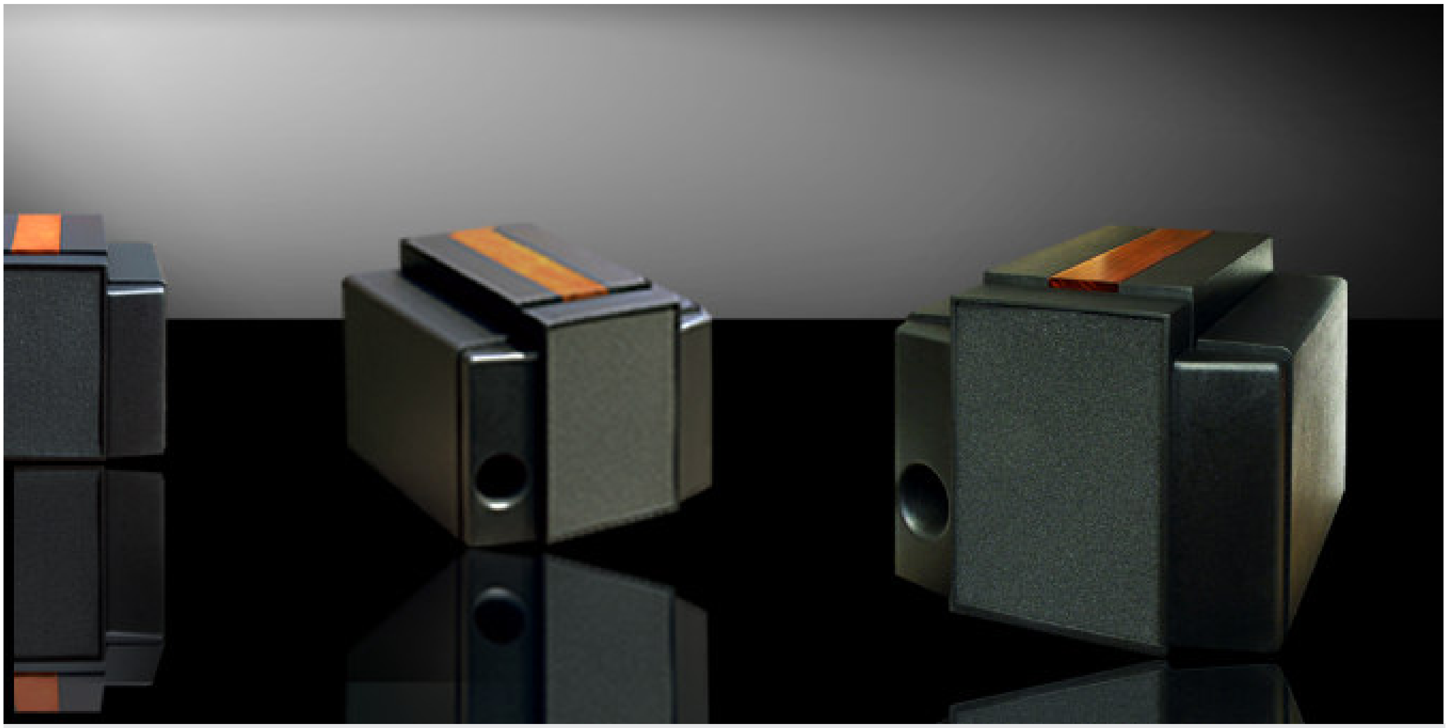


Aperture HD *featuring our new CopperMatrix™ wire from Marigo Labs*

Time-Coherent Sound Delivered From Tight Places

My Design Concept, by Roy Johnson, designer, Green Mountain Audio, Inc.

I CREATED THE APERTURE as the logical upgrade from the Continuum 0.5 Center Channel / Shelf-mount speaker. It was to be the best possible sound from a compact speaker designed specifically for use on a bookshelf, or from above (or below) a large screen television. The Aperture would have more clarity and improved dynamic contrasts than its predecessor by way of significant upgrades to its crossover and drivers' damping.

There were some special requirements, however. When a speaker is tucked away on a shelf or placed near the television screen, the last thing one wants to hear is reflections off those nearby surfaces, so the Aperture's dispersion had to be well-controlled in every direction. Also, those surfaces would boost the Aperture's natural bass response -- a consideration I would need to address when setting the speaker's low-frequency response during the design phase.

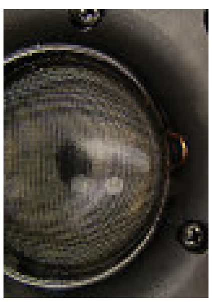
While it needed to be as small, the Aperture had to be able to nearly shake the room yet play very softly for those late night movies or for use in an office or restaurant setting. The rooms in which it would best perform would range from 10-24′ wide, 12-30′ deep, 7-10′ high. It would be magnetically shielded and designed with isolation feet to avoid vibrating everything else around it. These are significantly different operating conditions than for a speaker designed to be placed on a stand.

Driver selection

The requirement for the smallest possible size meant the Aperture could only be a two-way design, with a woofer and a tweeter. Because this speaker could be used as a center channel speaker in home theater applications, it was important that its sound did not change as one moved from left-to-right. This can only be accomplished when the woofer and tweeter are placed in a vertical stack. Most 'center channel' speakers use two woofers and midranges, with a tweeter in the center in order to make a long, thin cabinet. However, clarity in the voice range changes substantially as soon as one moves just a few inches off-center. This result defeats the purpose of a 'center channel' -- which is to keep the dialog clear and located with the video screen even when one does not sit in the middle. Those designs are driven by marketing, not by physics or psycho-acoustics.

Woofer choice

Because the Aperture needed to have substantial bass response, be capable of a high output, and able to play very softly, it was logical to retain the 6″ woofer I originally placed in the Continuum 0.5 in 1998 and since used in the Europa, Europa Max, and Callisto. To this day it remains unsurpassed in every area of performance. This woofer is fully shielded and has the ability to play both very loud and very soft. Its patented neodymium magnetic structure envelops the entire voice coil in a powerful and uniform field. Because the magnetic assembly exerts complete control of the coil on large bass-note excursions, it also features very low bass distortion. This driver has an extended voice and treble range for the smoothest blend to the tweeter. It is also efficient, since its blend of carbon fibers and long-fiber wood pulp results in a very rigid and light cone.



Tweeter choice

Although a complicated decision, I decided Aperture should include the same tweeter that was used in our Continuum 3. It is small, magnetically shielded, and produces the highest clarity. Unlike most tweeters, it is designed to operate in free space, with no reflective surfaces around it -- a feature which was very important for the design of the unique dispersion-control surfaces around it. Most tweeters lose their clarity when played softly because their suspensions seize on microscopic motions. This is something almost impossible to measure, but easy to hear. An ideal tweeter would have a suspension made of tissue paper (if it did not fall apart). It would have a lightweight and quite rigid dome with no high-frequency breakup modes. Although metal dome tweeters improve each year, they are still limited in their low-level clarity by the thick rubber surrounds used to damp the ultrasonic ringing in their metal. Over years of testing, I found certain tweeters work best with no cabinet around them, and others work best with a particular dense wool felt placed near them to absorb cabinet reflections. The tweeter selected for the Aperture has a linen dome coated with several layers of polymer that seal and further stiffen it. Linen is woven from flax fibers, which have very near the stiffness of Kevlar. This tweeter's dome and suspension is molded from one continuous piece of linen, which produces several features unattainable with Kevlar. Its suspension is soft and very flexible for excellent low-level reproduction. The dome has a very low resonance frequency, far below the actual crossover point, which lets its simple crossover circuit better perform. It gives the dome the ability to stroke like a miniature woofer, to accommodate large signals without compression.

Controlling dispersion

In the higher-voice range and the low treble, Aperture's woofer sends little sound off to the sides, but its tweeter would be happy to do so, if not for an unusual dispersion-control system surrounding it. Quite elaborate, it took many months to develop. The result is that the Aperture does not talk at all to nearby surfaces in the upper-voice range and treble and yet delivers a very clear and natural sound far off to the left and right sides. If a tweeter is designed to send out a spherical pulse of sound, like this tweeter, then there can be nothing around it -- the same approach I used in the Continuum 3. Any surface near the tweeter has to be completely absorptive for the highest performance. Since no material is completely absorptive, it has some reflection.

Creation of the Inverse Anechoic Horn™

The solution was discovered by way of contrast with the extreme opposite -- placing a horn around the tweeter. A horn works by forcing the sound waves out the front flare. There are an infinite number of reflections inside that come from the continual re-direction of the molecular collisions back towards the front. One reason a horn is loud is because the sound simply cannot escape elsewhere. So what is the opposite of a horn? The first answer is "no horn at all," but that does not lead to anywhere new. The second answer is "a horn that absorbs every molecular impact on its side walls, so that the direct sound still moves ahead, but without the reflections from the sidewalls." If there are no reflections, then that horn "must not be there," as far as the direct sound is concerned.

Because there are no perfectly absorbent materials, I began a series of experiments with angled surfaces and loaded them with various felts and acoustic foams. The idea was that if a reflection was to occur from a surface, it would leave at a pre-determined angle only to be captured by another surface, and so on until there was no further reflection. The experiments led to the creation of a 'baffle' which was placed around the Aperture's tweeter. The baffle sharply cut off the tweeter's output to the sides and yet had no effect on the sound directed out the front. I named my new creation an Inverse Anechoic Horn™.

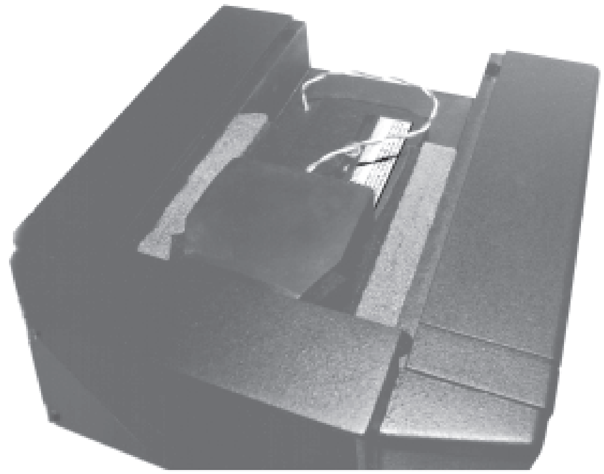
User adjustability

I also designed user-adjustability into the Aperture's tweeter. Its position may be moved from front-to-rear to further focus its sound up or down. I named this adjustability Soundfield Convergence™ and first introduced it in with the Continuum 1 in 1996.

Woofer port

The extraordinary woofer I chose to use generates very-low distortion bass, sufficient to fill small and medium-size rooms, but only with the aid of a properly-designed port. Placing the woofer in a ported cabinet would create more low bass than if placed in a sealed enclosure. To make the lowest bass louder, the port and cabinet volume needed to work together with the woofer's natural resonance.

A port also keeps the small woofer from stroking far on loud low-bass notes, which would distort the vocals. The mass of air inside a port's tube is an invisible piston and literally bounces off the air volume inside the enclosure. It is reacting to the woofer's motion, which is also bouncing off that same air volume. Good sound depends on the woofer stopping these bounces as rapidly as possible. When the woofer compresses the air in the cabinet, the generated pressure pushes air out the port's tube, which pressurizes the room. The woofer, the air in the cabinet, and the air in the port's tube form a resonating system.



Not much 'push' from the woofer is needed to begin the process, nor is much push from the port required to affect the woofer. To tightly control this resonant situation, the woofer and port must 'communicate' with each other as quickly as possible. Any time lag results 'sluggish' or 'boomy' bass.

In order for the air pressure in the cabinet to change all at once, as quickly as possible, four important parameters had to be considered.

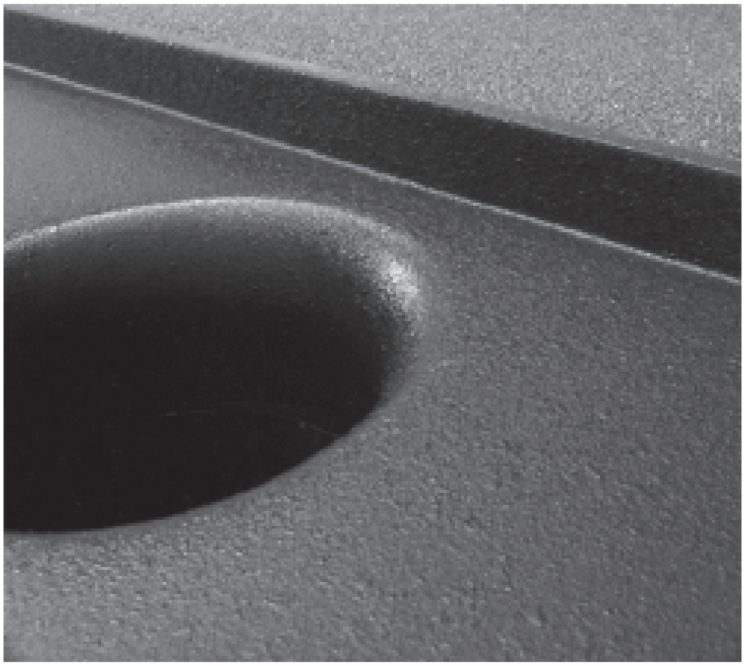
First, a cabinet's longest dimension has to be short enough so that air-pressure changes don't arrive at different times to the port and woofer. Second, the port's intake and the woofer must be located near each other and close to the center of the cabinet. This placement would create uniform pressure changes everywhere inside the cabinet in the shortest possible time and allow both the port's intake and woofer to quickly respond to them.

Third, the port's exhaust must be aerodynamically shaped since the air inside the port's tube oscillates at 40 miles per hour while the air at the end is free to move at 770 miles per hour, the speed of sound. Any air turbulence in the transition zone at the end of the port would mean that the pressure is not changing, and therefore, not being communicated. Harmonic distortion is the result, which is commonly called 'fuzzy bass.'

Finally, the acoustic-absorption materials inside the cabinet must be designed to absorb every sound above the port's resonance frequency and yet absorb nothing at that resonance frequency. These challenges were met in the Aperture in several ways. The Aperture's bass port exits to the side of the woofer and is angled inwards towards the center of the cabinet, so that it responds more evenly to the entire pressure change within the cabinet. Its output is not too close to the woofer, which would prevent the port and woofer from 'talking' to each other. Many compact speakers place the port in one corner of the cabinet, which lets it receive only part of the air pressure changes from the cabinet. When it is placed next to the woofer, less bass is heard since the port pressurizes the woofer from the front and vice versa, instead of pressurizing the room. The Aperture port's front location prevents the low-bass output from being influenced when the speaker is used in a shelf application.

The Aperture's port also has a very large surface area compared to what is commonly used for a small woofer. It creates more 'push' on a room's air, which then creates a louder output. The ends of Aperture's port exhaust are shaped in a wide, exponential flare to reduce air turbulence around its mouth, which results in less distortion. A unique combination of ultra-low density fiberglass and a Golden-Ratio Baffle™ creates a very quiet cabinet from the mid-bass though the entire voice range and yet doesn't interfere with the lowest bass for maximum bass output from the port. The port's 'tuning' to the woofer and cabinet is designed with a soft roll-off, to compensate for the boost that nearby surfaces give to the bass response. The result is an extended bass response.

It is easy to hear when a speaker has flaws in the voice range because we are so familiar with human voice.



Several factors contribute to producing the clearest possible voice range and ensuring a smooth transition from woofer to tweeter. The woofer must produce a uniform response throughout the voice range and into the low treble. The Aperture's woofer has the very rigid and light cone required for this uniform, low-distortion response. The voice coil behind this cone is also very light with wire wound around a strong, light Nomex voice-coil former.

The tweeter has its own large rear chamber behind the dome and is mounted in its own Q-Stone™ cast marble enclosure. We use dense wool felt Inside the enclosure to compressively damp any vibrations in the tweeter's housing. The results? Aperture's treble is very sweet, delicate, dynamic, and extended.

Cabinet construction

Constructing the Aperture's cabinet is a very complicated process. Its front panel is molded from our Q-Stone™ cast marble for increased strength and less vibration. The tweeter has its own Q-stone™ compartment.

Since the cabinet would have been to heavy had all of it been produced in our unique Q-Stone™ cast marble, the rest of the cabinet is made from layers of premium, high-grade wood panels. For the cabinet to be as rigid as a full cast marble cabinet, 19 panels of four different thicknesses were required. Each was cut to a tolerance of less than +/- 10 one-thousandths of an inch.

The Aperture fits inside of an 11 x 14" opening, and if its shape fills that space, there is no resonance from the opening itself. Five soft neoprene, screw-mounted feet -- with the one in the middle off-center to prevent the shelf or TV cabinet from vibrating up and down in a drumhead mode -- complete the quality and care with which the cabinet was designed and constructed. The feet are neither too soft nor hard. Soft feet would allow the cabinet to vibrate on bass notes; hard feet would transmit higher-frequency energy to wood shelves, which are prone to buzz.

The crossover circuits

When we look at how the woofer and tweeter must blend together, each must handle a specific frequency range so that the sounds from each spread evenly across the room. If one could ask a woofer cone to also be a tweeter, then all the treble from it would project straight ahead like a very narrow flashlight beam. Treble would be heard only from one best seat. The rest of the room would receive no treble at all. Sitting in one's chair, the sounds heard would come back from the room sounding very 'dark' or muffled. No recordings would sound 'right' by anyone's standards. Therefore, a tweeter has to be small and a woofer large -- but not too large -- for a two-way speaker. A crossover circuit divides up the musical spectrum. Everything we know and all that we do at Green Mountain Audio is to have those signals *re-combine at a listener's ear into the one original wave*.

Tweeter crossover

The tweeter in the Aperture operates from 2,850Hz to beyond 20,000Hz, which means it takes over from the woofer right in the critical 'ess' and 'tee' part of the voice range. Below 2,850Hz, the crossover circuit gently rolls off the tweeter's lower-range response at a rate of 6dB per octave. This gradual rolloff is a by-product of the only circuit which will simultaneously send the signals to those drivers so they move together as one unit -- a first-order crossover -- which results in the clearest sound. Time-coherent' behavior between a woofer and tweeter is very rare in speakers because it is difficult to engineer and can only come by using this type of simple crossover circuit. However, the circuit does not do a great job at protecting the tweeter from voices and bass.

So, this tweeter is required to handle more power, which it does gracefully. We are fortunate that this tweeter is so linear in its operation, so well-behaved, that the entire crossover circuit feeding it consists of one super-premium capacitor. There is no printed-circuit board to add resonances and impure conductors. One end of this capacitor is crimped firmly to the positive gold binding post and the other end is twisted and soldered to the wire that runs directly to the tweeter's positive terminal. The return wire is identical and connects to the negative binding post and terminal. The state-of-the-art solder we use sounds clean and clear. With such few parts in this circuit, no cabinet reflections, and such a low-distortion tweeter, it is easy to hear the differences made by wires, capacitors, binding posts, and solder. Can we explain the differences? Not entirely, but they are definitely audible.

Woofer crossover

The Aperture's woofer operates from the low bass up to 2,850Hz and to facilitate a smooth transition to the tweeter, it is capable of a smooth output well past 5,000Hz. The rate of rolloff at 2,850Hz is also 6dB per octave. Again, we are fortunate that this woofer is so linear in its operation that the entire crossover circuit on the way to it consists of one small Litz-wire OFC inductor to keep out the highs.

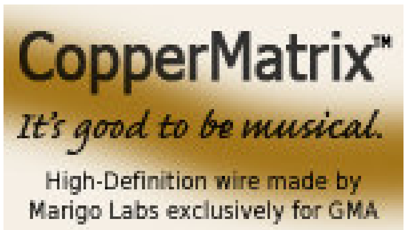
Our Balanced-Phase™ circuit design

One final point about our simple, 'first-order' crossover circuit. Any crossover circuit can be thought of, quite accurately, as a fork in the road for the electrical signals from the amplifier. Since the signals of the high-voice range and treble cannot easily get through the woofer's inductor, they are deflected down the path of less impedance -- through the tweeter's capacitor. If a crossover circuit can be made with only one electrical component feeding each driver, then a very nice thing happens -- the woofer's inductor and the tweeter's capacitor can be chosen to have opposite impedance curves, or 'mirror images,' exactly as if they formed a 'Y' adapter for the incoming signals. The ideal 'fork in the road' for the signal is a good thing for the amplifier, because it cannot then know that a capacitor or inductor exists. To the amplifier, only one 'path' is apparent, and it sees no stored energy returned to it. The measure of this is a 'flat impedance curve' for the entire speaker. The Aperture appears to the amplifier much like a 4- to 5-Ohm resistor at most every frequency, which allows any amplifier to deliver its power with the least distortion. Long speaker wires may be used, since they will have less effect on the sound.

Our exclusive CopperMatrix™ wire from Marigo Labs

In the Aperture HD, we are fortunate to be the first and the exclusive user of a new style of Litz wire developed by the physicist responsible for Marigo Labs products. Each positive and negative wire going to each driver from the crossover circuit is a conductor of 500+ ultra-fine strands of ultra-pure, oxygen-free copper. Each strand is individually coated with a proprietary damping and insulating polymer just millionths of an inch thick. These strands are then wound in multiple layers of differing tensions in a proprietary geometric pattern, with the effect of reduced magnetic-field interaction between layers and proper mechanical damping in both the transverse and axial directions. (Pure metals love to ring sideways and along their lengths -- these wires do not and can not.) The exterior of the entire 18-gauge conductor is protected by multiple threads of a cellulose-derived fiber wound in different directions to provide mechanical damping more so than any known plastic insulation and with far less dielectric effect than Teflon. The finished wire is doubly-cryogenically treated, tested, and marked for signal directionality.

Each of its 500+ copper strands is only about 25 microns in diameter (0.001"). Each wire must first be stripped of its organic-thread insulation and then prepared for soldering by applying a unique organic-salt flux, then immersed in a bath of liquid solder. For any connection it makes, it must first be aligned in its direction. Its solder-covered end is either wrapped tightly with the other wire from say, the capacitor in the crossover, or it is heated and bent around the terminal on the driver. Either way, it is then heated again, crushed into the other wire or terminal, and finally soldered again. This produces maximum contact to all the strands and minimum solder between each strand. Each connection is de-oxidized and strain relieved with heat shrink to last for life.



This wire made such a difference over the excellent-sounding wires we were already using that one could hear it in another room. Livelier on dynamics, but in a subtle way. Each peak was clearly defined and yet naturally rounded, with an edge and coarseness to it removed. The decays of any sound were far more defined than before, with much less 'noise' between each note, yet it was obvious no details were being lost. The timbres of each instrument and voice were more accurate and produced new textures. The power in the music or its subtle grace were much more evident. The improvement this wire made, in what we can most simply call clarity, was so great that we further refined the values and choices of any by-pass capacitors used in the crossover circuits, very small ones placed in parallel with any larger capacitors to (usually) make them more transparent to the signals. The result was even better blending between the drivers and increased dynamic contrasts btween any two signals. The total increase in definition is quite stunning -- hence the High-Definition (HD) identifier.

A lifetime of enjoyment

All of the physics and mathematics used in designing, engineering, and constructing the (retired) Aperture -- now the Aperture HD -- would be wasted if we could not get the separate sounds of the woofer and tweeter to *re-combine at your ear into the one original wave*. Why? Only then will you hear all of the musicality hidden in any complex waveform, follow any artist or voice, or hear a sound effect to its maximum intensity or subtlety. I am glad I designed a speaker to serve as either a bookshelf or center channel speaker. Its flexibility will serve its owner for a lifetime of listening enjoyment.