The Art and Science of Sound
RCC In-Wall Subwoofer Design

"The Science of Sound is easy. Mostly because the engineering principles that govern how audio is reproduced and then perceived by the human brain have been studied and applied to speakers for many years. Such factors as distortion, power response, phase, etc. are well understood and their effects have been used to improve the design and manufacture of Consumer Electronics products long before I was a part of this industry.

The Art of Sound is another matter. There are always new products that come to market which demonstrate ways in which consumers can be attracted to a new and different concept. It is the proper application of known scientific data and invention to new products that is the Art of Sound."

Cary Christie

President & CEO, ARTISON

Artison's Front Channel LCR DM's and SoundBars integrate into the television monitor and visually disappear, our surrounds are inconspicuous or can be sunk into a wall or ceiling and also disappear. The only remaining visible culprit to the perfect audio system was the subwoofer. It would be a shame to leave a conspicuous box sitting in the room when you can so easily make it go away. We decided that if we were to make a contemporary subwoofer it should be able to hide in plain sight. That meant that it had to go into a wall, floor, or ceiling cavity or be a very small and unobtrusive design. Again, we started with a clean sheet of paper and created a product definition. Ours went something like this:

- **The kinetic energy generated by the movement of the drivers must be isolated so as not to create vibrations in the wall**
- **The system should easily retrofit into an existing structure without having to rebuild the room**
- **Should play at realistic levels down to 20 Hz**
- **The drivers should be well controlled and reproduce the electrical signal perfectly**
- **The components of the subwoofer that are visible should be small and unassuming when installed**

A decade ago we made a subwoofer called the RCC-210 which was quite a good performer. It was unique in what we referred to as its reactance canceling configuration. It played loud and was considered by all that reviewed it as a very good subwoofer. One of the real advantages of the RCC-210's design was the use of dual woofers rigidly connected to each other via the cabinet in a way that used the reactive forces generated by the woofer movement to cancel the same reactive forces in the opposing driver. With this type of design the drivers are wired in phase and the cone motion in one driver of the pair is a mirror image of the complementary driver. The result was a perfectly balanced subwoofer that converted all of the amplifier's energy into a movement of air without wasting any of the power trying to move the cabinet.

Reactance Cancelling Configuration

Newton's Third Law of Motion simply is that for every action there is an equal and opposite reaction. Think of the explosion of a cannon and the recoil of the device, or conversely a bouncing a ball on the ground. The action, or force, is met by an equal and opposite reaction, or reactance force.

In subwoofer design this law is illustrated by the moving woofer cone creating a sound wave in one direction but also an equal amount of force is generated that wants to move the woofer frame and the cabinet that it is attached to, in the opposite direction. This periodic motion is the same on the opposite direction of travel of the woofer cone, like the bouncing ball. This reactive force is much less apparent, due to the much larger mass of the cabinet and speaker frame. The reactive forces create the dynamically imbalanced system, i.e. a shaking, vibrating system. With an In-Wall application, this vibration is instantly transmitted into and throughout the structure of the building being dissipated by shaking the walls, ceilings, windows, floors, etc which usually is converted back into acoustic energy. This not only robs the system of power and clarity but also wakes up the kids, when the bombs explode in the climax of the movie.

A subwoofer that is designed to work In-Wall in a Reactance Cancelling Configuration seemed to solve most of our product definition requirements. We needed at least 2 drivers which meant that they could be smaller than a standard large single woofer. This, again, actually turns out to be an advantage. Smaller drivers are lighter, stay in piston mode to a higher frequency, and are more controllable than their larger counterparts. They also are more efficient and collectively have much higher power handling capabilities than a single driver which aids in extending the usable range with the DSP in the RCC 620 Amplifier. A large piston area is simply achieved by summing up the S_d (a measurement of the piston's surface area) of the multiple drivers. Because of the in-wall, opposed driver requirement we decided to vent the audio signal into the room using the slot created between the opposing drivers. This slot loading feature also helps to lower the system resonance which allows for deeper bass extension.

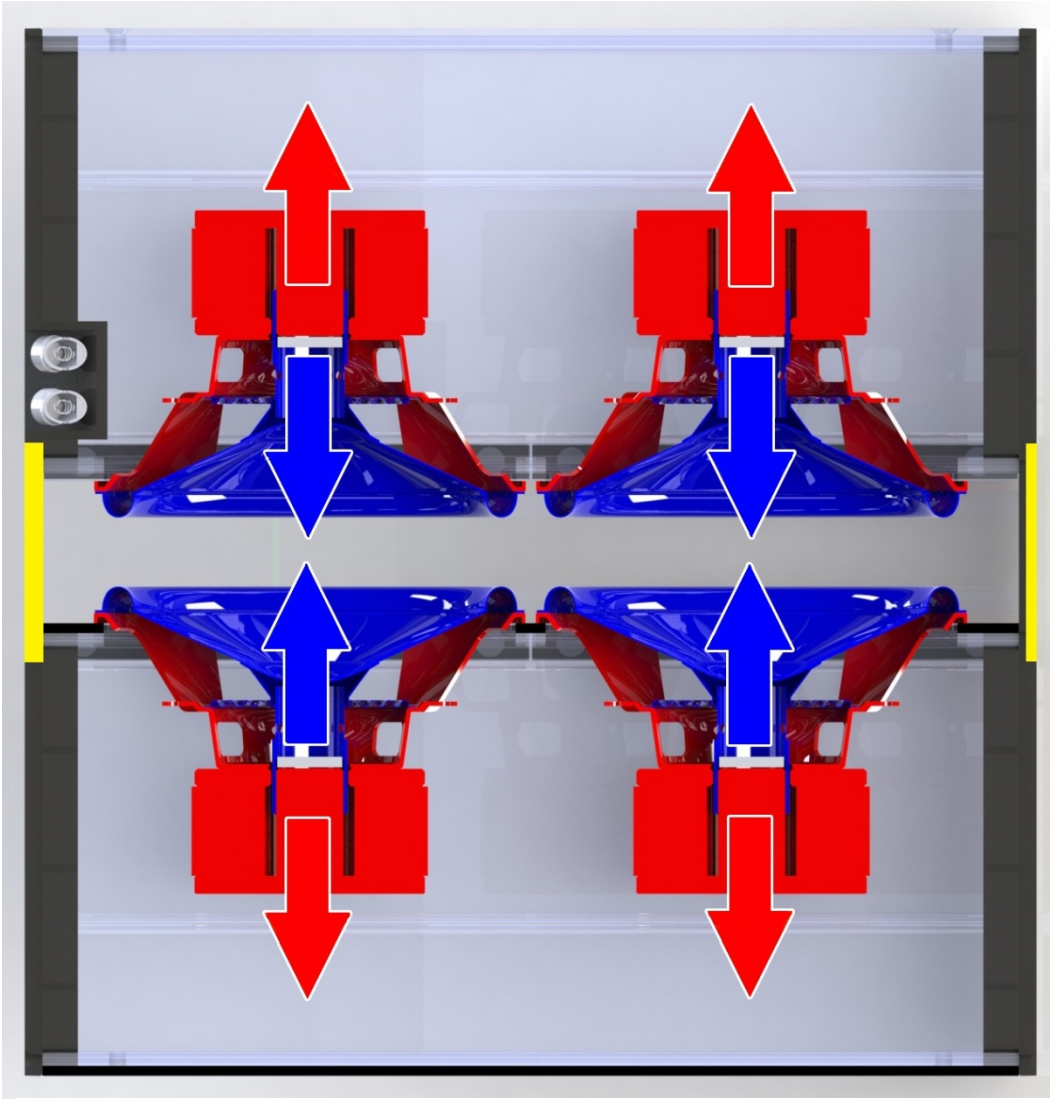

Figure 1 - Reactance Cancelling Configuration

Please refer to Figure 1 to see a cut-away of the mechanical geometry the In Wall RCC Subwoofers. The speaker cone, spider and voice coil, shown in BLUE have force

applied to it via the voice coil's motion thru the magnetic field. This force also generates an equal and opposite reactive force that tries to move the magnet structure and speaker frame, shown in RED, in the opposite direction. Since the components in RED are rigidly attached to the aluminum cabinets, reactive forces are mitigated due to the opposite cabinet's reactive forces transmitted through the aluminum cabinet and connecting plates, shown in YELLOW. The cabinet assembly itself completes the mechanical circuit of the system and allows these reactive forces to always be canceling one another out dynamically as the speaker cones go through both the positive and negative strokes. In addition to creating a vibration free inert system, the efficiency goes up and harmonic distortion is reduced.

The Driver

Our first challenge was to create a small long throw driver that would fit flush into a standard 2 x 4 wall and would have enough cone area to be effective. The driver size came out to roughly 4" x 6". Our goal was the have the equivalent output of a 12" woofer (The RCC 640). This required some significant design engineering on the driver suspension that would allow an overall linear motion of at least 25.4 mm [1 in]. To make a long story short it took a computer 4-5 hours per simulation and 14 different designs to come up with the surround shape and material that gave us what we wanted. Figure 2 is an actual FEA (Finite Element Analysis) computer generated plot of the surround at the extremes of

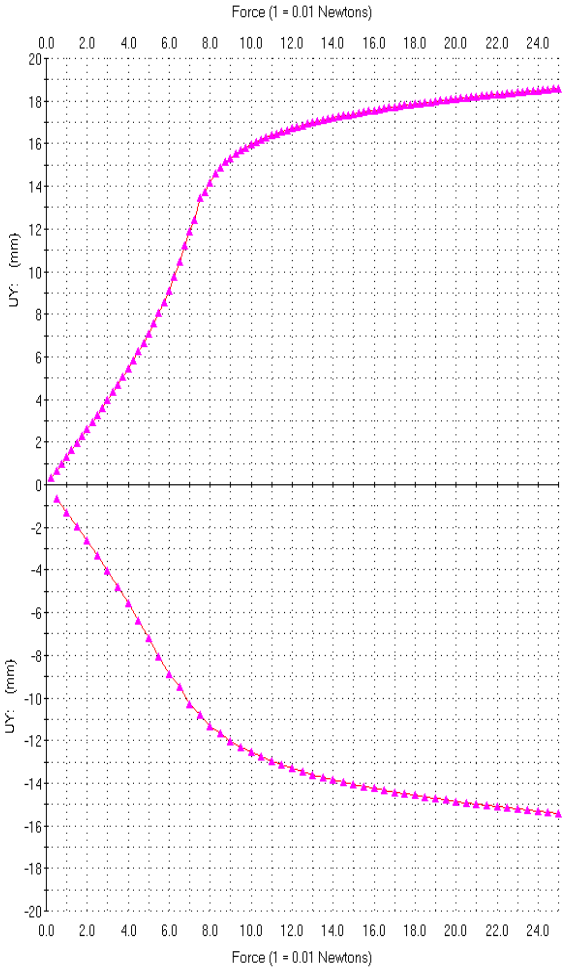

Figure 2 - Suspension Linearity

the drivers throw. Figure 3 is a sequence of images of the internal stresses the surround has the cone moves through one full cycle that came from the FEA. Notice the evenness of the colored hoop stress lines throughout circumference of the surround. The design of the driver's surround has been optimized to maximize the amount of piston area and minimize the area needed on the woofer basket for terminating the surround.

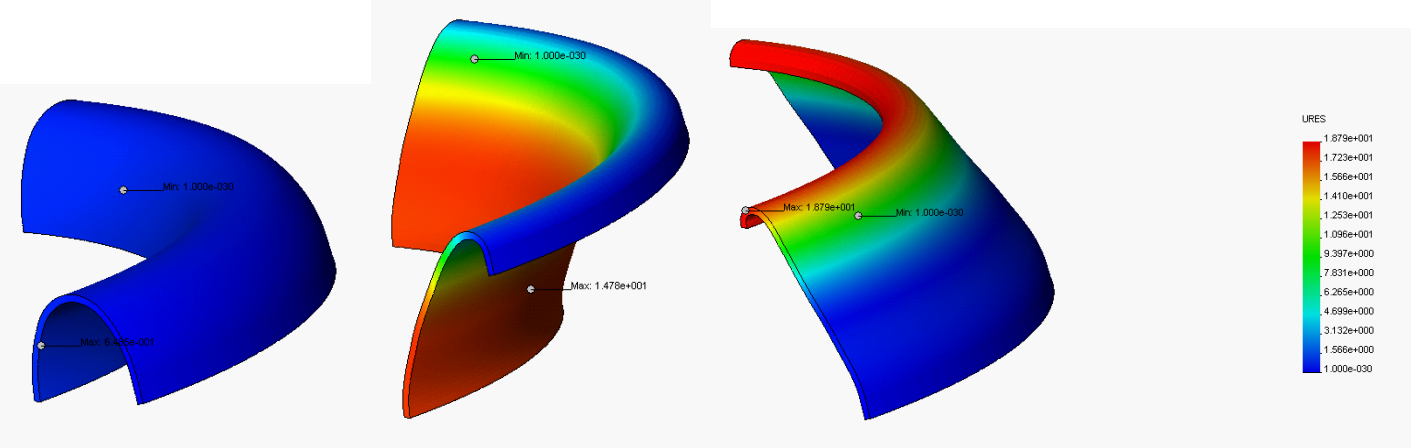

Figure 3 - Surround FEA

Motor Structure

X-Max is defined as how far a speaker cone can move without distortion and is an important factor for all subwoofers because it determines "how loud and how low" they can effectively be used. We decided to use a new motor design where the voice coil overhangs the magnetic gap with a very large primary high grade Ferrite magnet. This design increases efficiency and still provides a very long throw. In our case we were able to achieve and X-Max of 13 mm or 26 mm of linear throw, 115% of that number is generally considered usable piston movement. What all of this means in English is that our woofer drivers have peak to peak linear throw of just over 1". This is a huge achievement in such a compact driver.

A cross section of the driver shows some of the unique aspects of our final woofer, see Figure 4. Note the structure created by the inverted dust cap and the cone. There is a circular portion of the cone that is carried approximately 1/3rd of the way from the voice coil former to the surround attachment which gives the assembly a very strong but light mechanical construction. The spider is flat which allows for a linear movement in both the positive and negative directions. The Back Plate, Pole Piece, and the Face Plate which make up the magnet assembly are similar to a typical ceramic motor assembly but much deeper to allow for cone motion. The Pole Piece is significantly extended above the face plate with the Neo Magnet to create a more linear magnetic field, making the voice coil linear throughout its long throw. The gap looks to the voice coil to be very long and very high energy. The result is increased efficiency and long linear travel.

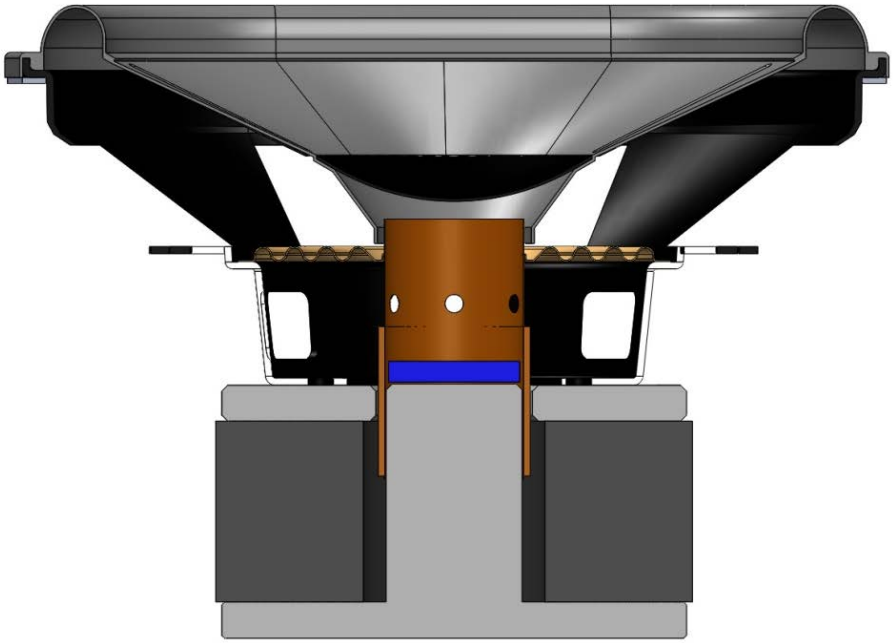

Figure 4 - RCC 4" x 6" Woofer Cross-Section

Damping Material

All speakers use a damping material inside the speaker cabinet. This allows the air pressure put into the interior cabinet to be effectively reduced by turning the air molecules kinetic energy into heat via frictional loss. Commonly used damping materials are cotton, wool or fiberglass we chose a lesser known option, activated charcoal. The benefits of using

activated charcoal come from its natural ability to circumvent one of the basic principles of speaker design. The immutable relationship of how low in frequency a speaker can play is how large the interior cabinet volume is; the larger the cabinet the lower the frequency by nature of lowering the cabinet resonance. This is due to air having a fixed density, relative to altitude, and that mass of air molecules vibrate at a specific resonance. Air pressure is simply a measure of the rate of collisions the molecules have with each other in a given volume. The only viable option up until now has been to exponentially increase the size of the cabinet volume or to increase the amplifier output power.

The activated charcoal allows a process called Physical Adsorption, not to be confused with absorption, which is related to osmosis. This type of adsorption is a molecular level attraction that occurs on the surface of the charcoal. The surface area is microporous meaning the surface has tiny small pores which came from the activation process of incineration. Just one gram of activated charcoal will have over 500 sq. meters (5,400 sq. ft.) of surface area. Imagine the adsorption process as a negative pressure sink inside the cabinet or a magnet for air molecules. The massive surface area of the pore structure on the charcoal is always attracting the air molecules 'detaining' them on the surface not allowing them to collide as often. The reduced pressure inside the cabinet, effectively the woofer drivers act as they are in a larger cabinet, lowering the system resonance and extending bass response. This also allows the system to accept more EQ from the amplifier and out-perform a subwoofer of the same physical size without the cabinet stiffness limiting the bass extension.

The System Assembly

Because our goal was to have an In Wall Subwoofer that would effectively compete with a High Performance Floorstanding System we decided to use 2 pairs of 4" x 6" drivers in the smaller design (RCC 320 PC and RCC 320 R) and 4 pairs in our larger models (RCC 640 PC and RCC 640 R). A typical 12" driver has an S_d of between 420 – 490 cm^2. Our final design

has an S_d of approximately 640 cm^2 in the larger system. The RCC320-PC System looks like the photos in Figure 5. The combined effects of the Reactance Canceling Configured multiple drivers, Slot Loading, Adsorptive damping material and huge power handling make this design able to perform at levels of extended deep bass in a small enclosure with much less power than most other subwoofers. By adding an additional subwoofer module to the amplifier the system performance adds 3 dB to the efficiency and 6 dB to the sensitivity.

Figure 5 – RCC320 PC Subwoofer Module

All Aluminum Enclosures

We chose Aluminum as our cabinet material because of its stiffness to mass ratio and because we could make a very thin wall which maximizes internal volume. The typical MDF cabinet would have to be prohibitively thick to be rigid enough for a good quality enclosure. The properties of aluminum make it the perfect choice for a subwoofer that needs rigidity but

must have a thin wall. The relatively thin wall allows the internal volume needed to support the response of the drivers and still have a small enclosure. Aluminum provides the strength, structural properties and the damping characteristics that we wanted for our subwoofer. Figure 6 shows a comparison of Aluminum to other popular materials.

Unlike a number of manufacturers who use an open extruded aluminum cabinet and add a baffle, we use a closed extrusion and CNC the holes for the drivers, etc. We do this because it eliminates any chance for air leaks and prevents "Bell Mode Resonances" which are common with open extruded metal enclosures.

	Item	Unit	Regular Thermoplastic	Polyester BMC	Aluminum Die Casting	Wood	Steel Stainless
1	Gravity		1.10-1.40	1.7-2.0	2.57-2.96	0.8-0.95	7.19
2	Shrinkage	%	0.9-0.4	0.3-0.05	0.45-0.35	NA	NA
3	Tensile Strength	kg/cm²	200-800	300-1500	600-1800	NA	1100-2100
4	Compression Strength	kg/cm²	500-1200	800-2000	100-300	NA	1800
5	Flexure Strength	kg/cm²	600-1000	700-2000	560-1800	NA	700
6	Impact Strength	kg/cm²	5-40	10-70	1-3	NA	4-6
7	Heat Deflection Temp.	℃	80-160	>200	NA	NA	NA
8	Electric voltage Resistance	KV/mm	12-25	9-25	NA	NA	NA
9	Arc Resistance	Sec	50-100	120-200	NA	NA	NA
10	Water Absorption	24hr%	0.1-0.3	0.15-0.5	NA	NA	NA
11	Corrosion Resisance		High	High	Low	High	Low
12	Design Flexibility		High	High	High	Medium	Low
13	Raw Material Cost		Medium	Medium	Medium	Low	High
14	Tooling Cost		Medium	Medium	Medium	Low	High
15	Finishing Cost		Low	Medium	High	High	High

Figure 6 - Material Comparison Chart

The Amplifier

The amplifier that we designed to power this system needed to be as efficient and innovative as the subwoofer modules it would be driving. Utilizing a cutting edge DSP-based preamp stage and high efficiency Class D amplifier design allowed us to custom design features into the product that are vital to both the installer and the end-user. The system offers multiple

installation applications for the same subwoofer in pairs as well as a single driver module. We engineered two different sets of equalization curve families to allow optimum performance from either of the two models that we produce. We also created a Music and Movie EQ which is selectable via the amplifier IR codes in either application. The Music EQ sets the frequency response flat with the subsonic filter set at 20 Hz. Whereas the Movie EQ takes the overall gain up by 6 dB and raises the subsonic filter to 35 Hz, this is most effective for movie playback and maximizes the system output to put the punch where you need it. The amplifier topology was designed to be convenient for the installer by placing all of the critical setup controls on the rear of the chassis and the minimal consumer controls on the front. This amplifier also has the ability to drive up to four of the smaller RCC 320 modules for a truly distributed bass system.

Amplifier Features:

- 1 Rack Unit Height with standard 19” rack mount ears
- Front Mounted Consumer Controls:
  - System Gain, Power Standby/On, LED Mode Indicator
- Rear Mounted Installer Controls:

  - **1/8” IR Jack**
  - **1/8” 12 Volt Trigger**
  - **Auto Signal Sense ON/OFF mode**
  - **2 pairs High-Quality Speaker Binding Posts**
  - **Unbalanced RCA L/R Inputs & Outputs**
  - **Balanced XLR Input**
  - **Digital Phase Shift Adjustment, 0-180°**
  - **Adjustable Low Pass crossover 40-160 Hz with slopes of 12 & 24 dB/oct.**
- **Amplifier Specifications**
  - **>100dB SNR**
  - **<± 0.5 % THD+N**
  - **± 0.5 dB Frequency Response (10 Hz – 500 Hz)**
  - **87% Efficient**
  - **400 Watts RMS into one Subwoofer Module**
  - **600 watts RMS into two Subwoofer Modules**

System Performance

The proof of the pudding is in the eating so how did all of this technology and innovation end up. In a word, phenomenal! The system is both musical and well damped. Transient response is excellent and low bass bloom is as it was recorded on the source material. The system is dynamic but the vibration of the cabinet and wall is virtually gone. We measured the system and were able to show results that very closely matched our predictions. Here are some of the highlights:

- **Music mode frequency response -3 dB @ 24 Hz (RCC 640)**
- **Movie mode output 109dB @ 40 Hz**
- **2 Module output of 112dB @ 40 Hz**
- **System Q = .707**

Distributed Bass Reproduction

We support the use of multiple subwoofers to properly reproduce low frequencies indoors. The total volume and dimensions of a room are what determine the size and number of the subwoofers that you need. The larger the room the more piston area and throw, or air volume, that you need to move. Because the wave length of a 100 Hz signal is approximately 10' in air at sea level you can see that the number of wave lengths that can be generated in a normal room is very small. In most rooms frequencies below 50 Hz will not generate a single complete wave. Due to the interference of low frequency sound waves caused by room geometry (parallel walls) there are what are known as Eigen Modes within virtually all listening rooms. If you were to use equalization to make a subwoofer flat below 100 Hz at a particular listening position and move the microphone a foot or two away from that position the speaker would no longer measure flat. By using multiple subwoofers in strategic locations around a room you can mitigate almost all of the uneven room response and make the room more uniform in its low frequency response, which allows everyone in the listening area to have the same experience. This idea was impractical with multiple traditional boxes to trip over but with an in-wall subwoofer it becomes not only practical but a better solution. There have been a number of studies done on the subject of distributed bass. Most show that Eigen Modes can be basically eliminated with the use of 2-4 subwoofers. This can easily and sveltely be achieved with the RCC Subwoofer System.