UNIVERSITY OF CALIFORNIA
SANTA CRUZ

**RESONANT WAVES: IMMERSED IN GEOMETRY**

A thesis submitted in partial satisfaction
of the requirements for the degree of

MASTER OF FINE ART

in

DIGITAL ART AND NEW MEDIA

by

**Richard Grillotti Jr.**

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# Abstract

***Resonant Waves: Immersed in Geometry*, Richard Grillotti Jr.**

*"Resonant Waves: Immersed in Geometry" is an interactive, multisensory cymatic experience. This work engages with sound, basic sine waves, and how sound naturally forms up into intricate, often symmetrical geometric patterns when passed through a medium, such as water, within a boundary condition.*

*Presented as a multimedia art installation in the 2019 UCSC Digital Arts and New Media MFA Exhibition titled "Receivership", which ran from April 20, 2019 - May 12, 2019, Resonant Waves consisted of several components: a live demonstration of wave patterns formed by sound passing through water in a 3" petri dish, speakers which allowed the same sound to be heard in the space, a 4' circular projection screen on which the wave activity in the water dish was being captured by a camera and displayed, and a seat with controls in the arms for the viewer to interact with & influence the sound being generated that also vibrated at the same frequency as the water. The viewer was simultaneously hearing, feeling, and seeing - through patterns that the sound would generate in the water in the dish which was projected onto the screen - the same exact frequency.*

*This paper describes the project in great detail both conceptually and technically and reveals the many iterations and changes from the original idea to the version that was presented in the Receivership exhibition, holding true to the essential goals throughout, as well as my prior works, motivations, inspirations, and a brief survey of its historical and aesthetic context.*

# Dedication

To my mother and father, Adrienne and Richard Grillotti.

# Acknowledgment

Thank you to Andy DiLallo for being my audio collaborator on this project, for your creative insight and for enriching this project with a dimension of interactivity I couldn't have produced on my own. Thank you to Edward Shanken for your support and encouragement in helping me feel more at ease with doing artwork that engages my deeper interests but had been less inclined to explore as topics for my art, and also for your skillful editing assistance. Thank you to Elizabeth Swensen & Angus Forbes for your inspiration and mentorship as professors and members of my thesis committee. Thank you to John Weber for your encouragement and belief in my project and for curating such a fantastic MFA show. Thank you to Colleen Jennings and Steve Gerlach for your technical help in making this installation possible. Thank you to Robin Hunicke and Bennett Williamson for your support and for helping me navigate taking so much time away from school and this program while my mother was passing. Thank you to the rest of the Digital Arts and New Media faculty who contributed to my learning and evolution as an artist and a person, and thank you to my DANM 2019 cohort for being such a great bunch of creative, strong & caring individuals to take this surreal journey with. Thanks to everyone else that directly or indirectly helped me find my way to this MFA exhibition project along the way.

# Introduction

*Resonant Waves: Immersed in Geometry* is an intersection of art and science and play that reveals and celebrates the normally unseen nature of sound to form into complex shapes and patterns. This multi-faceted project revolves around generating vibrational interference patterns that can form into complex, symmetrical geometries within boundary conditions. This visualization of sound as it actually appears physically is commonly referred to as *Cymatics*[1].

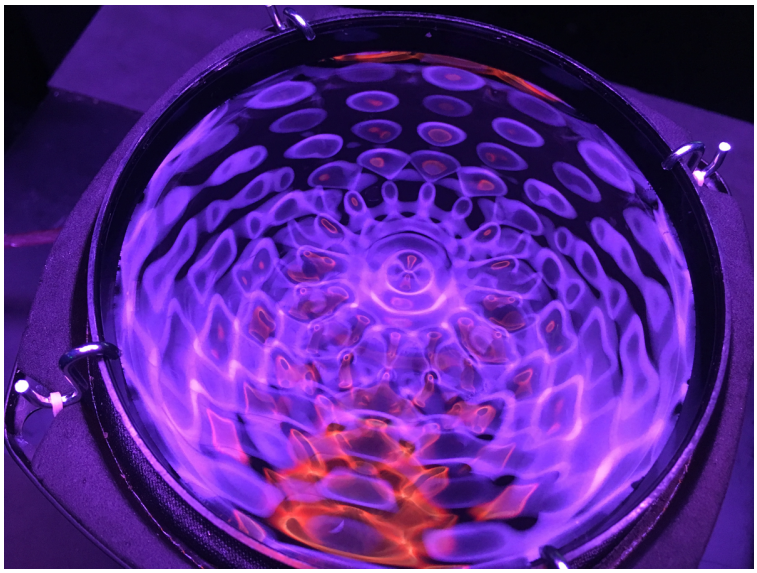


Figure 1: Wave interference patterns in water produced by sound, 2019

*Resonant Waves* as an art installation is designed to be an immersive, interactive, multisensory cymatic experience. Viewers are offered the opportunity to hear, feel and see - through the patterns that the sound is

[1] Hans Jenny, *Cymatics: A Study of Wave Phenomena and Vibration*, Revised Edition 2001, vol. Volume 1, 1967, Volume 2, 1974, 2 vols., n.d.

generating in the water dish and is projected onto the screen - the same exact frequency. Visitors are invited to sit down, relax, hear and feel the tones that create these geometries, and experience them in real-time as vibrations throughout their entire bodies. By adjusting the frequencies freely within a limited range, viewers can explore the connection between sound, its shapes, and its influence on their own physiological and emotional systems.

From the inception of this project, two primary goals served to be the guiding principles by which the work would evolve and change over the course of development. The first goal was for visitors to be able to interact with wave pattern formations by adjusting the frequency of the sound being generated. I felt that being able to influence the sounds and patterns that were appearing would help further demonstrate how each subtle change in frequency has a major impact on the geometric patterns and shapes being produced. The second goal was for the visitor to be "immersed" in these wave patterns. The end result of what "immersed" would mean was quite different from my original concept, but turned out to be much more effective as a result. A third goal, which came after the original inception, was to present this phenomenon live to visitors, by having on display a water in a dish on a speaker with sound in the form of sine waves passing through it. It became important to me that this work demonstrates to visitors that sound has a physical shape and that it can be made visible simply using water and some very ordinary equipment. Discovering this for myself had a significant impact

on me and I wanted to give others the opportunity to discover this as well.

This project benefited greatly from collaboration with Andy DiLallo, a UCSC undergraduate student in the Music department. With his help in developing the interactive functions and his conceptual alignment in thinking, we managed to create something very unique, engaging and effective that managed to achieve and exceed all of the initial project goals.

## Project Description

*Resonant Waves: Immersed in Geometry* is an exploration of sound and its vibrational effects, with a goal to enable viewers to interact with and be exposed to how sound physically looks and feels.

Figure 2: *Resonant Waves: Immersed in Geometry*, 2019

In the 2019 UCSC Digital Arts and New Media MFA exhibition *Receivership*, the *Resonant Waves* installation, a collaboration between myself and Andy DiLallo[2], consisted of a number of elements, including an armchair, a projection screen, two speakers and a live display of cymatics being generated, all carefully arranged in an 8' x 10' space. All pieces were

[2]"ANDY DiLALLO,", accessed May 27, 2019, https://andydilallo.com/.

positioned to draw the visitor's attention to the water dish as well as the screen, which was the most dominant visual component. Between the two was the seat, inviting visitors to sit down and interact with the controls. While the fullest experience of the work does require one to sit down to feel the vibrational aspect, the installation still offers much to engage bystanders.

Figure 3: *Resonant Waves: Immersed in Geometry (with an audience)*, 2019

The interactive controls of the piece, a button, a slider, a trackpad, and a color wheel, were pre-existing commercially available products. They were all set strategically into custom-made arms of the comfortable living-room-style cushioned armchair with the two larger speakers mounted closely to the left and right of it aimed directly at one another. The seat faced the circular projection screen that displayed a real-time video feed of the

wave activity in a water dish, which was secured to a smaller horizontal speaker on a stand, viewable about 4' off the ground.

Two different sized colored ring lights were mounted directly above and perpendicular to the water dish to illuminate the wave patterns from the camera's point of view, as well as cast ambient light around the local area so the live cymatics might be easily noticed and viewed. A primary goal of the piece was that the generation of cymatics in water in real time would be prominently on display, to allow visitors to see that this was the source of the visuals appearing on the projection screen, and also make the connection that the patterns in water were the result of the sound tones they were hearing.

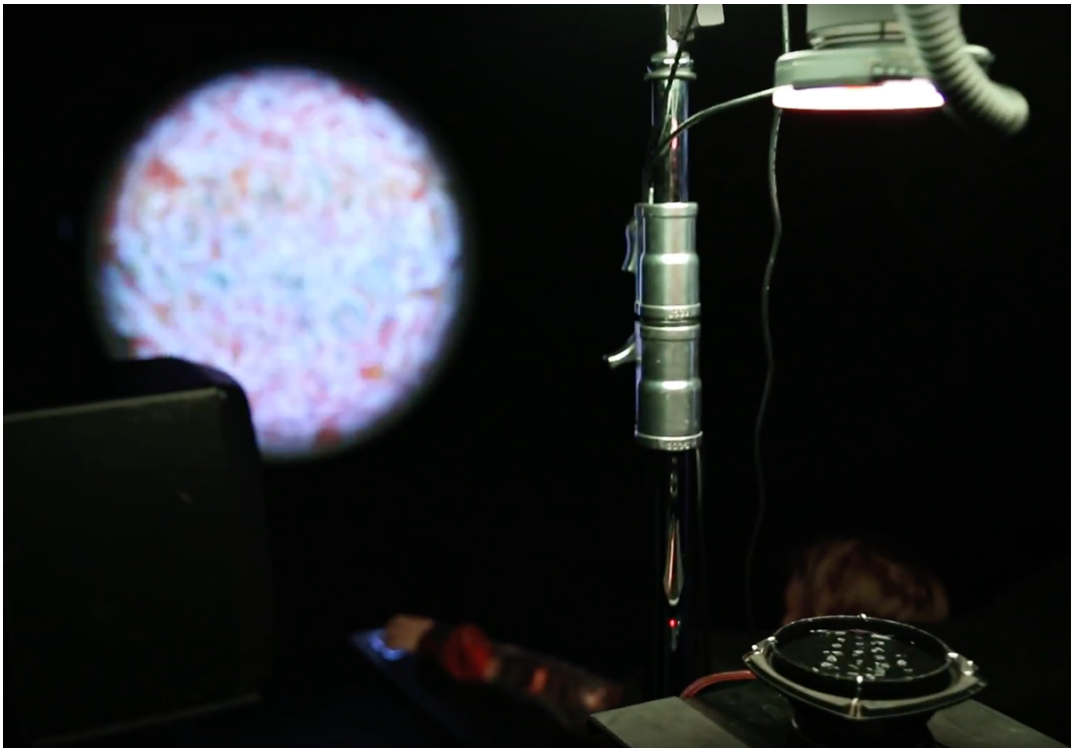


Figure 4: *Resonant Waves: Immersed in Geometry - water and projection*, 2019

The viewer is simultaneously hearing, feeling, and seeing - through the patterns that the sound is making in the water dish, projected onto the screen - the same exact frequency.

## Prior Work

My interest in making artwork focused on finding ways to make visible what is ordinarily invisible or overlooked began in 1995, during my time as an undergraduate at Florida State University working towards my BFA degree. One day in 1995 I found myself with a small magnet and placed it down near some iron filings in our BFA studio warehouse. Instantly some of the filings assembled along the magnetic field of the magnet, exposing what that field shape actually looked like. I was captivated. With a newfound curiosity for magnets and magnetism, I collected more magnets and iron filings and sought to find a way to share this with others through art.

Figure 5: Magnetic Field Study 03, 1995

I spent many evenings experimenting with magnets in the BFA studio which led to a discovery and one of the pieces I am most fond of, *Magnetic*

*Attraction.* In this piece, instead of making magnetic fields visible, I exposed them in their ability to defy gravity, suspending magnets from the ground which were held down by thin jute rope tied to rocks. I found the small range of distance between two magnets where one magnet could suspend the other in mid-air using magnetic attraction, with the lower magnet held back from snapping to the upper magnet. A precise length of rope secured the suspended magnet to a rock on the ground. If the rope was too long the strength of the attraction would cross a threshold, disregarding the weight of the rock it was tied to, tilting it upwards and snapping the magnets together. If the rope was too short, the lower magnet would be just outside the magnetic field's ability to suspend it and it would fall to the ground.

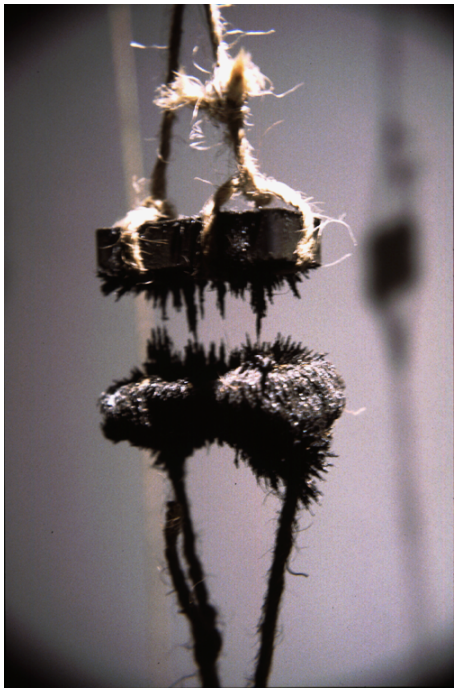


Figure 6 & 7: *Magnetic Attraction*, 1996

During the process of exploring this work, I found myself interested in energy in general, including creativity, which I was also seeing as a form of energy. I had recently been exposed to Abstract Expressionism and was very drawn to the work of Jackson Pollock in particular. It was my impression that he was tapping into spontaneous creation when producing his most famous paintings, acting intuitively, without much thinking getting in the way. It seemed to me he was drawing on his emotional energy in the moment and was expressing it fluidly through the use of paint and canvas. This reminded me of music improvisation, playing guitar & performing music live with others, and how fresh and beautiful music can emerge spontaneously if I was more attentive to what *felt* right, which required listening to what the other musicians were doing above all else. I learned that intuition and feeling had much more exciting and cohesive musical results than thinking much about what I was doing or what I should do next. Being in my mind any more than necessary would almost always derail a creative flow.

I wanted to see if I could tap that same creative source and create spontaneously in a visual way using light, as I was continuing my exploration of energy itself at the time and finding ways to make forms of it visible. I began a series of "Energy Studies", capturing light, physical motion, and emotional energy with time-lapse photographic exposures.

In a small room I painted black, I would generate different feeling/emotional states, such as "happy", "calm", "excited", "angry" and so

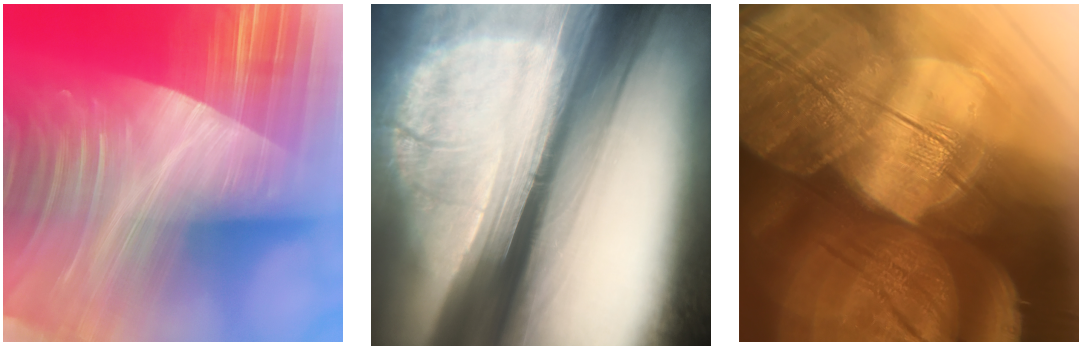
on, and proceed to amble, twirl, swing and sometimes leap around a roughly 10' square area with a flashlight as my "brush". I did my best to let the feeling play out physically, a non-intellectual dynamic force expressing through me.

Figure 8: *Energy Study #6 (Joy)*, 1996

Light, color, and texture have long been at the forefront of my artistic interests, and photography became a method of capturing it best. Through a camera lens, playing with distance, focus, and perspective I could find the sublime in the ordinary. I discovered that no matter the subject, there was a way to approach it with a camera that transformed anything into a work of art. I began creating abstract color fields out of everyday objects and nature with great satisfaction.

Figure 9: Color Field Series, circa 2001

I also found myself very interested in macro photography, as it offered the ability to see and enlarge textures and forms of things that I couldn't see in such great detail with my naked eye. I purchased a digital SLR camera with a high-quality macro lens and proceeded to aim it at everything that caught my eye. The focus of my art practice continued to be about finding ways to reveal the extraordinary as I would find it in the ordinary.



Figures 10, 11, 12: *Refractions* series, circa 2001

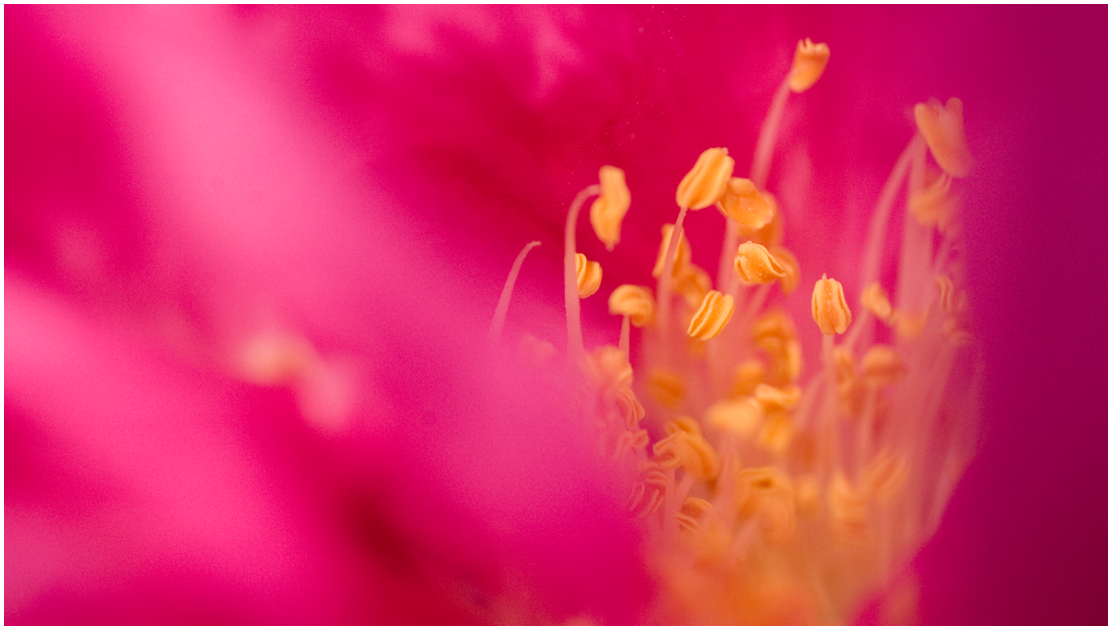


Figure 13: *Macro Flowers* series, circa 2004

Over the next 13 years, I would focus the majority of my creative efforts on making minimal pixel art and designing video games in my independent game company, Pixeljam[3], while continuing my photography practice sporadically on the side.[4] In 2016, I felt strongly pulled to resume my focus on making fine art, however that might look. I was accepted into the UC Santa Cruz Digital Arts and New Media MFA program in 2017 and proceeded to explore a variety of directions that were a hybrid of my time in game development, of my prior work and new interests. I began using Virtual Reality and 360° video in ways that would enable viewers to experience perspectives in spaces that otherwise are not possible with the scale of the

[3] "PIXELJAM," accessed June 12, 2019, http://pixeljam.com/.

[4] Pixeljam was a new and satisfying direction for me creatively but is beyond the scope of this paper to discuss as it is peripheral to my creative work leading up to *Resonant Waves*.

human body.

My first major piece at UCSC, *You Are Here (sort of)*, consisted of a series of video clips recorded with a 360° camera that a viewer could experience in VR. It was an exploration of scale and what it feels like to inhabit a variety of environments that are too small, difficult or otherwise impossible to perceive within using our human eyes, enabling viewers to experience (sort of) what is like to be small, around 3" tall, and see from unusual perspectives. My recordings included such locations as a refrigerator full of food, in a sink next to water pouring down a drain, on a shelf with antique glassware, on an espresso machine in a cafe, looking up at a towering daisy in the grass, inside the entrance of a squirrel hole in the ground, and sitting amongst children's toys in a colorful wooden blocks construction.

Figure 14: *You Are Here (sort of)*, 2017

Continuing this exploration of offering viewers novel perspectives in VR, in a follow-up project, *Ares*, I placed the 360° camera on the floor next to a very playful cat named Ares (under the influence of catnip!) in a one minute video. I replaced the camera's mic recording with a calming ambient music track. The experience turned out to be quite delightful, from my own experience of it and as reported by many viewers. In one instance, an individual watched it and let me know that he had never been able to get near cats due to a severe cat allergy, and how much he valued the opportunity to feel so intimately close to a cat.

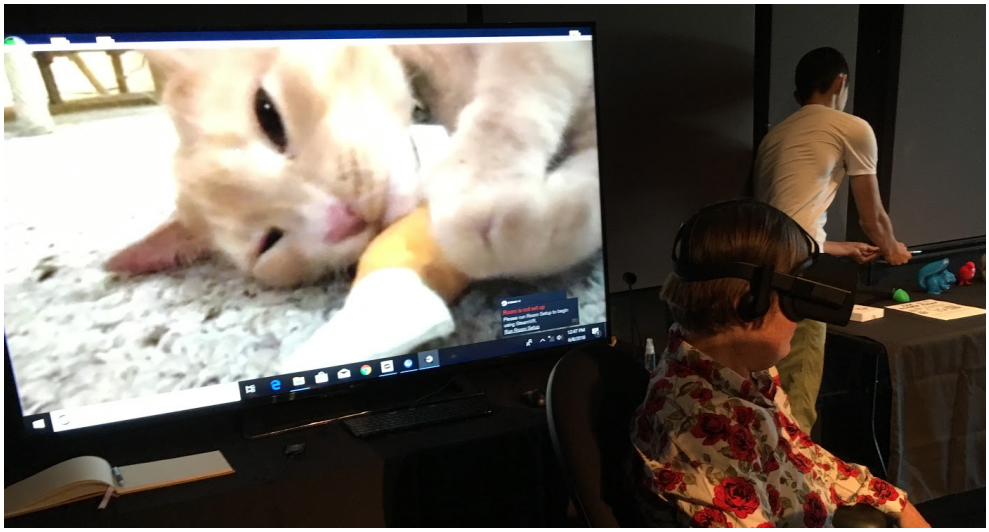


Figure 15: *Ares*, 2018

I continued to work with Virtual Reality in this way until the end of my first year in the Digital Arts and New Media program. By that time, I found myself frustrated by the limits of the technology, specifically in the area of stereo 360° cameras. I had recently experienced stereo 3D video and was

amazed at the illusion of depth it could offer when viewed in VR. I wanted that feeling of stereo depth in my own VR experiences but there didn't seem to be a 360° stereo camera on the market that would work for this sort of miniature, close-up filming work. Stereo recordings provide the illusion of genuine depth with the use of two (or more) lenses which capture the subject from slightly different positions, roughly human eye distance apart from one another. In general, this works well with these cameras, provided the subject is 3 or more feet away to be able to resolve in a realistic 3D image. However, for my interest in putting viewers virtually in these small, close-up, real-world spaces, I would need a stereo 360° camera with the lenses as close together as eyes would be on a 3-inch tall human body. This did not exist. I had considered pursuing the development of such a camera during my 2nd and final year but decided that I wanted to focus my energies on making art, not on making technology.

## *Resonant Waves:* Approaches and Iterations

In the Spring quarter of 2018, in *Dialogues and Questions* class with Professor Edward Shanken, we were given the assignment to conceive of a theoretical exhibition proposal without considering limits of what may or may not be possible. The idea was to imagine what would be most exciting for us to create, in what specific location and with what other artists. I used it as an opportunity to imagine what I might do with an Augmented Reality platform, such as the Microsoft Hololens. I had the thought of 3D virtually generated cymatics that users wearing a Hololens, or a Magic Leap headset (another AR platform as yet unreleased at that point in time), could interact with. I imagined this being exhibited at the Integratron, an acoustically perfect resonant dome in Landers, CA. Below is a mockup and a sketch of my initial idea that would eventually become *Resonant Waves: Immersed in Geometry*.

Figure 16: Richard Grillotti: *Geometries of Sound* (concept), 2018


Figure 17: Sketches of *Geometries of Soun*d (concept), 2018

In this theoretical exhibition proposal, which I did not imagine as my MFA thesis project direction, the main goals for the *Resonant Waves* project were established: for users to interact with cymatic formations by controlling sound tones, and for it to be an immersive experience in which viewers would be placed in the center of the 3D cymatic structures surrounding them. The particular expression of these goals would change significantly, but they served as the conceptual foundation of the project throughout its development.

After presenting this theoretical exhibition proposal in class, I found myself encouraged by Professor Shanken and my peers to actually pursue this project idea for my thesis work, in a form that could be presented in the MFA exhibition on the UCSC campus. As I began to research how this might

be achieved, I connected with a handful of very experienced coders and developers. I learned that the sorts of wave systems I was looking to emulate were incredibly complex and would likely require significantly more computational power than the current XR headsets are capable of. I would also need to find very skilled, experienced programmers to work with. I thought I would try my luck and attempt it anyway. I assembled a group of four undergraduate research assistants, including several coders at the beginning of the Fall 2018 quarter and began directing them to try a variety of approaches to generate these intricate wave pattern systems in 2D and in 3D, to explore what might be possible.

While the research assistants were busily working on this challenge, I searched the internet on how to produce cymatics in water and attempted to set up a system to generate them physically myself. I felt that gaining my own hands-on experience and familiarity of this phenomena was important if our group was going to digitally recreate cymatics authentically. Researching how to produce cymatics, gathering what equipment was needed, and learning how to light the surface of the water so the patterns could be seen clearly took me about 5 weeks. Following a good deal of trial and error without much success, I persevered and began to see positive results. Soon I was able to consistently produce cohesive symmetrical geometries in water.

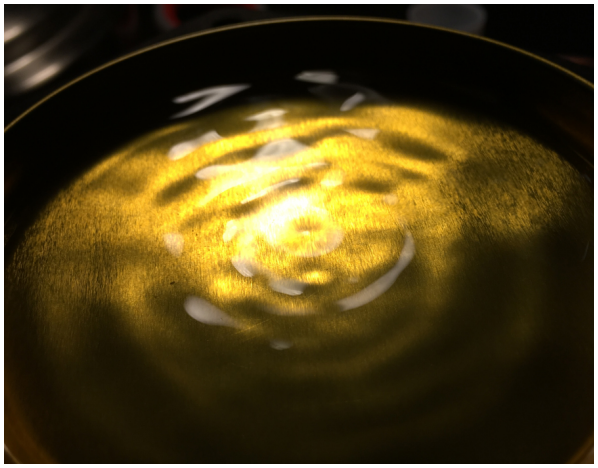


Figure 18: Early tests: the first hint of symmetry, 2018

Towards the middle of the 2018 Fall quarter, the effort to reproduce these complex wave systems digitally in real-time was proving unsuccessful. Some interesting looking 3D test forms were being generated based on 2D cymatic images as source data, but these were not possible to generate in real time with the approaches being explored. I was also feeling that the 3D models lacked a connection with how wave systems actually work.

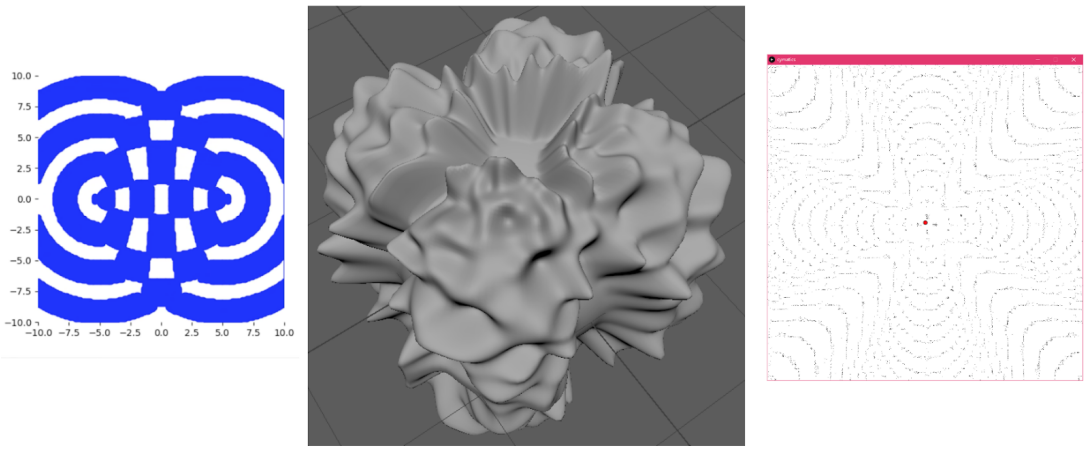



Figure 19: Tests of computationally generated wave systems, 2018

Rather than continue in this direction any further, I thought of trying recorded 360° video of cymatics that I created myself and mapping them to a dome in a VR space. The undergraduate coders mapped one of my cymatic videos to an upper "sky" hemisphere in a dark virtual reality environment.

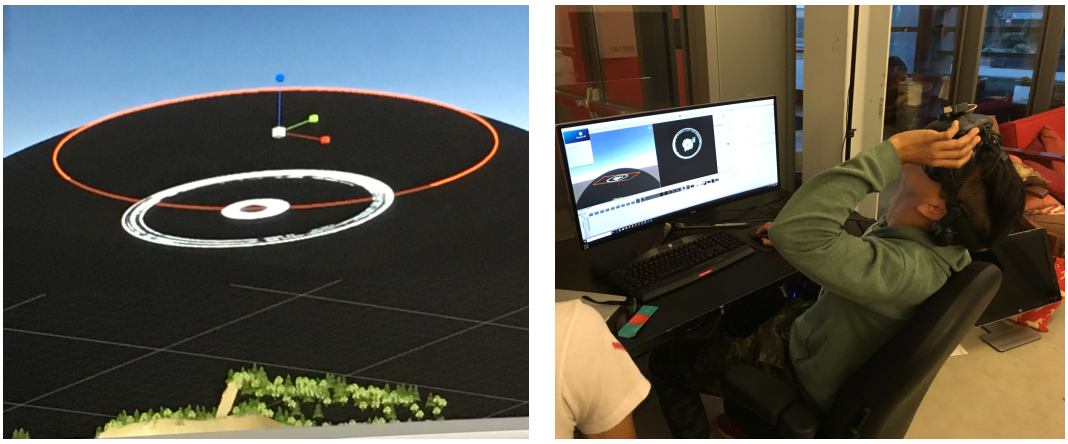


Figure 20: Early tests: the first hint of symmetry, 2018

The idea was to attempt to provide a different sort of visually immersive experience, seeking to give the viewer a perspective of being surrounded by the cymatic formations above and to all sides, while hearing the tones that generated the patterns. The results were interesting but largely unsatisfying to me. The experience proved to be more uncomfortable or unsettling than it was wondrous, peaceful or contemplative. Also, the resolution of the video recording and the resolution of the VR display were both lower fidelity than would be required for the experience to reflect the physical phenomena accurately and not look like compressed video. I also

learned that the experience felt claustrophobic to some testers, in part because VR headsets can have that effect in general, but also being so perceptually close to the video which was filling the majority of the user's field of view exaggerated the flickering nature of the cymatic wave fluctuations.

Seeing these results in what I thought would be the proof of concept, I knew this would not work as my MFA exhibition piece. I found myself reconsidering what it meant for the experience to be "immersive". Expanding the visual aspect of cymatics around the viewer did not feel or function like I imagined it would. This helped me to stop prioritizing the importance in visuals so heavily in the work, and to start looking more to balance the visuals with the sound more evenly. Remembering my experience at the Integratron, the feeling of the sound vibrations passing through my own body, I realized that it was important to the conceptual follow through of the piece for the visitors to be able to feel the vibrations in their bodies while seeing the patterns the same vibrations generate. This had been an important missing component, which could make this piece truly immersive in a more direct way, connecting the visitor's own body to the sound and the wave patterns on display. I wondered if being able to feel the sound frequencies physically would have an effect on a person's physical, emotional and/or mental state, as I experienced in the Integratron sound bath.

For the next iteration of the visual component, I had the idea to use projection mapping to display live video of cymatics onto the interior of a

physical dome, while the visitor would sit on a bench that vibrated at the same frequency as the water while hearing the sounds of that same frequency as well. The UCSC Arboretum has 3 geodesic domes, part of the Future Gardens project by artist Newton Harrison and Helen Mayer Harrison[5].

Figure 21: Future Gardens, UCSC Arboretum, 2018

After contacting Newton Harrison and describing my project to him in detail, he agreed to grant me permission to install and present my exhibition piece in one of them, if my plan to do so guaranteed that there would be no damage or ill effects whatsoever to the plants inside. I went to work on conceiving of how that could be done.

[5] "The Harrisons' Future Garden at the UCSC Arboretum | Institute of the Arts and Sciences," accessed June 10, 2019, http://ias.ucsc.edu/content/2019/harrisons-future-garden-ucsc-arboretum.

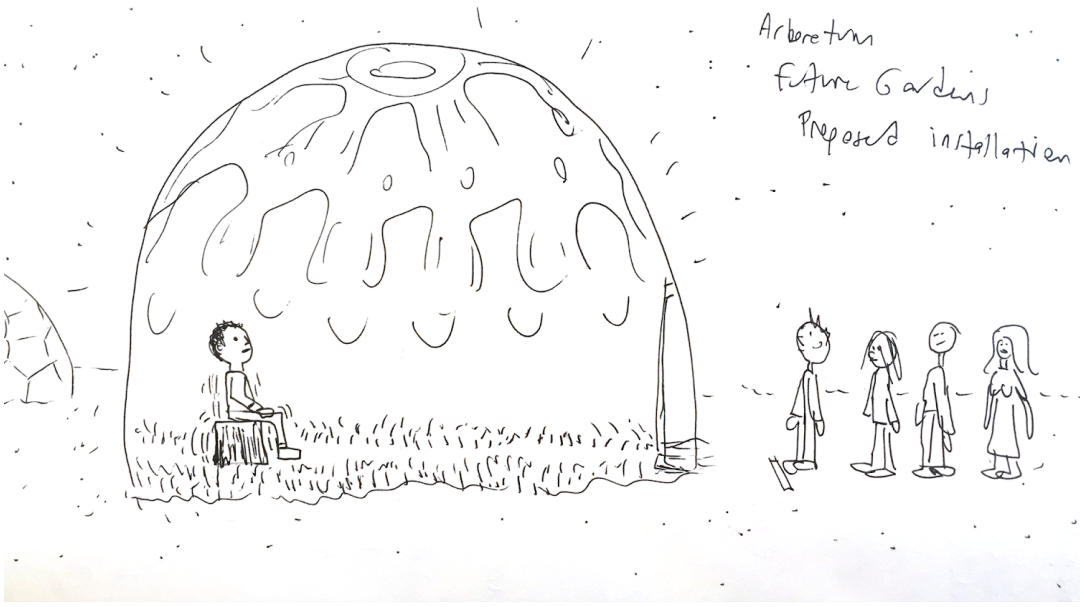



Figure 22: Sketch of project proposal in a UCSC Future Gardens dome, 2018

Visiting the Future Gardens in person, I saw that I would not be able to simply project directly up from the center, as that was where the path into the dome was. I would need to project the visuals from the side of the dome, and would likely need to figure out how to overlap two projections coming from opposite sides of the inside of the dome very precisely to make sure there was even coverage. I did not know much about projection mapping, much less doing so on the curved interior of a large dome with multiple projectors. Artists experienced with projection mapping informed me that it would be very difficult and time-consuming goal to achieve my goal. I wasn't ready to give up just yet.

At the beginning of the Winter 2019 quarter, I recruited an undergraduate research assistant, Andy DiLallo, to help out with the sound &

the interactive components of the piece. Having abandoned the idea of using VR, we needed to enable the visitors to control the sound with some sort of physical input devices, including its own set of controls. Andy was a music major that had experience with interactive sound installations and was precisely the collaborator I needed for this project.

We started with some ideas to make the piece interactive using Microsoft Kinect to track the physical movement of the viewer's body and arms. We made progress using the Kinect to control sound, but the problem of vibrating the user's body was still unresolved. About this time I found a comfortable cushioned armchair with a heavy wooden frame to which I could attach bass exciters. I modified the chair by attaching a heavy duty amp to power the exciters secured to the back and bottom. Then I ran low-frequency sine waves from my laptop through them. Sitting in the chair and feeling the sound vibrating my body, confirmed that this was an excellent solution. With the visitors seated, using Kinect was no longer necessary. I found some manual controls, Palette Gear,[6] and a Bluetooth trackpad, that a user could operate on the arms of the chair. We then began to consider exactly what sonic and visual parameters the users would be able to influence with these inputs.

The 2019 winter quarter was moving along swiftly. With our focus on the sound and vibrations, I had not scratched the surface of

[6] "Palette Gear," Palette Gear, accessed May 26, 2019, http://palettegear.com.

projection-mapping onto domes. I also realized that any projections on the translucent white Future Gardens domes would be hard to see in the daytime sunlight, so the piece would be effectively viewable only in the evening. The Future Gardens installation would therefore need to be a special evening event, instead of a continuous piece on display during the hours of the MFA Thesis Exhibition, which introduced various logistical issues. And I would still need to have work on display in the daytime hours for the three-week duration of the *Receivership* exhibition. Given that there was not time to create two versions of the piece, I jettisoned the idea of the Future Gardens dome installation. Now, with total focus to devote to a single, smaller scale piece, we could try a number of iterations out and refine quickly.

Throughout the Winter 2019 quarter, we had the opportunity to show the work-in-progress in three organized class critique sessions. This was valuable for getting feedback on the decisions we were making, learning what was and was not working towards the project goals. For example, the 70's style armchair placed in front of a television set tended to steer the critiques in the direction of this being a simulated living room, possibly being taken as a piece about the future of entertainment, or about surveillance through our televisions (often the formations of the cymatics in a circular dish can resemble an eye). As I was not looking for the piece to be about any of these things, I had to find ways to reduce or eliminate these associations.

Figure 23: An iteration of the *Resonant Waves* project in Winter 2019

In the image above, one can see the original chair, with the brown/orange colors and the shorter arms still in place. One of the bass exciters can be seen on the back of the chair as well as the amp powering it just behind. The camera on a tripod and the water dish on the speaker were placed next to the TV in front of the chair.

In the three different critiques, spaced a number of weeks apart, I presented the work using a different single colored light each time. I found that the color of light, meaning the color of the cymatics on display, influenced the aesthetic experience greatly. Warmer orange or pink light tended to draw associations to organic/biological structures, even womb-like impressions. Cooler blue light color tended to lead people towards the

association of surveillance or artificial intelligence, and more than one person thought it looked sinister. I concluded that it would serve the piece best if users could control what color the light was themselves, and not to have to select one single color light for the final piece.

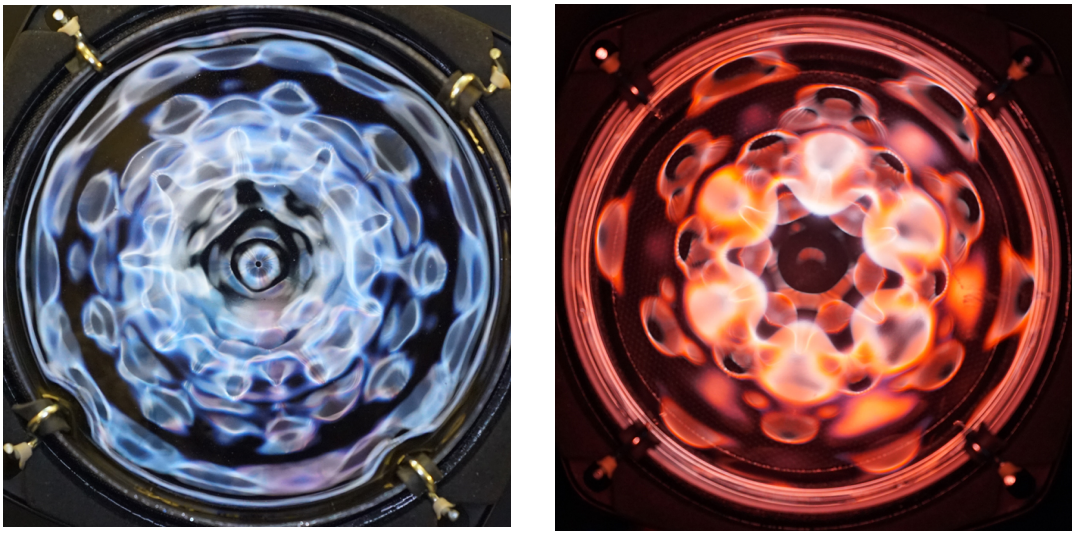


Figure 24: Aesthetic differences between blue and orange light, 2019

The sounds that we allowed users to generate the cymatics with was also being refined through these critiques as well. Using a slider input, the user could select frequencies between a comfortable 20 Hz to 80 Hz range. On the trackpad input, users could add harmonic overtones to the fundamental sine wave selected, but the harmonic range was very freeform; sound combinations could easily create discordant, spooky soundscapes. Since I was looking to make this piece into something that had the potential to relax and feel good to visitors, we needed to carefully select sound

possibilities that visitors could access.

In terms of the arrangement of the elements, it became clear that placing the water dish itself in front of the chair was not the best choice as viewers tended to not approach it or even notice it. Viewers mostly stood behind the chair if they weren't operating it. I felt it was crucial for the waves in the water itself could be seen so visitors would understand what they were seeing on the screen. For the third and final critique, we chose to put the water dish and camera behind the chair. This appeared to resolve that issue and gave the bystanders the opportunity to see it while they waited for their turn in the seat. We were very close to the final form of the piece at this point, with a few adjustments left to make, the most significant ones being the look of the chair, the more streamlined presentation of the interface controls and figuring out an alternative to using a television set to display the cymatics.

In the final piece, the chair arms were replaced with longer custom-fabricated arms with the controls securely embedded in them, making the interface options feel more natural. We also spray-painted the wood of the chair black and covered the orange cushion with soft black fabric, which seemed to remove the 70's associations. For the display, I envisioned projecting the cymatics onto a flat, circular screen that mirrored the shape of the circular dish in which the wave patterns were occurring. This new display choice further removed associations with a living room or a commentary on entertainment. For the sounds that the user could interact with, we chose to

limit the harmonic overtones available on the trackpad to the basic notes of a major chord, relative to what frequency the user was selecting. This meant that the sounds being generated were always in tune, and created a very positive sounding, soothing sonic experience. Additional refinements were made to the final piece, and all of these choices will be discussed in greater detail in the Technical Description beginning on page 52.

## Inspiration and Influences

A number of years ago I saw a video online of patterns being produced on metal plates with sand or salt on them for the first time. As different frequencies, or sine waves, were passed through the metal plates, the particles immediately formed into a variety of symmetrical geometric patterns. I was amazed at what I was seeing and felt that a secret of the universe had just been revealed to me.

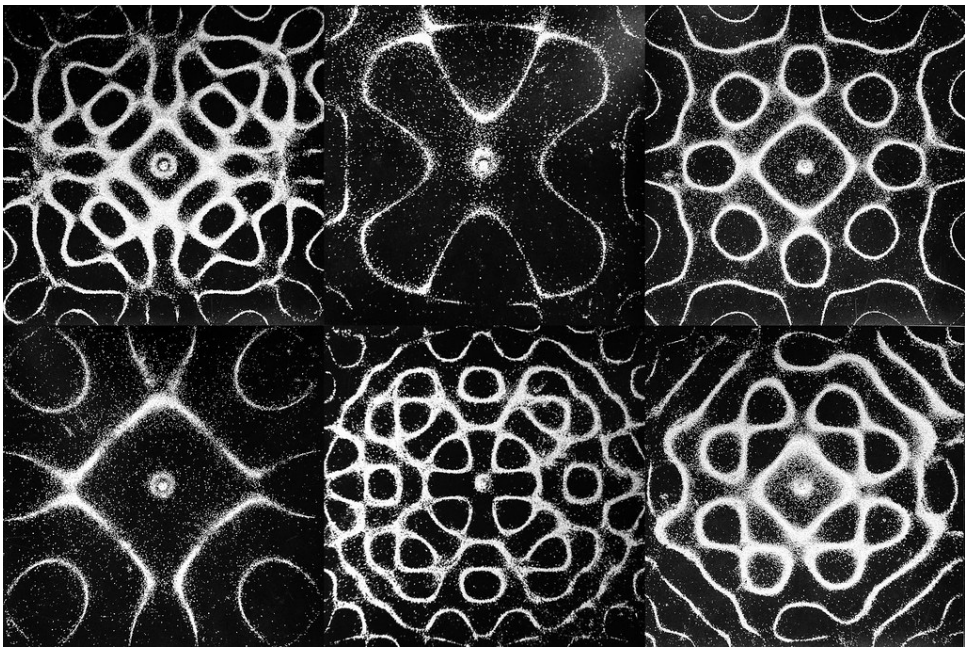


Figure 25: Chladni Plates, 2013[7]

I had no idea that sound and vibration were actually forming these beautiful, complex, symmetrical patterns all around us, that sound had a shape. I looked further into similarly themed videos and saw the same

[7] "Ernst Chladni: Physicist, Musician and Musical Instrument Maker," Text, accessed May 27, 2019, http://www.sites.hps.cam.ac.uk/whipple/explore/acoustics/ernstchladni/.

behavior in water and other mediums, with increasing astonishment. I eventually came across such wonders as seeing sonic fields demonstrating acoustic levitation or anti-gravity behaviors on water and very small objects.

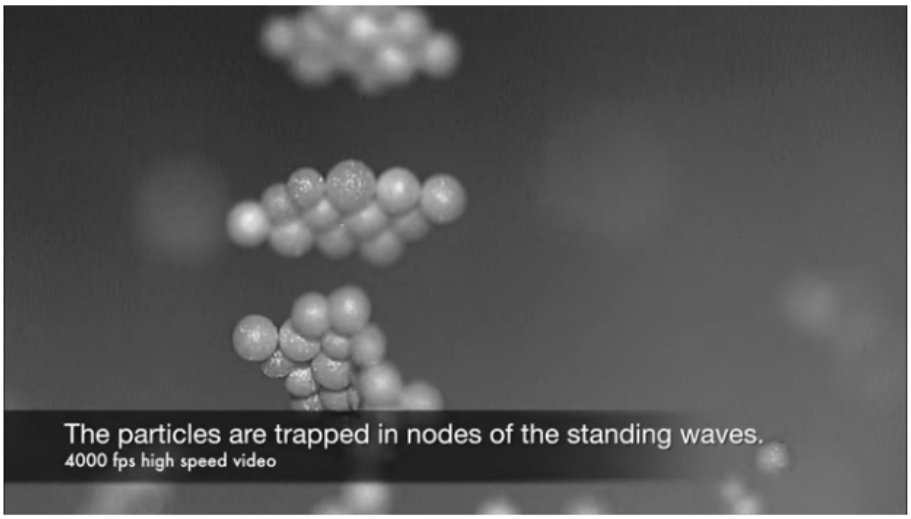



Figure 26: Particles suspended in acoustic standing waves, 2013[8]
https://www.youtube.com/watch?time_continue=108&v=odJxJRAxdFU

Describing how the above physics works is beyond the scope of this paper, but the short video above is worth looking at to see this in action. All of this opened up a great deal of curiosity in me about the function of vibration, sound, and waves in our lives, and how they may affect our bodies. A seed was planted in me that would eventually sprout during my time here at UCSC, realizing I had an opportunity in this MFA program to spend time exploring cymatics and find a way to make art focused on this so that I might

[8] Yoichi Ochiai, *Three-Dimensional Mid-Air Acoustic Manipulation [Acoustic Levitation] (2014-)*, accessed May 28, 2019, https://www.youtube.com/watch?time_continue=108&v=odJxJRAxdFU.

gain some insight into this incredible acoustic phenomenon myself.

**Ernst Chladni**

My first introduction to cymatics was seeing a YouTube video that used the basic concept of Ernst Chladni's "Chladni Plates", metal plates with a thin layer of sand on top that a frequency is run through, causing the sand to naturally form up into geometric patterns, revealing the physical previously invisible shape of that sound. In this instance, the YouTuber was using electronics to generate the frequency, but Ernst Chladni (1756-1827) simply ran a violin bow along the edge of his metal plates of varying shapes and sizes, to demonstrate this phenomenon.

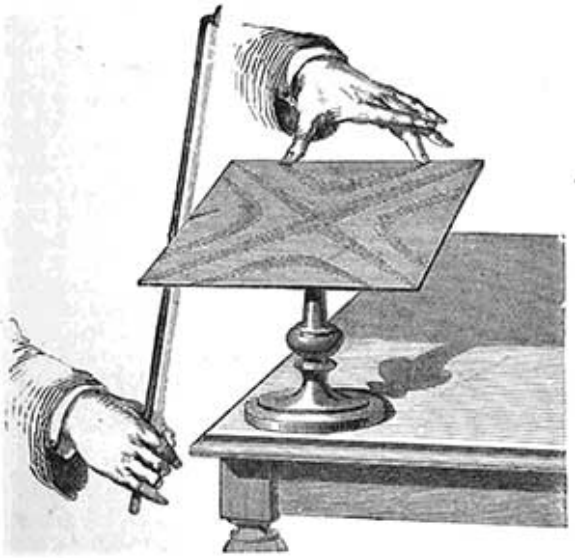


Figure 27: Chladni plate with a bow, date unknown[9]

[9] "Ernst Chladni - Monoskop," accessed June 12, 2019, https://monoskop.org/Ernst_Chladni.

Ernst Chladni has been called "the father of acoustics" on the basis of his studies of sounding bodies.[10]

**Hans Jenny**

Hans Jenny (1904-1972) literally wrote the book on Cymatics. In *Cymatics: A Study of Wave Phenomena and Vibration Vol. 1 (1967) & Vol. 2 (1974)*, Jenny conducts numerous experiments with frequency and different mediums, exploring the wide range of behavior of acoustics and vibration. Jenny says:

> "In attempting to observe the phenomena of vibration, one repeatedly feels a spontaneous urge to make the processes visible and to provide ocular evidence of their nature".[11]

I deeply resonate with this sentiment by Jenny and feel the *Resonant Waves* project at its heart is a result of this desire to demonstrate the visible nature of sound to others. One of the most important pieces of information I have gained from Hans Jenny's research is that these geometric wave interference patterns occur even at microscopic scales, a question I've had for a number of years. Jenney states:

> "Cymatic effects of this kind are also produced at the microscopic level and can be clearly recognized even after the original has been magnified several hundred times. We realize that these figures and processes appear in every dimension."[12]

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[10]N. J. Wade, "Sound and Sight: Acoustic Figures and Visual Phenomena," *Perception* 34, no. 10 (2005): 1275–90, https://doi.org/10.1068/p5295.

[11] Jenny, *Cymatics: A Study of Wave Phenomena and Vibration*. Revised Edition 2001: p21

[12] Jenny. Revised Edition 2001: p21

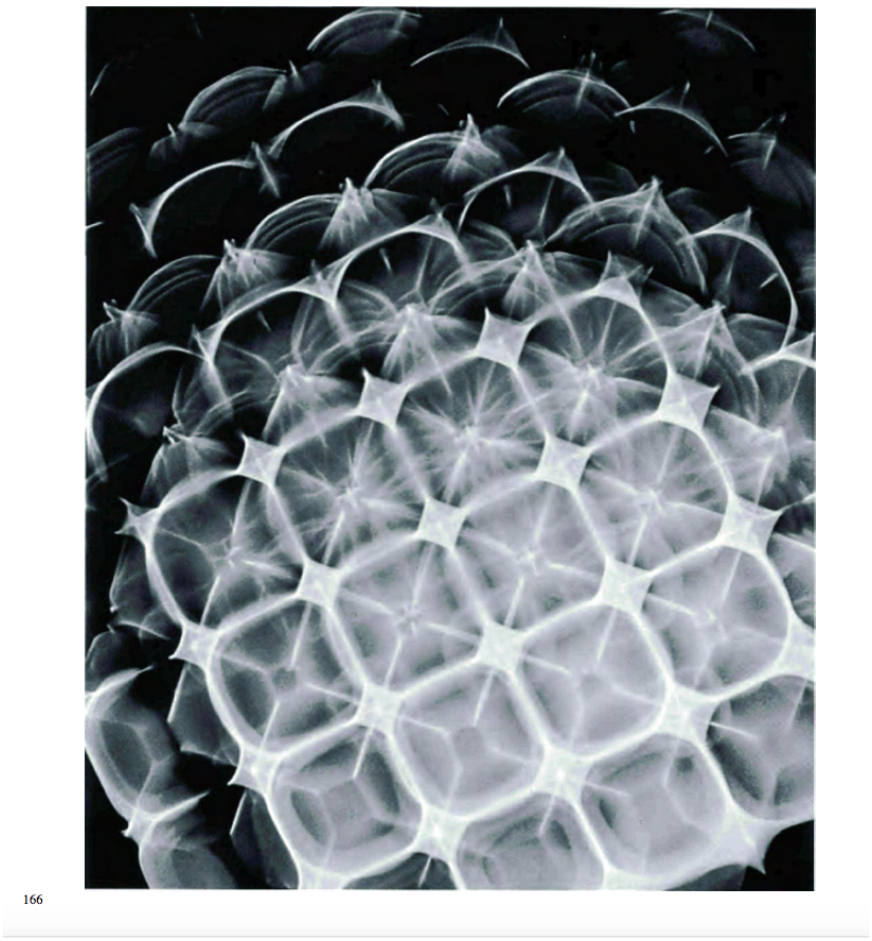


Figure 28: Microscopic cymatics, oil of turpentine, 1967[13]

I am interested to see how sound behaves at a variety of scales for myself, and in a variety of mediums, with the same sort of exuberance for exploration and experimentation as Jenny demonstrates in his research, making artwork from my discoveries that is available for others to experience.

[13] Jenny.

**Linden Gledhill**

I discovered Linden Gledhill's work in the Fall of 2018. His body of work is very scientific in nature, often high-resolution, high-speed microscope photography capturing and enlarging the beauty of various materials including ferrofluids, prismatic liquids, crystals, snowflakes, and butterfly scales.

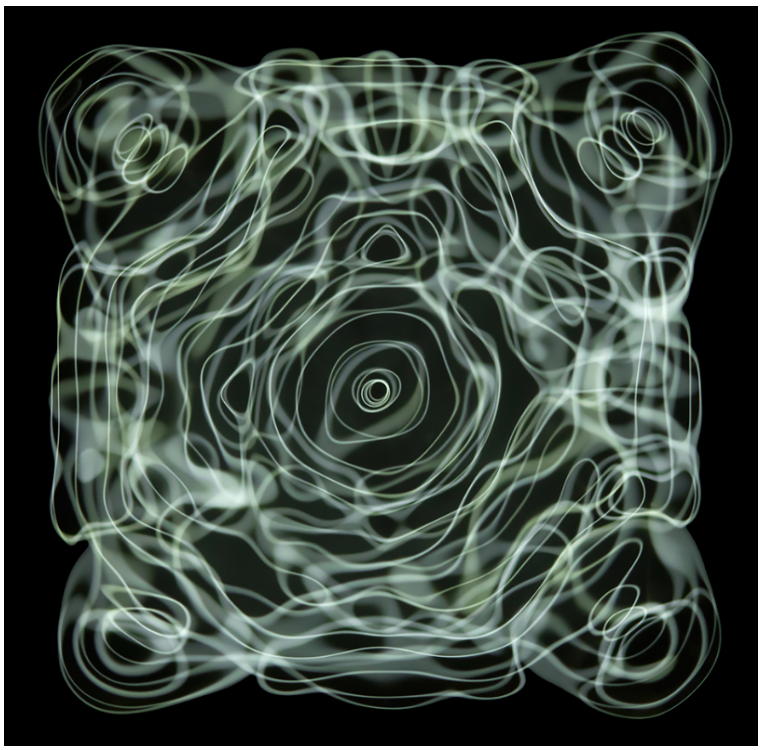

Figure 29: *Cymatics* by Linden Gledhill, 2018

In his work on Cymatics, Gledhill uses highly sophisticated scientific equipment to capture stunning macro photography images & unprecedented slow motion video of Cymatics. Gledhill co-patented a motor-controlled macro rail for close-up focus-stacking photography which he used in his

*Cymatics* series[14]. businessinsider.com reported in 2018 that "a company called iX Cameras loaned him a roughly $100,000 high-speed camera (an i-SPEED 726R) that can record several thousand frames per second in full color and at ultra-high resolution."[15] The results of this slow-motion video revealed the cause of the flicker effect seen at most frequencies in cymatics.

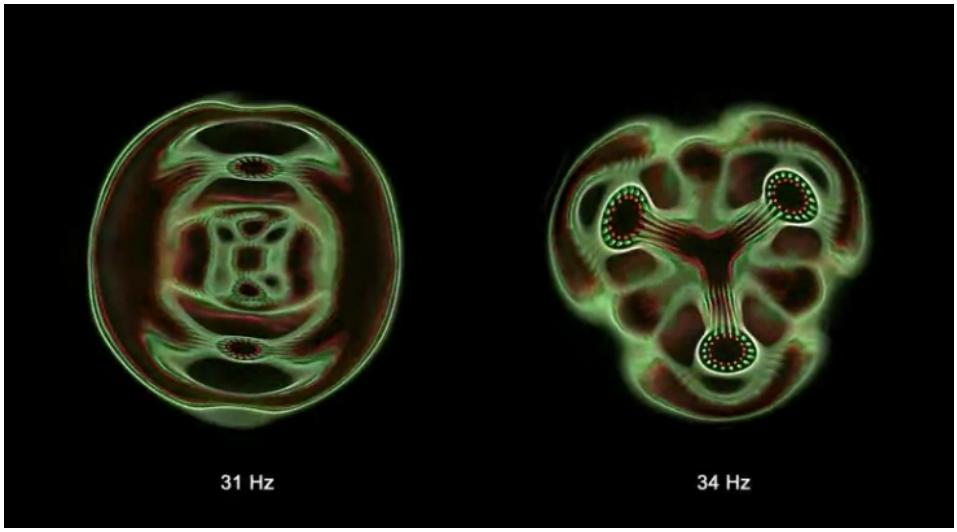


Figure 30: Still of slow-motion Cymatics by Linden Gledhill, 2018[16]
https://bit.ly/2YSYq5T

The above video shows two videos side-by-side of water vibrating at 31 Hz and 34 Hz, slowed down 125x. You can see in the greatly slowed down video how the formations are transitioning back and forth between two patterns. At their normal very-high rate, this back and forth appears mostly

[14] "Cymatics," Linden Gledhill Photography, accessed May 27, 2019, http://www.lindengledhill.com/new-gallery.
[15] Dave Mosher, "Trippy Photos Show How Beautiful Water Can Look When It's Blasted with Sound," Business Insider, accessed May 27, 2019, https://www.businessinsider.com/water-slow-motion-video-standing-waves-cymatics-2018-5.
[16] Gfycat, "Cymatics: Water Vibrating at Resonant Frequencies in Super Slow-Motion (by Linden Gledhill" Gfycat, accessed May 27, 2019, https://thumbs.gfycat.com/RichWhirlwindCrossbill-size_restricted.gif.

as one hybrid pattern of both states, flickering rapidly. This flickering causes the visual component of this work to be unsuitable for those who are triggered or have a sensitivity to flashing lights. In the *Receivership* exhibition, warning signs outside the doors to the gallery space alerted visitors that one of the pieces inside had flickering lights.

Not all frequencies create this flicker effect, however, as some frequencies can generate stable looking synchronized "standing waves", where the frequency is a mathematical match for the diameter of the water dish, and the waves appear as if unmoving. Standing waves are defined as "a combination of two waves moving in opposite directions, each having the same amplitude and frequency."[17] As far as I understand it, when the sound is tuned perfectly to the dish size, the wave height in the center of the dish is the same at the boundary of the dish, and the reflecting waves overlap with the oncoming waves perfectly, making it appear smooth and unmoving.

Gledhill also found that the temperature of water affects how the wave formations appear using the same exact frequency and using the same container size. "Minor variations in liquid volume and temperature ensure that no two cymatic patterns are exactly alike. These two at the exact same frequency, 62.8 Hertz, look slightly different."[18]

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[17] "Standing Wave | Physics," Encyclopedia Britannica, accessed June 4, 2019, https://www.britannica.com/science/standing-wave-physics.

[18] Mosher, "Trippy Photos Show How Beautiful Water Can Look When It's Blasted with Sound."

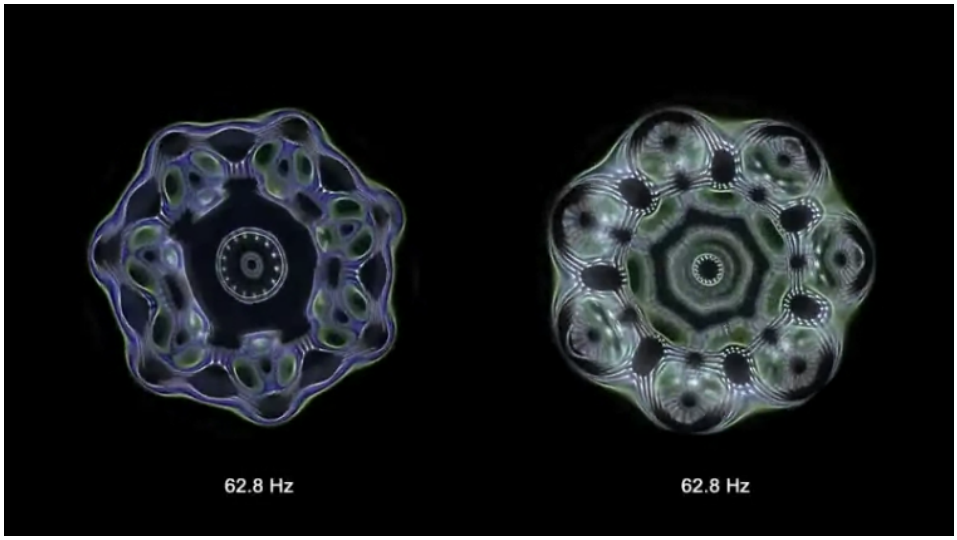



Figure 31: Still of cymatics affected by temperature by Linden Gledhill, 2018[19]
https://bit.ly/2X9yxyl

In the process of developing *Resonant Waves*, the fact of slight differences in the water temperature affecting what sort of cymatic activity we would see - or not - was elusive until just before the *Receivership* exhibition opened. We were baffled as to how in one session, the piece would easily dial in symmetrical geometric patterns with ease at most of the sound frequencies we selected, but using the same exact settings and frequencies in another session the system would not generate wave patterns (requiring more amplitude) or they would be chaotic and difficult to form into symmetrical patterns (requiring less amplitude). On the morning before the *Receivership* exhibition opened, I refreshed the water in the dish mid-session to eliminate dust particles in the water. We were getting very tight formations previously, and after I put fresh water into the dish, the results were different. It didn't

[19] Gfycat, "Cymatics Affected by Temperature."

make sense to adjust any of the settings for better results, as they were clearly working very well moments earlier. The change had to be the result of refreshing the water. The volume of water I would pour into the dish each time was fairly consistent, but I guessed the fresh water was a slightly different temperature than the water that had been in the dish. Once I began writing this paper, returning to review Gledhill's work, my hypothesis on the effects of water temperature on cymatic formation consistency was confirmed.

# Historical and Aesthetic Context

*Resonant Waves* sits in an art historical context with works and artists that I wasn't specifically aware of before the making of the piece, particularly the psychedelic nature of the projected, dancing geometric patterns and the connection to sound and sound visualization. The following is a brief survey of the most relevant artists, work and movements with which *Resonant Wave*s appears to have a strong aesthetic connection.

**Mark Boyle and Joan Hills**

With an interest in making light art that also turned out to be live demonstrations of scientific processes, artists Mark Boyle and Joan Hills began working in the 1960s with performative light projection shows displaying, among other things, chemical reactions. One of their earlier pieces *Son et Lumiere For Fire And Water* in 1966, "presented physical and chemical reactions including evaporation, corrosion, combustion and effervescence"[20].

Producing chemical reactions live and projecting them on a large screen for an audience to witness is most definitely in the spirit of the *Resonant Waves* project, revealing beautiful and captivating processes of nature that we ordinarily are not exposed to.

[20] "Boyle Family Early Projections," accessed June 4, 2019, http://www.thecentreofattention.org/exhibitions/projections.html.

Figure 32: Zinc being destroyed by acid in Son et Lumière for Earth, Air, Fire and Water, 1966

Following a performance of their *Son et Lumière for Earth, Air, Fire and Water* at London's UFO Club in 1966, Mark Boyle and Joan Hills found themselves invited to combine their chemical reactions as stage projections for live improvisational music acts such as Soft Machine, Pink Floyd, and Jimi Hendrix. While their projected visuals were not a direct visualization of sound as *Resonant Waves* demonstrates, they would perform in response to the music that was happening live, improvising their choices of what sort of reactions to experiment with, being directly influenced by the music, as an integral part of the performance.

> "We had four projectors and would try to get different reactions going in each one, mixing them with coloured filters. There was a lot of chance as the images were based on the chemical reactions that happened in the slides. Some created amazing effects. When we put acid on to perforated zinc it would immediately attack the zinc and there was a ferocious action: pieces of zinc would fly off the screen with bubbles exploding. You would put it on when Mike Ratledge, the keyboard player, was going mad on the organ, or Robert Wyatt was doing one of his amazing drum solos. It was very fast-moving work. When you saw that one of the chemicals was reaching the end of its cycle, you had to fade that out and bring in something else. It was not synchronised with the music, though your brain forced the two things

together, making you think it was, which created something totally magical."[21]


Figure 33: The Soft Machine play inside the Discotheque Interplay, July 1967

It wasn't only the music that the lightshows were interacting and improvising with or that the projected visuals were a product of, but the audience was also a key element for these early VJs. Robin Oppenheimer explains that responding to the audience characterizes music and light show performances in general:

> "The light show artists I've met and researched tell great stories of how they could feel the people dancing in the room responding collectively to the music and their projections. As pre-electronic media folk artists, they learned quickly that they could tap into the group consciousness of their audience by improvisationally connecting layered collages of images both abstract and representational to the lyrics and rhythmic beat of rock and roll. The immersive, mosaic quality of light shows,

[21] "Tune in, Turn on, Light Up," accessed June 4, 2019, https://www.tate.org.uk/context-comment/articles/tune-turn-on-light.

when mixed with drugs and loud music, provided a powerful means of altering one's consciousness and connecting to new ideas and ways of seeing the world that were outside mainstream media."[22]


Figure 34: Frank Zappa and the Mothers of Invention, Fillmore East, Joshua Light Show, 1970

While *Resonant Waves* is a more individual experience, it is also designed as a sound-and-light-projecting instrument of sorts. The user can influence the sound being produced, which generates the projected visuals and the deep vibrations in the chair. Each individual can become familiar with how to "play" the piece and can produce unique patterns in the water according to their mood and preferences. The piece becomes a feedback loop of sorts, with the user making adjustments to the sound, changing the patterns and vibrations in their body, further affecting how they would

[22] "Maximal Art: The Origins and Aesthetics of West Coast Light Shows," Rhizome, accessed June 4, 2019, http://rhizome.org/editorial/2009/apr/15/maximal-art-the-origins-and-aesthetics-of-west-coa/.

interact with the piece, and so on. Interestingly, some visitors seem to be "naturals," producing stable symmetrical geometric patterns on the water with ease, while others may have greater difficulty, either not seeing activity in the water or winding up with more chaotic, asymmetrical waves.

**Evelina Domnitch & Dmitry Gelfand**

Even closer in spirit to the *Resonant Waves* piece is the fascinating work of Evelina Domnitch and Dmitry Gelfand, who succeed in making the invisible visible and revealing processes of nature in very remarkable and surprising ways. In their paper *Art as Rigorous Phenomenology*, they explain:

> "The artworks we create may be considered phenomenological investigations, clarifying not only the content of our perceptions, but also descending further into the non-rigid, morphing structures of consciousness itself"[23]

Phenomenology is "the direct investigation and description of phenomena as consciously experienced, without theories about their causal explanation and as free as possible from unexamined preconceptions and presuppositions."[24] I believe my approach to art-making must be phenomenological as well, in that I endeavor to present work such as *Resonant Waves* as directly and as accessible as possible without the audience needing to know or understand anything, to such a degree that even young children and toddlers can enjoy

[23] E Domnitch and D Gelfand, "ART AS RIGOROUS PHENOMENOLOGY"(.pdf) http://portablepalace.com n.d., 8. Accessed June 6, 2019.
[24] "Phenomenology | Philosophy," Encyclopedia Britannica, accessed June 6, 2019, https://www.britannica.com/topic/phenomenology.

the immediacy of the exploration and experience. I chose not to include any instructions on the interactive controls of the piece or indications of what they influenced. My hope was that the live display of the generation of patterns in water would satisfy the curiosity of those interested in discovering what the projected visuals were, in a completely direct way, where someone could "grok" (to understand profoundly and intuitively[25]) what is going on.

Domnitch and Gelfand's work is deeply engaged with natural, physical, and chemical processes which they display in stylish and well-considered installations and performances. In their 2003 piece *Camera Lucida* (light chamber), they explore the light that is released inside of imploding micro gas bubbles in an elegant sculptural installation.

Figure 35: Evelina Domnitch & Dmitry Gelfand, *Camera Lucida*, 2003

> "Within a transparent chamber filled with water, sound waves are transformed into light emissions by employing a phenomenon known as sonoluminescence. After adapting to the absolute darkness surrounding the installation, one begins to perceive the fleeting

[25] "Definition of GROK," accessed June 6, 2019, https://www.merriam-webster.com/dictionary/grok.

> configurations of glowing sound fields. Though it has been established that the source of light arises inside of imploding gas bubbles, the underlying energy amplification cannot be fully explained."..."It is our intention to uncover this delicate bio-chemi-physical interface where the visible is the condition of the invisible (of the audible) and "where the inverse is also true, where invisibility [the disappearance of the observer in total darkness] is the condition of a new kind of visibility"[26]

*Camera Lucida* transmits sound through water to create standing waves and gas bubbles. It is educational for me to see standing waves *within* a volume of water, not just on the surface as *Resonant Waves* demonstrates. *Camera Lucida* displays a function of sound passing through water that I had wondered about but had not witnessed. The creation of very subtle light generated from the implosion of bubbles enables us to see the standing waves themselves.

Fig 36: Sonoluminescent standing wave in Camera Lucida: Sonochemical Observator, 2003[27]

[26] "Evelina DOMNITCH Dmitry GELFAND: CAMERA LUCIDA," accessed June 4, 2019, http://portablepalace.com/camera_lucida.html.
[27] Domnitch and Gelfand, "ART AS RIGOROUS PHENOMENOLOGY."

One of their other marvels of light, liquid, and sound that Domnitch and Gelfand have turned into sublime art is *10000 Peacock Feathers in Foaming Acid* (2007). In this piece, the artists scan the surface of soap bubbles with a single white laser beam, which would get trapped inside the thin soap bubble membrane and refract back out in a highly organic, prismatic light show. They projected this large scale onto the interior of a huge inflated dome space with many visitors in attendance. Additionally, an audio-visual feedback system was also arranged where the light from the laser passing inside the bubbles would be used as an input to be read by a computer and would influence the pre-arranged sounds that were playing. The filtered sound would vibrate the bubbles on their surface, further influencing the path of the laser light, further filtering the sound, and so on, in a loop.[28]

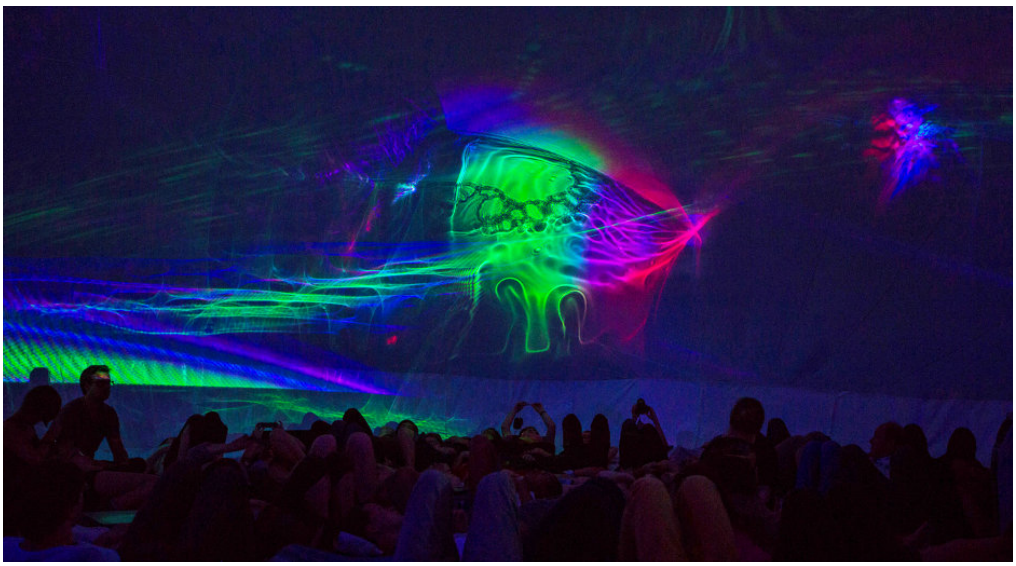


Figure 37: Domnitch and Gelfand, *10000 Peacock Feathers in Foaming Acid*, 2007.

[28] This video interview with the artists describes and shows the work in greater detail: https://www.youtube.com/watch?v=fE8zx8domD8

Having the sound influence the projected forms *1000 Peacock Feathers* shares close affinities with *Resonant Waves*, and the projected light show magnifying the activity of light through the surface of the soap bubbles is also very much akin to how my work reveals sublime activity that we do not ordinarily see.

**Sachiko Kodama**

Sachiko Kodama's work with ferrofluid is very much in line with my approach to *Resonant Waves*, involved with revealing what is normally invisible. However, rather than visualizing what sound looks like in water, she exposes dynamic, moving magnetic fields in pools of ferrofluid. Ferrofluid is a thick, black, magnetic liquid that responds to magnetic flux due to its metallic content, creating its signature smooth, almost high-definition 3D computer graphics-looking radial spikes.

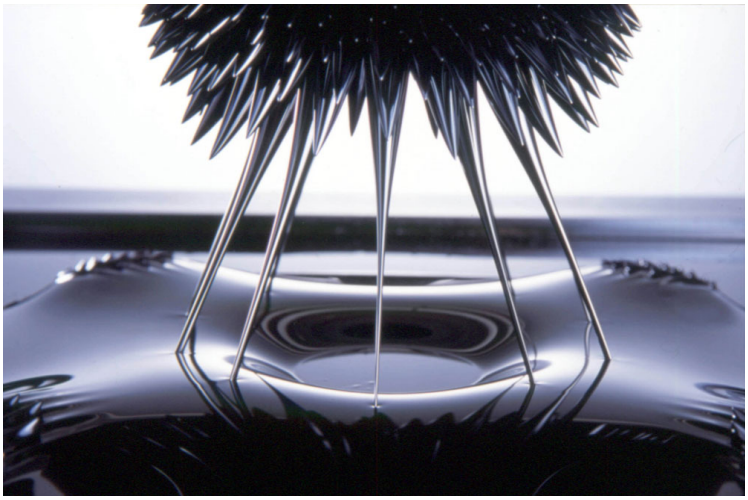


Figure 38: Sachiko Kodama, *Fluidity*, 2007

In her various ferrofluid sculptures and installations from 2001 to present, Kodama manipulates electrically powered magnetic fields with a computer in surreal and hypnotic ways, and places them on display for visitors to witness, often projected large in the space, and in some cases, the audience can interact with the work. In *Protrude Flow*, sound in the room is able to influence the magnetic fields and the ferrofluid forms. (See 2:53 in the linked video, below.)

https://www.youtube.com/watch?time_continue=209&v=c4rLG5Aaie4

Figure 39: Sachiko Kodama, *Protrude Flow*, 2008

As mentioned above in the Prior Works section, in my 1995-96 undergraduate work, I was also fascinated with making magnetic fields visible and putting them on display. Rather than working with ferrofluids, I worked with iron filings and non-electric magnets, which resulted in a much more earthy, gritty and mostly static display of magnetic fields.

Figure 19: Richard Grillotti, *Magnetic Field*, 1996

## Technical Description

The *Resonant Waves* installation, as installed in the April 2019 UCSC Digital Arts and New Media MFA exhibition *Receivership*, had four main components: a 4' circular projection screen facing a comfortable, vibrating seat with control units embedded in its custom-made arms, flanked by two speakers on stands, and a display of sound passing through a water in a 3" water dish sitting on a 3" speaker, illuminated directly from above. The visitors were also able to hear the sound in the room that was passing through the water and also the vibrating the chair.

Figure 41: *Resonant Waves* installation, *2019*

The natural phenomena of sound generating complex shapes and symmetrical geometric patterns in real-time, visible to all visitors, is at the

core of this project. A good deal of research was required to learn how to generate cymatic formations myself and what equipment I would need to assemble, as well as learning how to effectively light and capture the activity through the lens of a camera, and what sort of lighting gear I would need for that. While conducting my early research in the Fall of 2018, I came across an Instagram user, @benbrowncymatics who focused on geometric patterns that repeat in nature, as well as photographing and posting cymatics phenomena he had generated himself in water, much like I was looking to do. At just the right time for my need to build my own setup, he posted a diagram of a homebrew cymatic equipment chain.


Figure 42: Home cymatics setup diagram, *@benbrowncymatics*[29], 2018

[29] "Ben Browne on Instagram: 'Does Anyone Know Who Did This?" accessed May 26, 2019, https://www.instagram.com/p/Bp0eSzmHdXC/.

I had already been working with a setup similar to everything in his diagram except for the ring light. I purchased one right away and soon after, along with finding the right size & material petri dish, I was able to successfully generate my first very stable and symmetrical cymatic forms. The following is a photograph of the first major success I achieved after roughly 5 weeks of trying to generate a cohesive, symmetrical cymatic pattern, giving me the results and confidence I needed to continue on with my project.

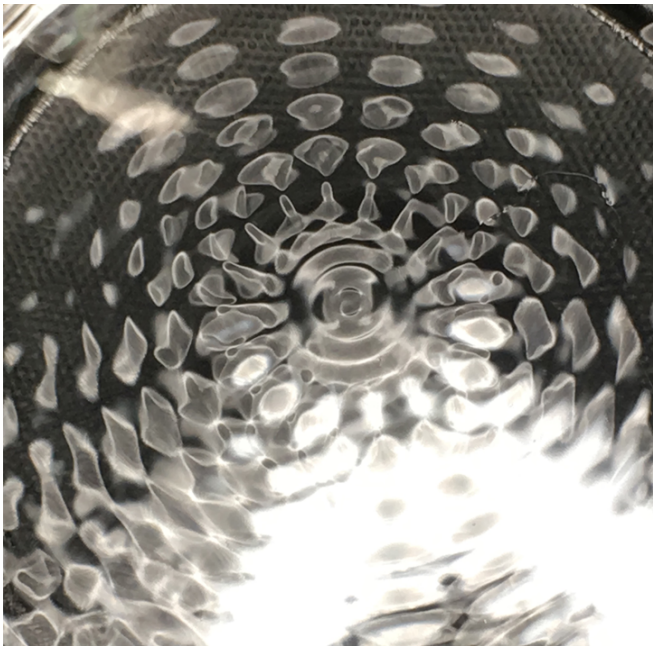


Figure 43: First major cymatic success, 2018

The container for the water I found worked best was a 3" diameter round plastic petri dish. After trying a number of different dishes and cups, including glass and metal and thicker plastics, it became clear that using a lighter, thinner material more allowed the patterns to more easily form.

Originally I had expected the sound from the speaker to pass through a denser material with ease but learned after not seeing any waves form at all that I needed to pare down material densities.

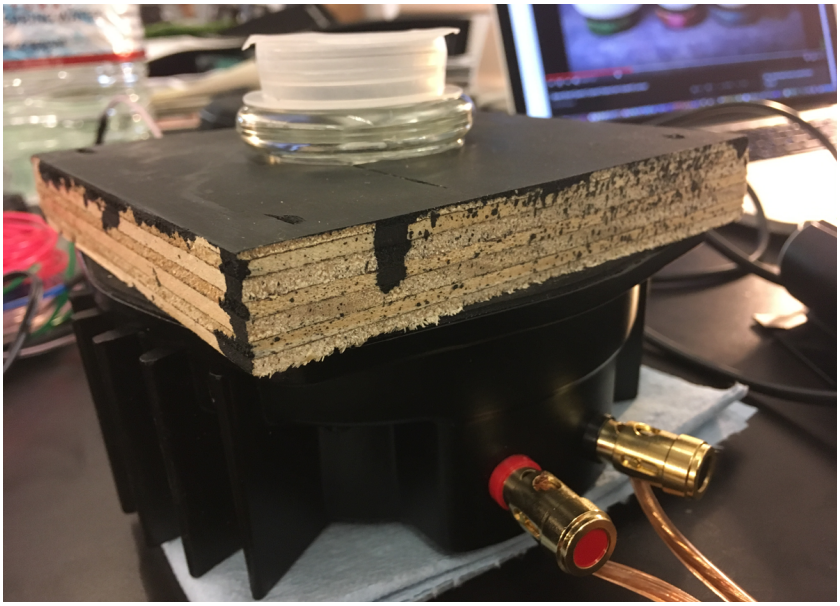


Figure 44: *First (failed) attempt at generating cymatics,* 2018

As seen in the above photo, I was originally using a bass exciter/transducer to attempt to generate the wave patterns, but that piece of equipment is designed to vibrate more than produce sound. After many unsuccessful attempts, I switched to a 3" mid-range speaker like I had seen in the diagram above. This resulted in achieving waves in the water much more easily.

The following is a detail of the working studio setup I used for much of my early experiments.

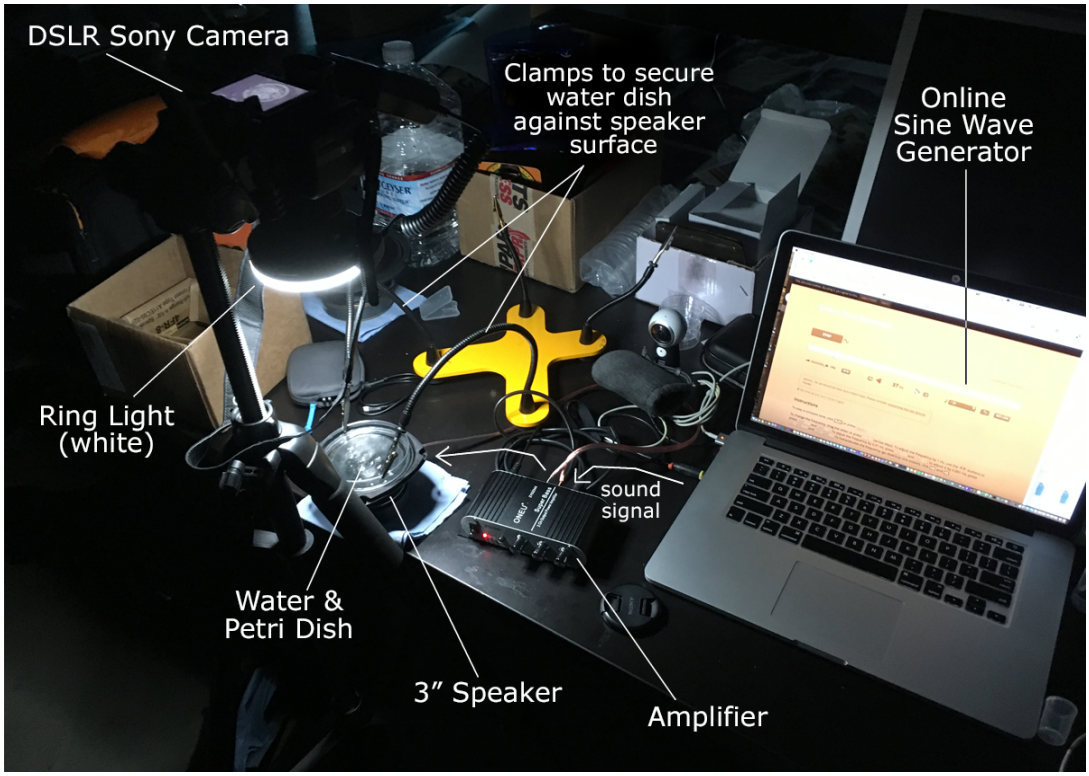



Figure 45: *Working studio setup*, 2018

For lighting the water dish in the *Resonant Waves* installation in the *Receivership* exhibition, I chose to add second larger ring light to the mix. What I was looking for was a variable RGB ring light that could be controlled remotely. I wanted to enable the audience to control the color of the light in the final piece, as a means of changing and further customizing the emotional feel or mood of the experience. The light I found, the Prismatic Lighting "Spectra" portrait light, is about 12" in diameter, horizontally mounted about 1' above the water dish, on a sturdy stand. Before the *Receivership* show opened, I had imagined that the larger Spectra light would replace the smaller one I had been using that was mounted directly on the camera lens.

The smaller ring light is white without an option to change the color dynamically, although it was possible to change the light color manually by placing colored transparency gels inside the white LED light diffusion cover. This worked well for experimenting with colored light in the studio and presenting prototype versions of the project for critique using different gel for a static light color each time, to see if the color of the light had an impact on the viewers. I found that the color of light did indeed influence the experience for the viewers, particularly the "feeling" of the piece. Warm colors, such as red or orange, would give viewers the feeling of something organic, biological, peaceful. Using cooler temperature colors, such as blue and green, induced feelings of fear and felt cold and clinical, more "surveillance" associations, when the formations would resemble an eye shape. I felt it was important to explore giving the visitors the option to choose the color of light for themselves.

I attempted to find a variable RGB remote control ring light that would sit directly on the lens, as I knew that setup worked well, but the much larger Spectra ring light was the only ring light I could find in my searching that would allow reliable remote color changing, in this case using a smartphone app. The Spectra ring light did work to a degree; it managed to illuminate the more dynamic, larger waves in the water but it did not catch the more subtle, shallower waves that the smaller ring light mounted directly to the camera lens could.

As a result, for the *Receivership* exhibition, I chose to use both lights simultaneously, a decision made the morning before the gallery doors opened for the first time. I'm thankful for this decision, as both ring lights in this centered concentric circle arrangement allowed for a broader range of waves sizes in the water with different angles of reflection to become visible. This increased the range of complexity and intricacy of the patterns, as well as allowed for a variety of gorgeous color combinations in the projected video feed. A side benefit was a "surprise" element that would occur as the waveforms and patterns emerged. Usually, the waves visible with the smaller ring light would appear first, followed seconds later by the unexpected secondary color, appearing in a brilliant display.

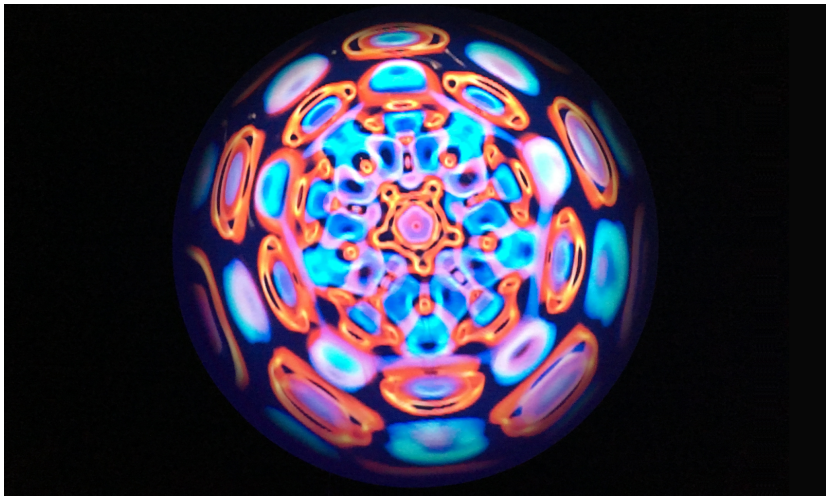


Figure 46: *Resonant Waves* color combinations example 01, *2019*

For the smaller white LED ring I chose red and orange transparent gels to color its light for the duration of the exhibition. I felt the variety of color

combinations possible with a consistent red-orange light were the most lush and exciting and also offered a more consistently "warmer" experience to the visitor when the waves were too subtle for the color selected in the Spectra ring light to become visible.

Figure 47: *Resonant Waves* orange-light-only example 01, *2019*

For capturing the cymatic activity in the water dish, and for output to the projector, a Sony a7 DSLR camera was used as it was the highest quality camera available in the Digital Arts and New Media program. The camera was mounted in the center of the larger Spectra ring light, about 1' up, facing directly downwards into the water dish. A 35-80mm lens was used at maximum zoom level to capture the water dish as large as possible while still being in focus.

The camera's preview display was output via a micro HDMI cable, fed down & underneath the gallery floor, and back up again to an Optoma short-throw projector, a brilliant, high-quality model. The Optoma was

mounted roughly 8' behind the seat and about 10' up in the air on a sturdy steel pole and mount. The camera's live-feed was projected onto a 4' white circular screen mounted on a television stand, with its center point around 3' off the ground. The screen was made from thin plywood and painted with 3 coats of white paint with a paint roller, to make sure it was as bright white as it could be.

Choosing a circular projection screen, in the end, seemed an obvious and natural choice, serving the circular nature of the cymatic patterns in the round petri dish on the round speaker very well. However, the consideration for using an irregularly shaped projection screen began with a desire to remove unwanted associations from the project that I was receiving as feedback on earlier prototypes. I had been using a large television to display the camera feed for most of the organized critiques of the piece. With a television set as the focal point, coupled with the very 1970's living-room seat that I was using for the visitors to sit in resulted in many living-room associations for people. Some felt it was work commenting on 1960's psychedelic culture and others thought maybe this was a piece about what entertainment would be like in homes of the future. Replacing the television set with a round projection screen helped to free the project from those associations. The other aspect to refine was the 1970's style armchair.

In the *Receivershi*p exhibition, facing the projection screen squarely, about 6' away, was a comfortable cushioned armchair with a heavy wooden

frame. Originally the chair had a reddish-brown wooden frame and arms, and very 1960s or 1970s style orange fabric cushions (Fig. 23). DiLallo and I spray painted all of the exposed wood on the chair black and covered the orange patterned seat cushion with a soft black sheet of fabric. We also removed the existing chair arms and built custom arms to house the controls that visitors would use to interact with the piece.

Figure 48: *Resonant Waves* chair before adjustments, *2019*

The chair pictured above shows the original wood color and the original arms before they were removed, with the original orange fabric already covered up in black. Two heavy duty "Buttkicker" bass transducers/exciters were securely attached to the chair bottom and back, which gently vibrate the chair - and the person seated in it - at the frequency or combinations of frequencies as the water in the dish. Both bass exciters are hidden from view, with one

underneath the chair and one attached to the back of the chair covered by black fabric. In Fig. 49 below, you can see the Buttkicker bass transducers prior to attaching them to the seat frame.

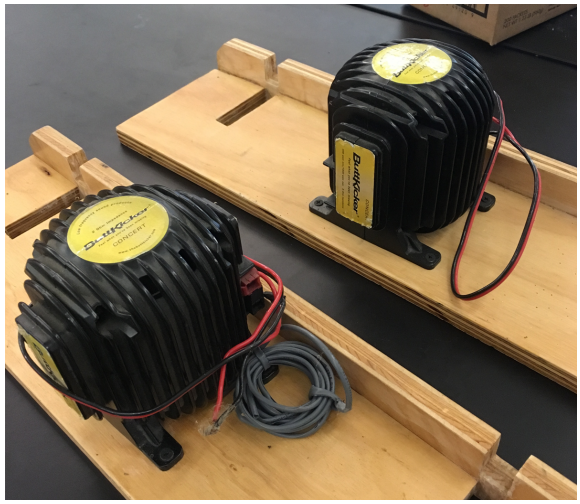


Figure 49: "Buttkicker" bass exciters, *2019*

The arms of the original chair were about 8" too short to comfortably host the interactive control elements for the user. Custom arms were required that could have the controls built-in at a comfortable distance for an average sized adult and secured neatly in place. I used Adobe Illustrator to design the new arms and a laser cutter to cut the different layers out of ¼" wood, which I spray painted black once they were assembled.

Figure 50: *Resonant Waves* chair arm controls, 2019

The controls available for the visitor seated in the chair consisted of 4 different elements: A slider, a button, a color wheel, and a trackpad. The 3" rectangular slider, part of the modular "Palette" controls suite[30], is housed in the left arm. This slider is used to adjust the sine wave frequency being generated and run through the chair, the water dish and the speakers. A range of 30 Hz to 60 Hz was chosen very intentionally to be comfortable to the visitors audibly and physically. 30 Hz is just above the lower range of human hearing and 60 Hz is still a low enough pitch to not be annoying or abrasive for extended periods. This limited lower frequency range also was important for the vibrational aspect of the piece, 60 Hz being course enough to still be felt and 30 Hz being above the range of vibrating the chair too aggressively. For a number of the earlier prototypes, the lower frequency range was set to 20 Hz and numerous testers reported feeling that the vibrating was too aggressive and made them uncomfortable.

[30] "Palette Gear."

Connected to the right of the slider is a second piece of the modular Palette system, is an arcade-style black button. When pressed once this adds in a .5 Hz lower frequency of whichever frequency is currently running, creating a natural beat or pulse due to the close but slightly offset waveforms. Pressing the button again removes the offset frequency and the pulse effect. Above the button module is the control unit, or "brain" of the Palette system, required to run the Palette gear and communicate with the computer. Users often tried touching it to see if it would do anything.

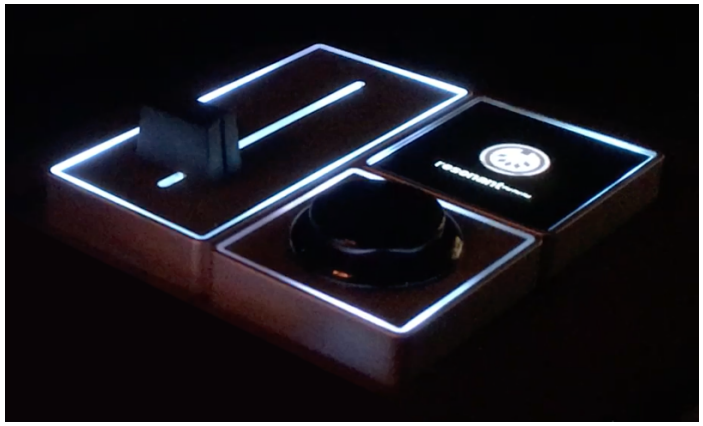
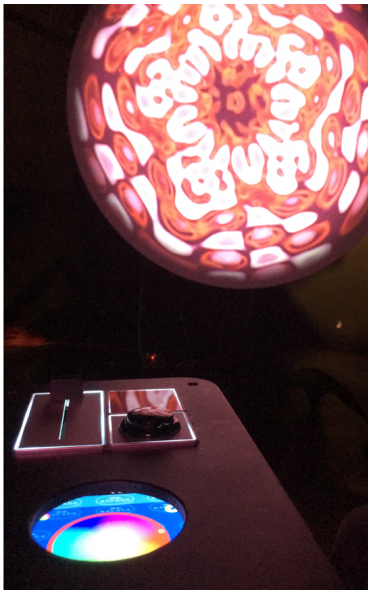


Figure 51: *Palette* controls, 2019

In the left arm of the chair, just below the Palette controls is a circular hole with an illuminated touch-sensitive color wheel showing through. This is a Samsung Galaxy 7 smartphone with an app designed to control the larger Spectra ring light (provided by Prismatic). I designed and built the arm this way so that the viewer could *only* interact with the color wheel itself, and not access any of the other functions of the smartphone. This was semi-successful,

as it was very easy for a user to wind up with a bright white light as the secondary color, rather than a deeply saturated color. Selecting a saturated hue required touching at the very outer edge of the color wheel, which most visitors did not tend to do. In future iterations of this project, I would consider using a different interactive lighting setup that offered tighter control, and control of all of the lights, not just one of them.

Figures 52 & 53: Smartphone & Spectra ring light controls, 2019

Embedded in the right arm of the chair is a square brushed aluminum Apple trackpad. This enables the user to add harmonics to the currently selected frequency. The trackpad is set to absolute positioning, meaning each location on the trackpad always has the same function. The upper left corner of the trackpad mixes in the same frequency at the next higher octave. The upper right corner adds the Major 5th, and the lower right corner adds the

Major 3rd. These are the relative component notes of a major chord. Touching the trackpad at the lower left removes the harmonics, leaving the base frequency only. Touching other positions in between the corners on the trackpad will mix these harmonics to different degrees. The center of the trackpad is an even mix of all four pitches.

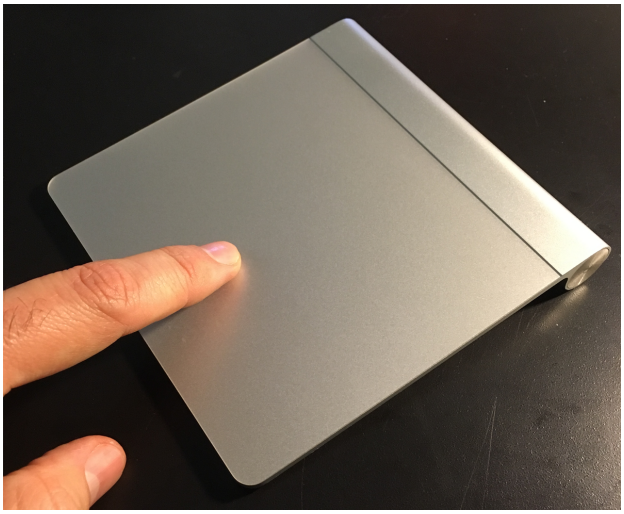


Figure 54: Apple trackpad, 2019

Including some sort of basic information or instructions as to what the controls influenced was certainly a consideration but we felt that the options we arrived at for what could be controlled were simple enough, and the results of any changes immediate enough, to allow for user exploration and discovery. Another reason for wanting to keep details to read or think about out of the experience is that this project is an opportunity for a visitor to relax out of thinking, to be direct and feel and explore with their senses.

For the audio component of the installation, there were two 6" Rokit

speakers on minimal black speaker stands set to a medium-low volume, for visitors to hear the sine waves and harmonics currently playing. These were positioned roughly 2' to the left and right of the seat aimed at each other and at the general position of where the head of the average height individual might be when sitting in the chair. These speakers played the same sound that was passing through the water dish and the two Buttkickers attached to and vibrating the chair.

Behind the scenes, the project's audio was being generated and controlled with an intricate Max MSP[31] software patch, designed by DiLallo. Obscured from the view of the visitors, we placed all the computing and audio gear used in the project on a small table directly behind the projection screen. This equipment included a Mac Mini with a display and mouse, a powerful amplifier used to power the Buttkickers attached to the chair, and a Scarlett Fusion audio interface needed to send the signal from the Max MSP patch to the Rokitt speakers and the small 3" speaker used to generate the wave patterns in the water dish.

[31]"Max Software Tools for Media | Cycling '74," accessed May 26, 2019, https://cycling74.com/products/max/.

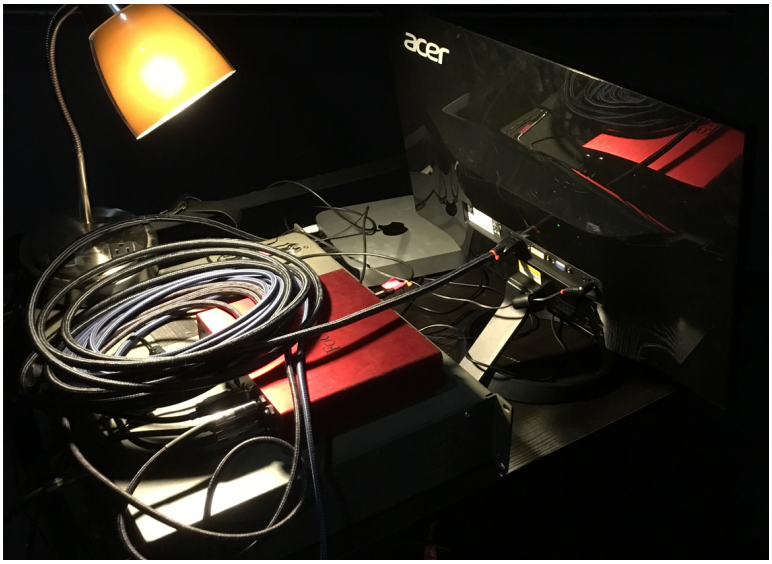



Figure 55: audio and computing equipment, 2019

One of the most vital functions of the Max MSP audio patch to the success of the piece was to carefully control the volume of the different sine wave frequencies being generated. I learned early on in the process of generating cymatics at different frequencies that lower Hertz frequencies required more amplitude/volume to generate wave patterns than higher Hz frequencies. Without increasing the volume for lower frequencies, waves wouldn't form in the water, and without lowering the volume for higher frequencies, the wave formations would lose coherency, get chaotic, and eventually would start to splash the water out of the dish the higher the frequency went. Using the same volume across the board for all frequencies would have left a very narrow range of frequency that resulted in cohesive, symmetrical wave patterns.

This inverse relationship of frequency to ideal amplitude would have

been rather straightforward if *Resonant Waves* didn't include the additive harmonic functions of the trackpad. With the addition of mixing in the octave, the 3rd, and the 5th harmonics for any selected frequency, and any combination or mixture of those three, the challenge of adapting the volume to frequency became nearly impossible. Nonetheless, DiLallo managed to do a great job of keeping the volume managed well enough to keep the water from splashing out of the dish, which was a major accomplishment in itself. The side effect of erring on the lower volume range was that in some cases, the user would have difficulty generating activity in the water dish, depending on what frequency and harmonic space they were exploring.

# Conclusion

***Resonant Waves: Immersed in Geometry*** merges art, science, and play in a fresh new way. Visitors can sit down, relax, and take control of their sonic experience as they simultaneously hear, see and feel sound, becoming familiar with its effects on their body, mind, and emotions. The user becomes a co-creator of the impermanent forms and the co-orchestrator of their experience. As one spends more time with the piece, greater control can be achieved, much like learning a musical instrument; indeed, one can argue that *Resonant Waves* is itself a multimedia instrument.

I am deeply satisfied with the final piece. Throughout many iterations and significant changes in form and technology, *Resonant Waves* remained true to the essential objectives: to create an immersive experience of sound, and for visitors to be able to control and interact with the frequencies generating the cymatic waveforms. I feel the final, refined form of the project struck a precise balance of elements and user control, ultimately becoming more effective and successful than I could have imagined possible. That said, I consider the version presented in the *Receivership* exhibition to be a very successful proof of concept, with plenty of room to explore and refine this work in the future.

*Resonant Waves* innovates and furthers the area of interactive sound and projected light art, enabling a person to simultaneously hear, feel, and see the sound being produced, with the ability to interact with and influence the

sound, experiencing its various effects immediately and directly. This combination is not something I have seen achieved before, specifically exploring cymatics, and visualizing sound authentically. It is clear from my own time spent playing/experiencing the piece, witnessing others interacting with it, and hearing responses afterward, this work offers a fresh perspective on sound and vibration, and reveals the largely beneficial physical, mental and emotional effects sound and vibration in the Hz range presented can have.

A guest book was available in which visitors could leave feedback about their experience. I also hosted the piece for the majority of its time on display, speaking with many visitors as they explored the piece and afterward. Common experiences include relaxation, reduced stress and anxiety, alleviation of body aches and pains including cases of back pain, increased mental clarity, joy, happiness, recognition, surprise, awe, and wonder. The realization that what they were seeing on the screen was simply sound passing through water in a dish resting on a speaker was a major surprise to most and made the experience much more meaningful. Before a visitor realized where the visuals were coming from it was often assumed they were computer generated.

Not all visitors had the most positive experience, however. On occasion, I would hear that a visitor felt overstimulated, or didn't enjoy the sound, the vibration or the sometimes rapidly flickering visuals. Of course,

individuals triggered by flashing lights should not attempt to experience this piece.

In the future, I plan to continue to develop this work, to refine it, create multi-user versions, and will seek to bring it to as many places as possible throughout the country and the world as I find opportunities, invitations, and funding to do so. My fascination for working with light, energy, magnetism, vibration, waves, and unexpected shifts in perspective continues, as does my interest in revealing normally unseen or overlooked phenomena and finding ways to make them visible and accessible to as large and diverse an audience as possible. Underlying it all remains my desire to explore and look much more closely our natural world, at what may seem ordinary and familiar, to increase this sense of wonder and amazement for myself and others in this mysterious life we find ourselves in and are an integral, inseparable part of.

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