws that holds the IEC connector in.



Electronics installed on back plate

Amplifiers

Hypex NC250MP and NC100HF amplifier modules were used. Using an NC252MP would have greatly simplified the wiring but it costs more and would be too large to fit on the plate.

Because these modules are only OEM, different amp modules will have to be used. There are a number of different companies that provide class D amp boards. These include Pascal, ICEpower, and Powersoft. Hypex also provides the NC400 module which anyone is able to buy. Hypex offers their Fusion plate amps which could be used as a way to harvest individual Hypex modules.

The design will almost certainly have to be changed to suit whichever amp you end up using. This includes the backplate and all of the connectors related to the amps. 250W + 100W is recommended for this design. A 2-channel 250W would also work well and may be easier to find. Depending on the form factor of the amp being used the entire cabinet may have to be redesigned to fit a larger back plate. The connectors for the headers on amplifier boards can typically be found at distributors like Digikey, Mouser, and Newark. The specs for the connectors required will typically be found in the manual for the amp board being used.

DSP Board

The DSP boards used in the GWM4 were custom made and need to be ordered in quantities of at least 25 units so it is not possible to use the same boards if you want to build these. Unfortunately there isn't really anything on the market that offers all of the functionality and I/O required. The main limiting factor is the FIR filtering requirements.

The miniDSP 2x4HD is a budget friendly solution although it only offers unbalanced I/O and the sound quality is not the best. MiniDSP used to offer their miniSHARC kit which has all of the processing power required and digital I/O (to use with your choice of DAC) but it has recently been discontinued. Their OpenDRC-DI uses the miniSHARC boards so those could be purchased and used for parts but then you're wasting some money on buying a finished product instead of just a circuit board.

The PWR-ICE250 is another option which comes with amplification and the entire back plate ready to go. The main drawback is that in order to run FIR filtering it only operates at 48kHz instead of 96kHz. Whether running the filtering at 96kHz offers any improvements in sound quality is up for debate. Many high end speakers like the Kii Three and D&D 8C run at lower sample rates.

There are a number of products in the live and installed sound market which offer the processing required although they typically cost several thousand and the quality of conversion is often questionable. There are some companies like Apex Audio which have some OEM products that you may be able to order a pair of.

In terms of I/O requirements, the input will depend on your own needs. A digital input should be used but many studios aren't willing to change the rest of their system to suit that so an analog input is often used instead. The DSP unit (if separate from amp) then needs to have a pair of analog outputs to connect to the amps. A digital output could also be used going to a DAC like a Geshelli J2 or RME ADI-2 which then goes to the amp. The boards in the GWM4 were powered off of the Hypex amp boards but most other units will require their own power supply so that must be factored into the design of the wiring and/or back plate.

The processing requirements for the DSP board are as follows:

- 2048 FIR taps for the woofer channel
- 300 FIR taps for the tweeter channel
- Gain adjustment for the woofer and tweeter channels
- Polarity inversion
- Ability to switch between different signal paths or presets if a low latency mode is required
- Delay on the tweeter channel
- Single band of parametric EQ on the tweeter channel
- 4 bands of parametric EQ on the woofer channel
- 5 or more bands of parametric EQ for room correction
- Protection limiting if desired
- If creating a low latency mode:
    - 8th order LR crossover
    - Separate tweeter delay, polarity and gain from main FIR signal path
    - 2 bands of parametric EQ on the tweeter channel (in addition to EQ from before)
    - 3 bands of parametric EQ on the woofer channel (in addition to EQ from before)

DSP Processing

The GWM4 are programmed using Audio Weaver from DSP Concepts. It offers a simple graphical way to program by connecting various blocks giving virtually unlimited flexibility (as long as the DPS board has enough processing power). It also allows the DSP board to run the program as you edit it live.

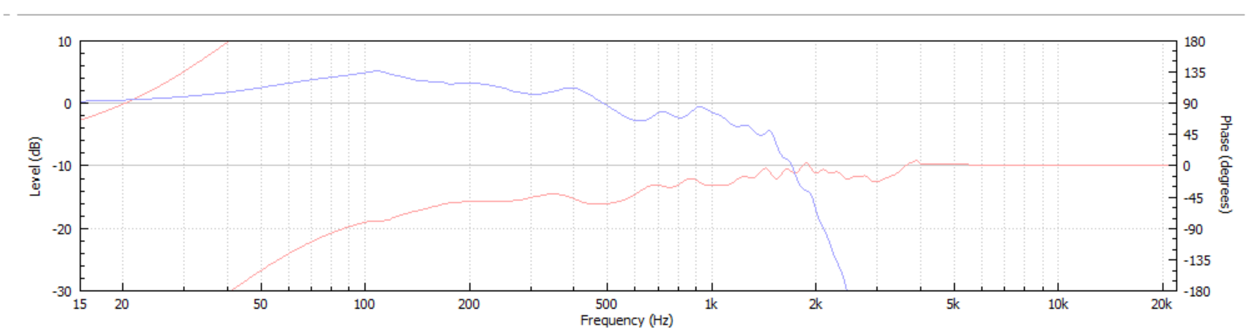
In order to program the speakers they must first be measured. Anechoic measurements are required so that the effects of a room are not present in the measurements. This requires a large reflection free window. The larger the time window, the lower the measurements will be accurate for. Since most people don't own a large anechoic chamber, measuring outside away from any buildings or other structures is usually the best option. The speaker and microphone should be placed as high up as possible. Measuring at a distance of 1.5m away from the speakers will usually give good results for a speaker like this. The speaker and/or microphone can be moved for off-axis measurements.

REW is the most popular tool for speaker measurement (at least for the average speaker building enthusiast). While all of the processing that runs on the GWM4 will be shared, there will likely be adjustments needed which require measuring the speakers that you build. This would mainly consist of checking woofer and tweeter levels, time aligning the drivers, checking polarity, and any necessary adjustments to the EQ bands.

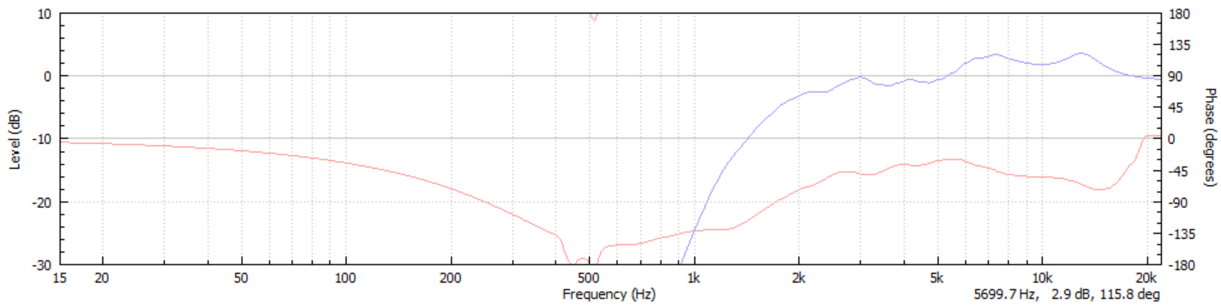
An outdoor measurement using a tall ladder will give accurate results down to around 200Hz. It's important to adjust the measurement window so that it is only looking at the reflection free window and not influenced by reflections (mainly the reflection off of the ground). In order to judge the low frequency performance, measurements can be taken with the microphone right up against the woofer. Perhaps 1" away. The microphone can also be placed in front of the power to make sure that it has been tuned correctly.

While anechoic measurements are required for creating the FIR filters, ultimately the speakers will be used in a room so if you build a pair of these yourself you can work on them in the room. The only thing that you won't have is a "flat" setting that's created without the effects of the room.

The FIR files provided work down to around 200Hz providing frequency and phase correction as well as the crossover filtering. These files are created for use at 96kHz. If 48kHz files or a different file format is required for a specific DSP platform please contact me. I can't guarantee that I'll generate those files but will try if possible. If you'd like you could also attempt to generate your own FIR filter files.

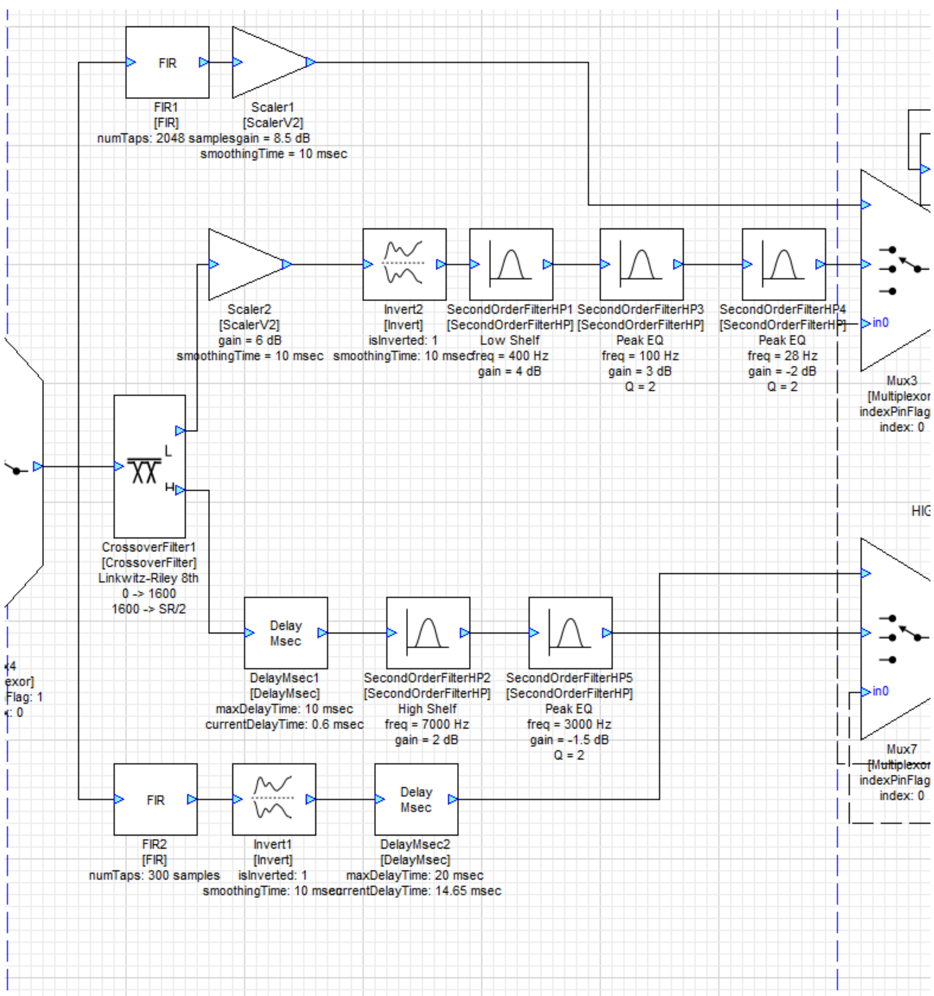


Frequency and phase response of woofer FIR filter (not woofer response)

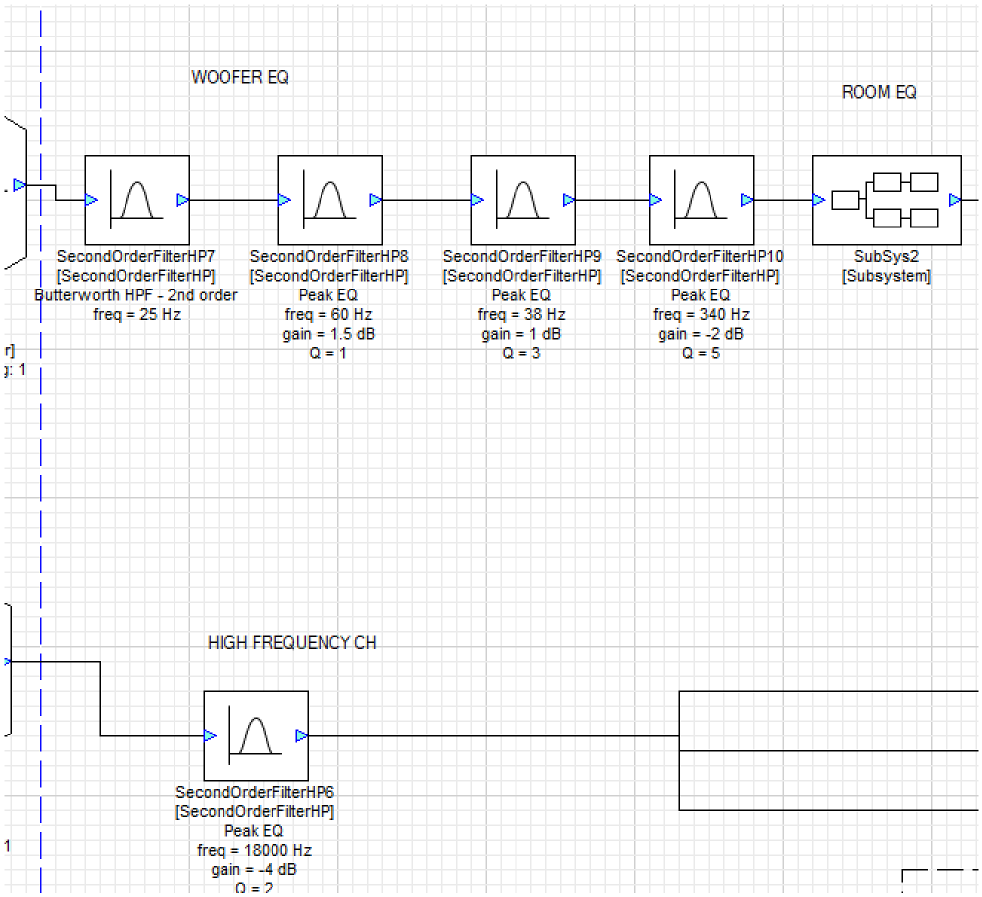


Frequency and phase response of tweeter FIR filter (not tweeter response)

The following images show a simplified version of the settings used on the GWM4. The specific gain values should be ignored as there is additional padding in the GWM4 which is being accounted for. The signal is split between the FIR and low latency paths. A multiplexor after that allows the user to toggle between those modes using a switch on the back plate. Following this multiplexor are the additional EQ bands that apply to both modes.



FIR and low latency signal paths in Audio Weaver



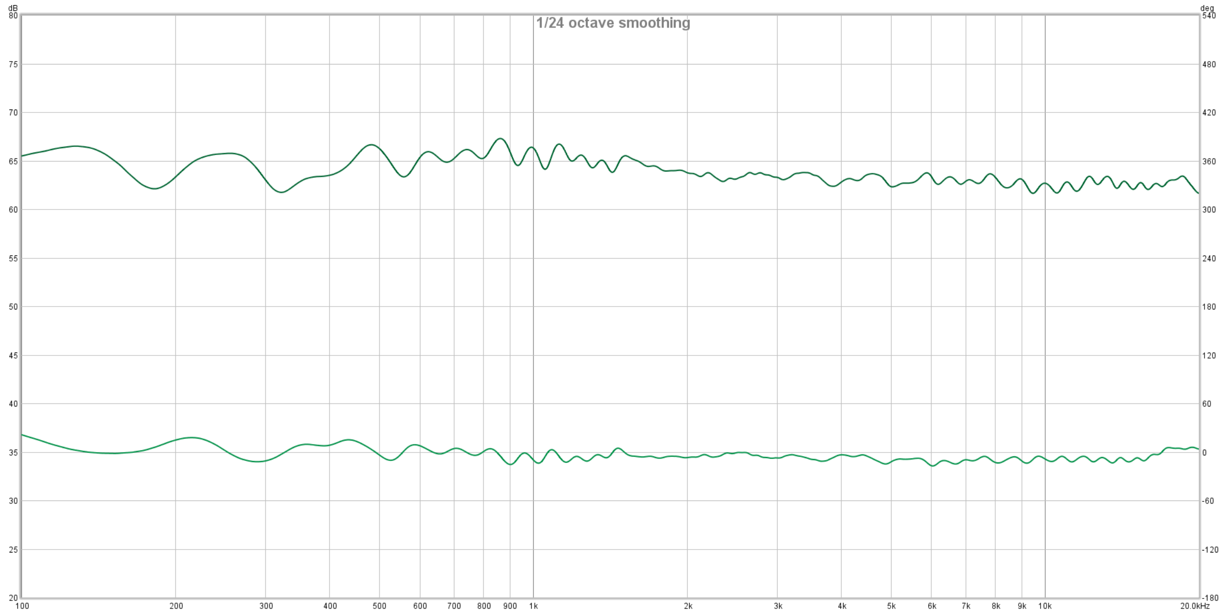
Additional EQ bands applied to both operating modes in Audio Weaver

Room Tuning

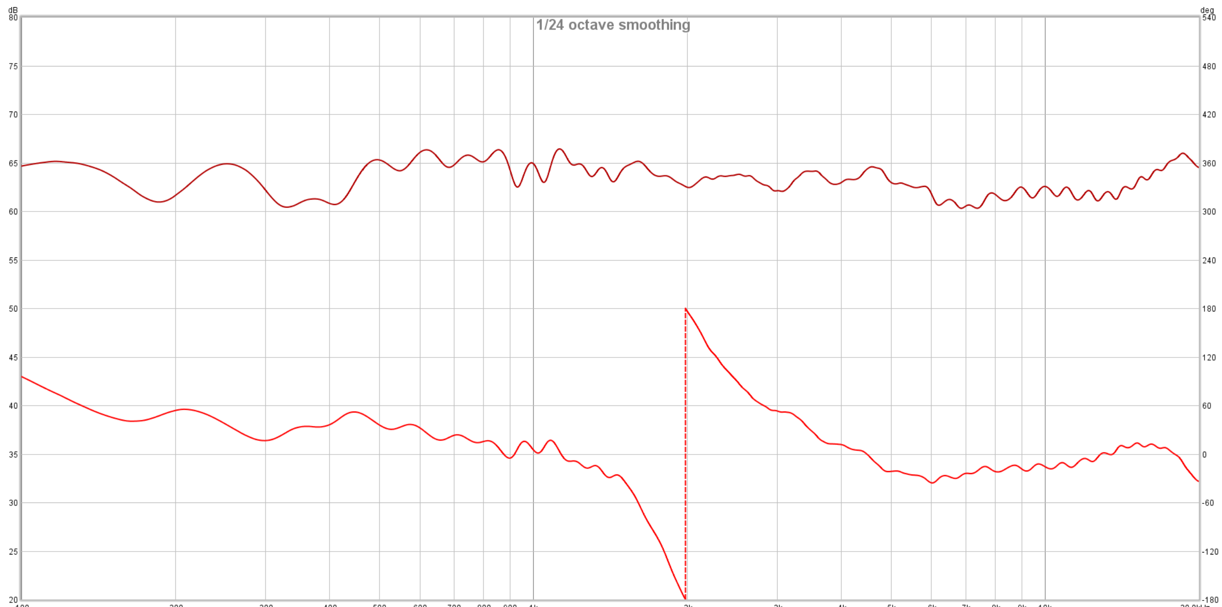
One of the design criteria for the GWM4 was built in room correction. This involves using a number of EQ bands to counteract certain room issues. This guide will not cover how to properly calibrate the speakers in a room but the basic process includes measuring in-room response, applying filters, remeasuring to confirm if the desired effects have been achieved, and adjusting filters as necessary. Great care must be taken to not be heavy handed with this additional filtering.

Measurements

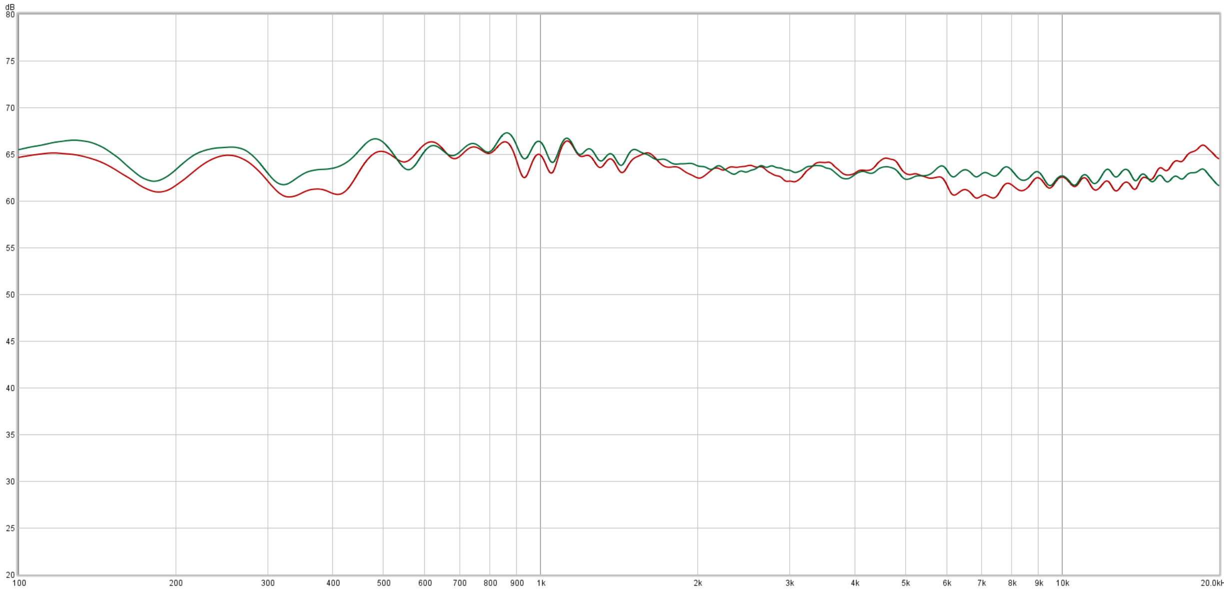
The following images show the final measurements of the GWM4. They were created outside and are accurate down to around 200Hz. If you've built your own pair you should end up with something that resembles this.



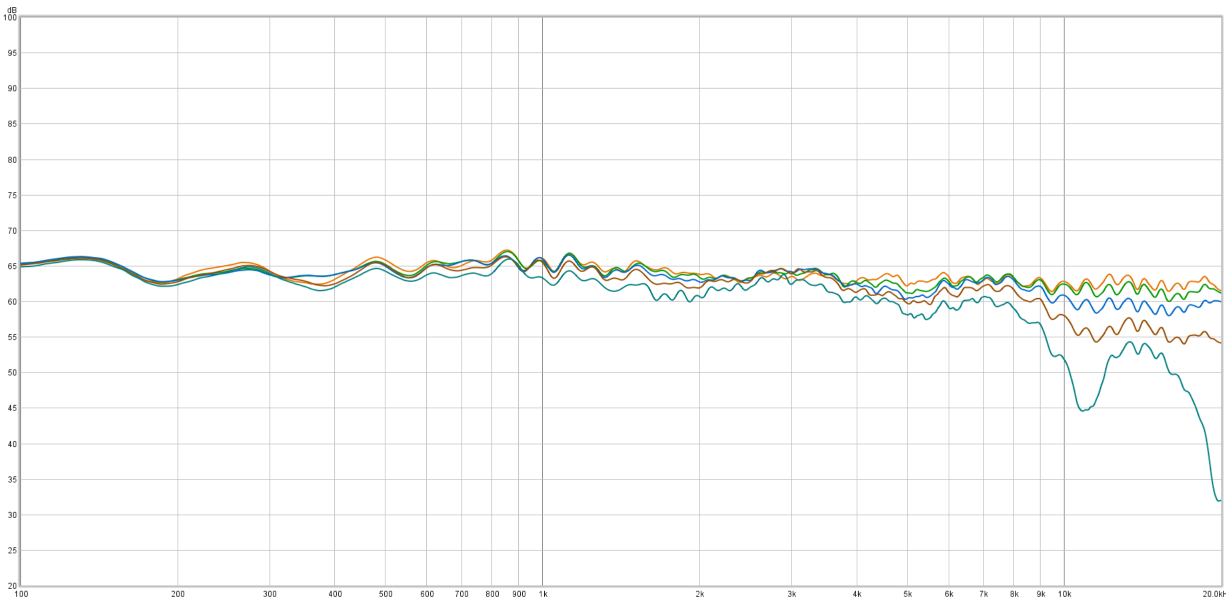
Frequency and phase response in FIR mode



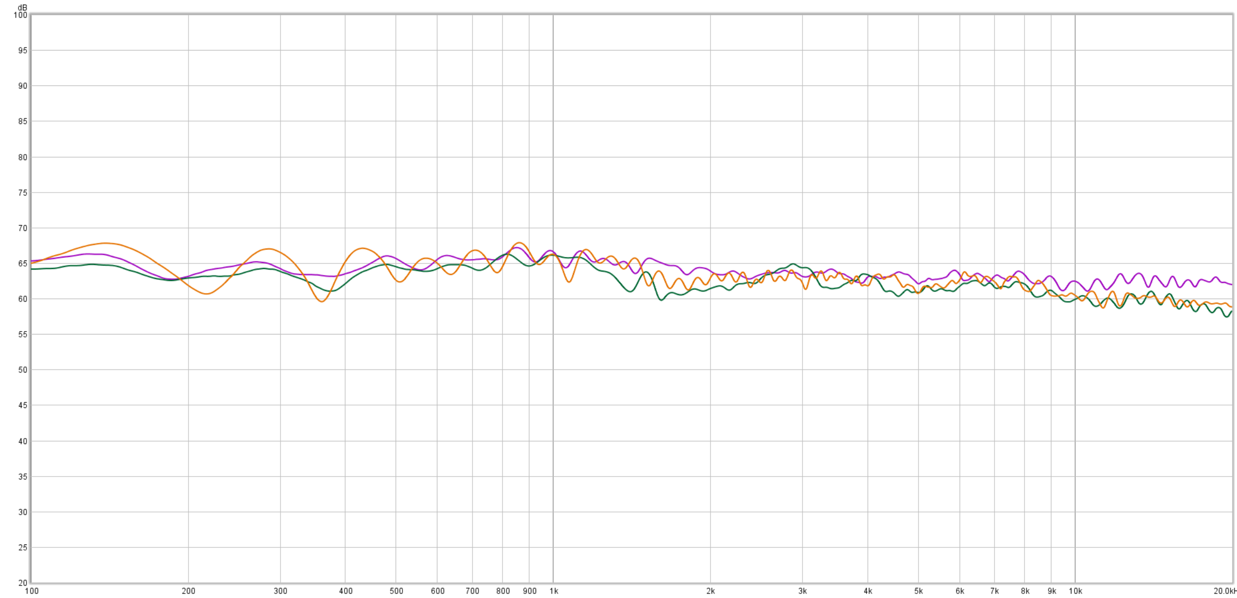
Frequency and phase response in low latency mode



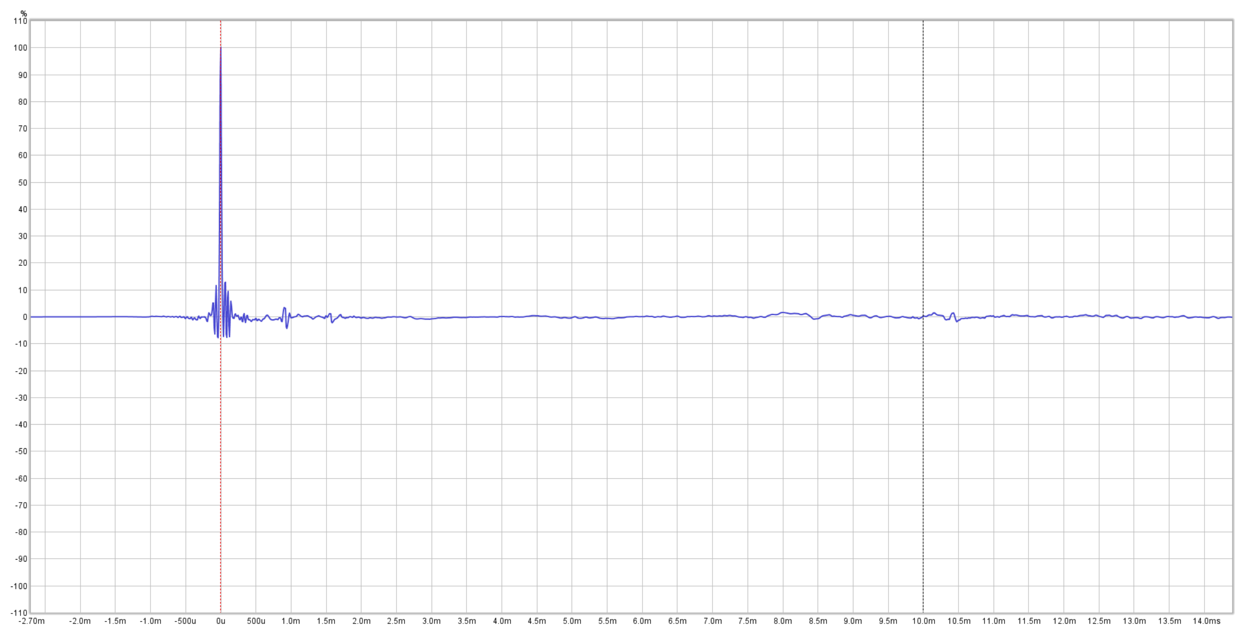
Comparison of FIR and low latency mode frequency responses



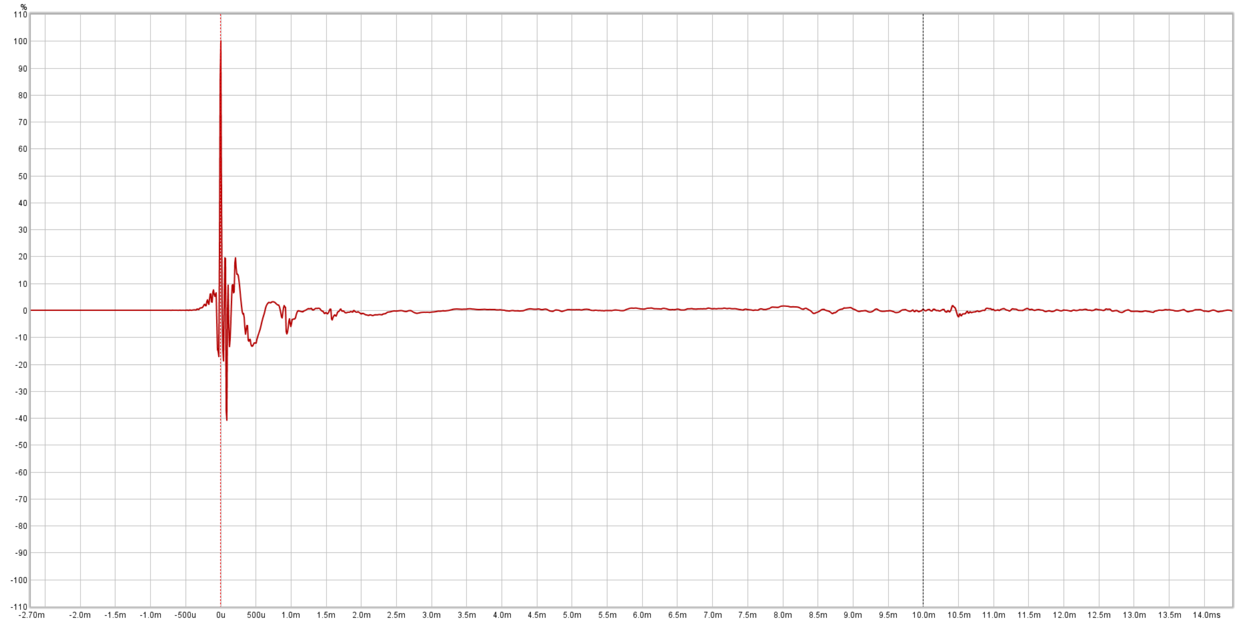
Horizontal off-axis measurements of FIR mode 0° - 60° in 15° increments



Vertical off-axis measurements of FIR mode 0° - 30° in 15° increments



Transient response of FIR mode



Transient response of low latency mode

Alternate Versions

There are a few ways to build these speakers that will simplify the process. One way is to use a predesigned plate amp with built in DSP. The PWR-ICE250 was mentioned before and would allow for FIR processing at 48kHz. At 96kHz only the low latency processing mode would be possible which would sacrifice a large part of the magic behind the GWM4. They would still have incredibly low distortion and great dispersion characteristics that likely outperform any speaker costing at least twice as much.

Hypex offers their line of Fusion amps which anyone can purchase. These are their amplifier boards plus their own DSP module conveniently packaged on a plate. The drawback is that these don't offer any kind of FIR processing so once again only the low latency processing would be possible.

With either of these options a premium will be paid for buying a conveniently prepackaged plate amp. It's important to point out that I have not personally tried out either of these products and so cannot guarantee that they would work as required and not have any issues.

The main alternative version to build this system is using outboard electronics. The speakers themselves would be built only with a pair of binding posts on the back directly connected to the drivers (no passive crossover aside from the protection cap on the tweeter). The construction of the cabinet could likely be outsourced to a local company (or friend/relative) if you aren't able to do the woodworking yourself.

A number of electronics would be required to go along with each speaker. There are countless options for these products so for the sake of this guide it is assumed that separate units would be used for the amplification, DAC, and DSP. Units with higher channel counts can also be used to cover the needs of a pair rather than separate units for each speaker.

The following components would be required for each speaker (not the pair):

- 2 high quality speaker cables
- 2 channels of amplification (VTV and Nord offer some affordable Hypex amps)
- A stereo DAC (Geshelli J2 or RME ADI-2 DAC are good options)
- A DSP unit with the required input and a digital output (MiniDSP OpenDRC-DI is recommended)

A basic set of these electronics for a pair of speakers that offers similar performance to what's built into the GWM4 would cost around $2700. That would put the total cost of this project at around $4000. Of course higher end amplifiers and DACs could be used where the sky's the limit.

Conclusion

Hopefully this guide is of use to someone whether they build their own pair of speakers or not. This guide can hopefully also be used as a resource for designing and building other sets of speakers following the same principles outlined here. A similar approach has been taken on all systems I've built including the main speakers in my studio.

I'd like to thank everyone who has supported or been a part of the GWM4 project. In particular, those who graciously spent their time auditioning the speakers and giving me feedback which helped improve them and find issues that I may not have been otherwise aware of.