Signal to Noise: Harmonic Temperaments and Patterns of Interference

by

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Submitted in partial fulfillment

of the requirements for the degree of

Master of Fine Arts in Integrated Media Arts, Hunter College

The City University of New York

May 2021

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Abstract

Signal to Noise is a collection of long-form microtonal sound compositions and corresponding audio-reactive videos. The project constitutes an audio/visual exploration of historical tuning systems and temperaments. Most contemporary Western audiences will seldom if ever encounter harmony outside of post-Renaissance tuning conventions. This material highlights some of those pre-orthodox harmonic relationships which existed throughout most of history, and continue to exist outside of the sphere of Western influence. This corresponding paper documents that history, as well as recent correlates in advances of acoustic ecology and sound as therapeutic intervention.

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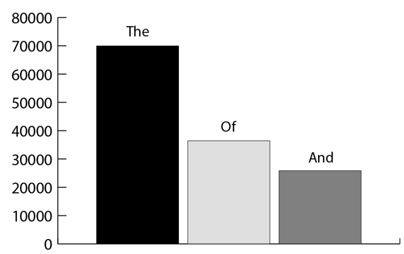
In 1935 an American linguist working at Harvard made a surprising discovery. The first few hundred words in any large body of text approximates an uncanny pattern of distribution: the second most frequently used word in a book appears roughly half as often as the first, the third most frequently used word appears roughly 1/3 as often, the fourth roughly 1/4 and so on. The linguist, George Zipf, was a polymath working across linguistics, philology, statistics, and sociology. He documented the statistical regularity, wrote a few books on it, and it was later popularized as Zipf's law.[1] It was found to be a Power Law which applies not just to collections of text, but likewise to language as it is spoken. The top ten words in the Oxford English Corpus are, in order of frequency: the, be, to, of, and, a, in, that, have, I.



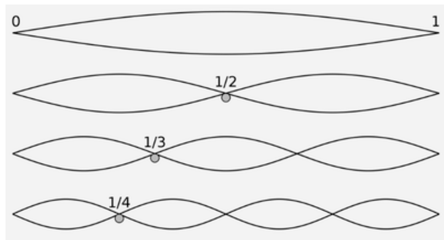
- word frequency in the Brown Corpus of English Text (fig. 1)

It was discovered later on that the distribution pattern persists across all languages, not just English, and that the phenomenon is not unique to language either.[2] Over the following decades it was shown to describe uniformity, along with the Pareto distribution model and others, observable in a variety of disparate phenomena, most famously the density of cities, but also cooking ingredients, protein

1 Eric W. Weisstein, "Zipf's Law," Michigan State University, May 26,1999, https://archive.lib.msu.edu/crcmath/math/math/z/z040.htm

2 Wentian Li, "Random Texts Exhibit Zipf's-Law-Like Word Frequency Distribution," *IEEE Transactions on Information Theory*, 38, no. 6 (1992): 1845 ; Radboud University, "Unzipping Zipf's Law: Solution to a century-old linguistic problem," Phys.org, AUGUST 10, 2017, https://phys.org/news/2017-08-unzipping-zipf-law-solution-century-old.html

sequences, neural networks, the number of people who die in wars, the diameter of craters on the moon, website traffic and rates of income inequality. It has been used to programmatically gauge public sentiment by analyzing posts to social media and to aid in the search for extraterrestrial life.[3][4] Furthermore, the graphic above should look familiar to musicians as well, as it reflects the harmonic series.[5]



f, 2f, 3f, 4f, 5f, 6f, 7f … (fig.2)

In the context of music, the harmonic series is a term given to the harmonics above a fundamental tone, be it an oscillating string, such as a piano string, or a resonating column of air, such as a flute. If you pluck a string it will oscillate back and forth, thereby disturbing the air around it and producing a pressure wave that reaches your ear. At that point the fibers in your ear mechanically respond to the air pressure and convert the energy into an electrical signal that your brain processes as an aural event. If a string were drawn tight, depending on the length, mass and tension, the string could be made to oscillate back and forth, cycling one hundred and thirty times per second, also know as 130 Hertz (Hz), or about one octave below the typical middle C. As this ideal string vibrates the waves that are produced travel back and forth creating transverse standing waves, with nodes and antinodes as pictured above. When the string disturbs the air around it we hear not only the fundamental wave (the C note at 130.81 Hz to be exact) but also this series of wave partials:

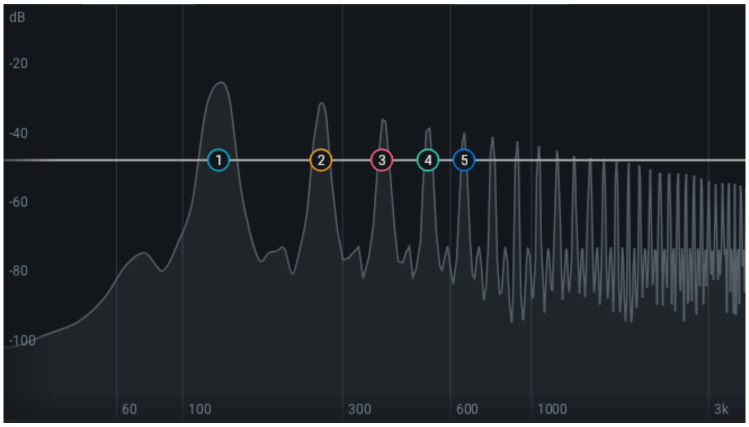
3 Peter Sheridan Dodds, "Zipfian Measurements," Principles of Complex Systems, University of Vermont, August 18, 2018, http://www.uvm.edu/pdodds/teaching/courses/2020-08UVM-300/docs/2020-08UVM-300zipfian-data-handout-optimized.pdf

4 Art Owen, "Discrete data analysis," Statweb, Stanford University, May 1, 2021, https://statweb.stanford.edu/~owen/courses/306a/

5 Ernie Croot, "Zipf," Mathematics, Georgia Institute of Technology, May 1, 2021, http://people.math.gatech.edu/~ecroot/popular_math/zipf.txt

$$\sum_{n=1}^{\infty} \frac{1}{n}$$

130.81 C 1
261.62 C 2:1
392.43 G 3:1
523.24 C 4:1
654.05 E 5:1



- harmonics of an electronic oscillator at 130.81 Hz (fig.3)

For the sake of clarity it might help to define some commonly used terms before moving on:

Fundamental = the lowest, typically loudest tone.
Partial = any single wave which makes up a complex sound.
Harmonic partial = any single wave which makes up a complex sound, and is also a member of the ideal harmonic series.
Inharmonic partial = any single wave which makes up a complex sound, and is not a member to the ideal harmonic series.
Overtone = any partial above the fundamental, typically used in the context of music and beginning with the second harmonic.

The volume, or amplitude, of these additional waves trails off lower than the fundamental tone, and their amplitude relative to the fundamental is determined in part by the design of the instrument. These overtones, and their variance, are what give the instrument or voice its timbre. Timbre is the unique quality which makes a sound identifiable and allows you to distinguish one sound from another. As shown above, the note "C" is repeated in the illustrated harmonic series multiple times, which helps to reinforce the fundamental wave or "*C-ness*" of the complex tone of the string. In some sense you could think of this complex tone as a chord unto itself, or a group of tones. Although some wind, metal, and glass instruments can get close to producing a sound wave with only a small number of partials, only an electronic wave generator can produce a pure wave, known as a sine wave, which would be a single tone. For acoustic instruments the ear combines the partials into a cohesive tone, and the distribution of partials represents the character of the tone, which you remember as the quality of someone's voice or instrument. This all plays a significant role in musical composition, orchestral arrangement, and instrument design, among other things. Clarinets for example tend to have strong odd harmonics, organs can manipulate their harmonics by way of opening and closing pipes, and likewise most instruments can be played in such a way as to emphasize or de-emphasize harmonic content.[6] Most importantly, a musical scale is itself created by approximating the individual overtones of the harmonic series in a diverse number of ways.

This paper will examine some of the implications of the harmonic series in the broader context of Western musical development and in the specific context of my own audio-visual work. The long-form microtonal compositions which I have presented in partial fulfillment of the Master of Fine Arts degree consist of studies of the overtone series, and are informed by the historic developments detailed in this paper. In my work I utilize electronic oscillators and analog modulation to construct harmony and dissonance in a variety of ways unlikely to be encountered in traditional musical settings. The corresponding audio-reactive videos serve as abstract visualizations of those harmonic relationships. The works that have been presented constitute an audio/visual exploration of historical tuning systems and temperaments. Most contemporary Western audiences will seldom if ever encounter harmony outside of post-Renaissance tuning conventions. This presentation of analog audio-visual material highlights some of those pre-orthodox harmonic relationships which existed throughout most of history, and continue to exist outside of the sphere of Western influence.

6 Rod Nave, "Closed Cylinder Air Column," HyperPhysics, Georgia State University, 2016, http://hyperphysics.phy-astr.gsu.edu/hbase/Waves/clocol.html

The example above (fig. 3) illustrates a clear mathematical relationship in the harmonics of a saw wave: the second harmonic partial is a doubling of the fundamental, and the fourth harmonic partial is a doubling of the second. When a tone is doubled it’s called an octave, and our ears sense the tones to be so similar that they are typically assigned the same note name due to their perceived consonance. This regularity of oscillations, the periodicity, is something that the ear seems to naturally gravitate towards. In fact studies have even shown evidence of prenatal cognizance of the interval of a 5^{th}.[7] Most music in the Western world has been organized around this principle, and we tune our instruments such that all of the other notes we use are distributed logarithmically across twelve discrete units within the octave, giving us the familiar twelve-tone scale. As may be obvious, this forces most of the notes and their overtones to be adjusted away from pure harmonic consonance with some of the other tones in order to fit within this division. In the case of Western tuning systems this sensation of the octave has been given precedence over the harmonic consonance of the other notes.

Inharmonicity can be defined as spectral interference.[8] Extreme inharmonicity is what is typically referred to as “noise.” Noise is a group of seemingly random pressure waves, and your brain assumes they contain no discernible information. If you have ever been in a crowded reverberant space, with sound waves bouncing off the walls in every direction, your mind can have a difficult time resolving the individual sounds and everything can become a wash. Alternatively, if you are at home and you hold a piece of paper up and strike it with your hand it will return pressure waves from the surface, but they are chaotic, with no obvious fundamental tone or uniform series of partials. That is because unless an object has been designed to resonate at certain frequencies it will sound as noise, an aural event seemingly devoid of a signal.

7 Richard Parncutt, “Prenatal and infant conditioning, the mother schema, and the origins of music and religion,” *Musicae Scientiae* 13, no. 2 (2009): 21.

8 Peter M. C. Harrison and Marcus T. Pearce, “Simultaneous Consonance in Music Perception and Composition,” *Psychological Review* 127, no. 2 (2020): 216-244.

Rhythm is the term we often use to describe a repetitive aural event below 20 Hz, which is to say it has a periodicity below 20 times per second. What we call the musical note 'C' is an aural pulse that occurs with a periodicity of 130.81 Hz, “A” is generally agreed to be 440 Hz in North America. The names are arbitrary and are an organizational convention, but our brains and ears have an astounding ability to pickup on very minute shifts in frequency. Maybe you've had a buzzing fan or some appliance that distracts you because its periodicity is right on the threshold of being a fast rhythmic buzzing or a slow low-pitched hum but your brain is unable to parse which it is. When it comes to light and color, most people cannot tell much of a difference between a 1% change in frequency, but a 1% change in pitch between two notes yields dramatic results, and taken together would sound like two notes slightly out of tune with each other, with the sound waves producing a type of phasing effect as the amplitudes rise and fall. One of the conventions used for thinking about this type of physical phenomena is the Weber Fraction, a system of categorization used to analyze our ability to perceive changes, which is to say how much something needs to change in order for us to notice that it has changed. Humans have a hard time processing sounds with an inter-onset interval smaller than 100ms, which is the point at which the time elapsed between events is smaller than 100ms. As that interval shrinks below 100ms the impulses start to blur together in our brain and we have a hard time separating them. That sensation peaks at about 50ms, which is about 20 Hz, the point which we commonly refer to as the bottom of the human hearing spectrum. At that point things become a "pitch" in our mind. The same repeating sound is there, but suddenly we hear a pitch forming around or beneath the periodicity of the aural event, and eventually the pitch overtakes the rhythm and firmly moves into the realm of a tone, well beyond our brain’s ability to distinguish between the individual pulses.

Harmony is when you have multiple pitches, or events, occurring at complementary ratios. As with the partials they cannot just be any assemblage of pitches, what harmony refers to is a group of pitches that relate to each other in specific mathematical ratios, otherwise the sounds are considered inharmonic, dissonant, “out of tune” in the typical sense. There are different methods for describing harmony, but the easiest one to understand is in terms of mathematic proportion. The periodicity of the sound waves must align to one another in specific ways to be heard as harmony: 3/2, 5/4, etc. is what the ideal ratios would be if the goal was to achieve pure, whole number ratios – what is known as "just" intervals. However that is often not possible on the fixed pitch instruments that have been developed over the past few hundred years. Most people can sing these whole number ratios, even if they don’t sing well. Were you to join a group of people who could sing properly you would likely be surprised at your ability to identify and reproduce the ratios. While the inner-ear is responsible for our sense of balance and equilibrium, our conscious positioning in space, the middle ear has an astonishing ability to process sound (pressure) waves mathematically on a granular level. Many of the earliest known musical instruments were in fact some form of resonating drone instrument designed to exploit this ability of the ear, and were often focused on the partials of a tone, constituting the instrument’s timbre.

Bone flutes, whistles, gourds and animals horns are among the most prevalent instruments of the Paleolithic era, and demonstrate the importance of overtones to early musical developments. Devices such as the bull-roarer and didgeridoo have been documented at sites worldwide dating back at least 20,000 years, and are two of the oldest known instruments. These are both instruments specifically designed to produce a drone, a sustained note, rich in overtones that the player can manipulate. In the case of the bull-roarer, a slat of wood is altered so as to produce a series of partials based on the carvings of the surface area. It is then attached to a cord and spun on an axis to accentuate certain overtones. In the case of the didgeridoo, breathing techniques are employed to cause a hollowed stalk to resonate at a certain pitch, and the breath is manipulated to produce complex overtones. The jaw harp, which uses the mouth as a resonator, likewise has a history dating back thousands of years, and in more modern times was documented as “the principal musical instrument for at least 21 ethnicities in

Russia, who occupy over half the territory of the country."[9] These and other early instruments were typically believed to have held a sacred place in prehistoric civilization, and in many instances a society's settings for religious and musical ceremony were often conflated and the instruments shrouded in secrecy. This disentangling of music and ritual is something of a perpetual task for archeologists and musical scholars.[10]

- various bull-roarers (fig.4)[11]

- Paleolithic bone flute (fig. 5)[12]

Likewise to scholars working in the field of acoustic archaeology the human ear is becoming recognized to have played an outsized role in establishing the myths and religious experiences of prehistoric people. "Men sang out their feelings long before they were able to speak their thoughts. But

9 Nikolsky Aleksey et al, "The Overlooked Tradition of 'Personal Music' and Its Place in the Evolution of Music," *Frontiers in Psychology* 10, (2020): 2.

10 Jeremy Montagu, "How Music and Instruments Began: A Brief Overview of the Origin and Entire Development of Music, from Its Earliest Stages," *Frontiers in Sociology* 2, (2017): 4.

11 Throwawayhack, *Bull roarers.jpg*, Wikimedia Commons, May 1, 2021, https://commons.wikimedia.org/wiki/File:Bull_roarers.jpg

12 José-Manuel Benito, *Flauta paleolítica.jpg*, Wikimedia Commons, May 1, 2021, https://commons.wikimedia.org/wiki/File:Flauta_paleol%C3%ADtica.jpg

of course we must not imagine that ‘singing’ means exactly the same thing here as in a modern concert hall.”[13] Twentieth-century archeological practices have made significant progress in the field of *archeo-acoustics*, which is the study of acoustic properties of prehistoric sites to better understand the development of man’s relationship to sound. While those working in this field have made most notable progress in analyzing theaters and temples of the ancient world, some of the lesser known contributions to the field are just as fascinating for those interested in matters of harmonic resonance.

In the Lanzón gallery of the Chaví de Huántar archeological site, circa 3000 BCE, it was discovered by a team at Stanford that the extensive tunnels of the site’s underground chamber resonate at a frequency near 300 Hz, closely matching the tone of the local *pututu* shells played by priests of the pre-Incan culture.[14] The shells, found scattered near the site, were believed to be played in the underground chamber, thereby allowing the tones to travel above ground via resonating ducts and be amplified in the ceremonial courtyard, swirling around those in attendance and causing omnipresent pulsations of sound. Similarly the now famous Chauvet Cave paintings in France are located at points of greatest acoustic resonance in the cave network, possibly in order to exploit the reverberations as sound effect during the relaying of myths.[15] Less known to the general public but of prime importance across the fields of history, archeology, and architecture, the UNESCO World Heritage site of the Hal Saflieni Hypogeum sits on the small island of Malta and predates the Great Pyramids at approximately 4000 BCE. Considered to be one of the oldest and best preserved prehistoric sites, the multi-level complex extends thirty feet below the ground, and upon discovery was found to contain dozens of

13 Otto Jespersen, *Language: Its Nature, Development and Origin* (United Kingdom: Routledge, 2015), 436.

14 Miriam A. Kolar, “Conch Calls into the Anthropocene: Pututus as Instruments of Human-Environmental Relations at Monumental Chavín ,” *Yale Journal of Music and Religion* 5, no. 2 (2019): 22-55 ; Miriam A. Kolar, “The Code of the Conch,” Nautilus, NautilusNext, October 17, 2013 https://nautil.us/issue/6/secret-codes/the-code-of-the-conch

15 Bruno Fazenda, “Cave acoustics in prehistory: Exploring the association of Palaeolithic visual motifs and acoustic response,” *The Journal of the Acoustical Society of America* 142, (2017); 1332-1349.; National Geographic Society Newsroom, “Rock Spirits at the Portals to Afterlife,” National Geographic, September 12, 2010, https://blog.nationalgeographic.org/2010/09/12/rock-spirits-at-the-portals-to-afterlife/ ; Iegor Reznikoff, “Sound resonance in prehistoric times: A study of Paleolithic painted caves and rocks,” *The Journal of the Acoustical Society of America* 123, no. 5 (2008):3603

mutilated and deformed skulls thought to belong to a religious order.[16] The site is especially notable for the acoustics of its Oracle Chamber, from which low-pitched male voices travel out into highly-resonant passageways, reverberating into rooms throughout the complex believed to be designed for ceremonial sound propagation.[17]

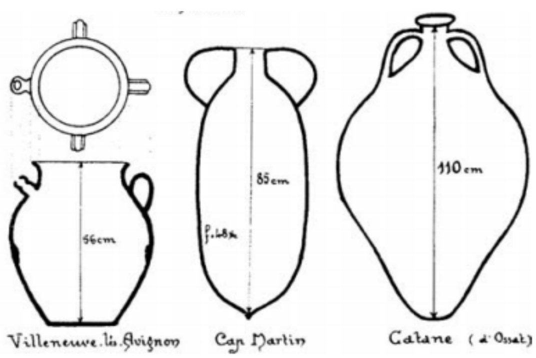
- famous deformed Maltese skulls
of Hal Saflien (fig. 6)[18]

At Stonehenge, a site of perennial speculation, many researchers have likewise posited that the setting was designed to highlight the psychoacoustic properties of the architecture, with researchers documenting diffuse sonic interference patterns which some believe to have been a fundamental ceremonial component.[19] Although the field of archeo-acoustics continues to make progress, questions of use and intent are difficult to prove conclusively in prehistoric study. More definitive case studies have been made of the resonances, interference patterns and diffraction at the Theatre of Epidaurus,

16 Anton Mifsud and Simon Mifsud, "The subterranean sanctuary at Ħal Saflieni," *Facets of Maltese Prehistory*, (1999): 149-168.
17 Ibid. ; Paolo Debertolis et al, "Archaeoacoustic Analysis of the Hal Saflieni Hypogeum in Malta," *Journal of Anthropology and Archaeology* 3, no. 1 (2015): 59-79.
18 Melanie Drury, "Why are these elongated skulls at Hal Saflieni Hypogeum shrouded in mystery?," Guide Me Malta, March 13 2021, https://www.guidememalta.com/en/why-are-these-elongated-skulls-at-hal-saflieni-hypogeum-shrouded-in-mystery
19 Rupert Till, "Songs of the stones: the acoustics of Stonehenge," *Journal of the International Association for the Study of Popular Music* 1, no. 2 (2010): 1-18.

which scholars believe inspired later designs of the Greek odean.[20] Likewise in more modern times we can find similar considerations of sound treatment built into better documented religious settings of the middle ages, right down to the present day.

Worldwide from the Noyon Cathedral in France to the Church of St. Nicholas in Russia architects have for centuries incorporated the treatises of the Roman architect Marcus Vitruvius and, unknown to most parishioners, included methods for a variety of vases, vessels, and jars to be built into church walls to serve as resonating chambers as a way of “tuning” the spaces to the desired harmonic content.[21] There are likewise numerous architectural correlates in the musical developments succeeding the Early Middle Ages, when contemporary musical documentation began in earnest.



- drawings of acoustic vases (fig. 7)[22]

20 Philip Ball, “Why the Greeks could hear plays from the back row,” *Nature*, Springer Nature, March 23, 2007, https://www.nature.com/news/2007/070319/full/070319-16.html

21 Benedicte Bertholon, “Acoustic Pots in Ancient and Medieval Buildings : Literary Analysis of Ancient Texte and Comparison with Recent Observations in French Churches,” *Acta Acustica United With Acustica* 99 (2013): 70–81 ; Panagiotis Karampatzakis et al. 2011. "A study on Aristoxenus acoustic urns" The Acoustics of Ancient Theatres Conference, Patras, September 18-21, 2011, http://ikee.lib.auth.gr/record/127577/files/A%20study%20on%20Aristoxenus%20acoustic%20urns.pdf ; Marc Crunelle. 2011. “There an Acoustical Tradition in Western Architecture?” Institut Supérieur d’Architecture Intercommunal, Brussels, http://www.wseas.us/e-library/conferences/skiathos2001/papers/102.pdf ; Adrienne Lafrance, “Hearing the Lost Sounds of Antiquity,” The Atlantic, February 19, 2016, https://www.theatlantic.com/technology/archive/2016/02/byzantine-angel-wings/470076/

22 Andrew Tallon, “Acoustics at the Intersection of Architecture and Music: The Caveau Phonocamptique of Noyon Cathedral ,” *Journal of the Society of Architectural Historians* 75, no. 3 (2016): 263–280.

Medieval frameworks for the understanding of sound were inherited from the Romans, who inherited their musical traditions from the Greeks, who in turn considered music to be a marriage of mathematics and art, and it is here that we find the origins of many of the foundational texts of Western music theory. Musical practices were flourishing in the west up until the fall of Rome, at which point artisan instrument makers declined in number drastically, and communities became isolated and impoverished. Throughout this period however religious institutions remained relatively stable, and the power of music as a tool of prayer and meditation was recognized and incorporated into religious practice. This Christian plainchant, often referred to as Gregorian chant, evolved throughout the Dark Ages as the roots of modern musical notation began to form. Early on this vocal music was strictly unaccompanied, owing to the perception that instruments held connotations of paganism and secularism. But as in earlier pagan eras the *a capella* music was significantly affected by church architecture, and the harmonic resonance and interference patterns functioned as components of an omnipresent sound design similar to what has been observed at ancient ceremonial sites.

Gregorian chants were traditionally single line, monophonic melodies sung in unison, at the time polyphony was considered something which unnecessarily complicated the texts, which were considered sacred. As with contemporary unison plainchant, the phasing of the different voices and their overtones provided the style with its characteristic sound. Around 800 AD the inclusion of young boys with higher voices, and later classes of *castrati*, meant that groups would begin to include the octave as a drone, but the melodies were still constrained to only eight notes.[23] In many ways the sacred music of the era was a culture of constraint, and the vast majority of the compositions were authored anonymously as a dedication to the church. Only later do we begin to see individuals emerge with progressive musical innovations: *organum* often employed a parallel voice transposed down, whereas *melisma* incorporated the spreading out of syllables over several notes, and later holding one note over

23 The *castrati* were a class of male singers who had been castrated in order to prevent them from reaching sexual maturity, so as to maintain a higher vocal register.

several notes which developed into a mixture of drone and parallel lines. There was some effort made to codify and define these organum and proto-polyphonic developments in a pair of anonymous treatises of the ninth-century known as the *Musica Enchiriadis* and *Scolica Enchiriadis*. Again it might help to define some terms before moving on:

Monophony = one melody, sometimes in octaves, typical of Gregorian plainchant
Heterophony = two or more versions of one melody sounding simultaneously
Polyphony = multiple melodies sounding simultaneously

Until around 900 CE the monks and nuns working on musical pieces had a minimal amount of textual musical direction to rely on, there was no musical notation in the modern sense. One of the oldest surviving musical texts, the *Winchester Tropa*, offered only relative pitch information, and served primarily as a mnemonic aid to the performer. Pieces were memorized, or improvised, and the role of the musician was a specialized job, often requiring feats of musical prodigiousness by modern standards. Some of the earliest symbols of musical notation, nuemes, primarily indicated syllables, not pitch information, as the text itself was of primary importance, pitch secondary. Guido of Arezzo began development on the modern form of musical notation at the turn of the tenth-century by formalizing the long-running oral traditions with multi-line staffs, meaning that pitches no longer needed to be recorded as relative to a single melody, thereby allowing for more complex musical structures. Around this time the physical structure of the church began to change as well, moving from Romanesque places of worship to the iconic Gothic architecture of the era. Choirs were being repositioned and experimented with in service of sound conductivity and intelligibility: as the church grew in a physical sense so too did the reverberation of the space. The groin vault style of Gothic cathedrals offered a significantly more expansive musical setting than the barrel vault style of Romanesque architecture, sometimes inspiring polyphonic innovation.

"The Gregorian chants sung in the cathedral in medieval times were monophonic, featuring only one note at a time. But the drawn-out acoustics meant that consecutive notes and partials tended to overlap."[24] With diffraction now playing an outsized role in the unique sacral sound of Gothic cathedrals devotional music was increasingly blurring the lines between intelligible sacred speech and abstract song, often to the consternation of church leaders. Nevertheless, under the guidance of the composers Léonin and Pérotin liturgical polyphonic music began developing in earnest in the cavernous spaces of the Cathédrale Notre-Dame de Paris. Whereas permissible sacred harmonies of the past had relied on the octave, perfect 4th, and perfect 5th, these new works began incorporating additional melody lines, exploring dissonance and more adventurous rhythm. Over the next century innovations in permissible harmonies would come to the forefront: with John Dunstable's notable use of the imperfect 3rd sacred music was becoming more affective and increasingly stylized to the lyrical content. At this point most people in Europe were still primarily encountering music in church settings. But with improvements in material conditions and instruments becoming more commonplace troubadours were popularizing alternative forms of music, with Arabic styles and instruments making their way to Western audiences. By the time of the Reformation Martin Luther, himself a composer, was collecting folk songs and repurposing chorales and hymns in service of the church, a lasting hallmark of Lutheranism. Shortly thereafter counter-reformation forces at the Council of Trent would attempt to decouple the increasingly complex musical settings from devotional music, arguing that these developments constituted manipulation and an abuse of sound as an art form. They sought to reduce musical harmony back to its more simple, earlier consonance.[25] But by this point the richness of the harmonies could not be contained. Composers, partly inspired by the sonic nuances of St. Mark's Basilica in Venice, were increasingly experimenting with the diffusion of sound. By repositioning choirs they found ways to exert greater control over the harmonic content of the music as it rang out through the resonant chambers of the cathedral, bouncing off surfaces and arriving at listeners' ears at

24 Emily Conover, "How to restore the legendary acoustics of Notre Dame," Science News, January 12, 2020, https://www.sciencenews.org/article/notre-dame-cathedral-fire-legendary-acoustics-restoration

25 K. G. Fellerer and Moses Hadas, "Church Music and the Council of Trent". *The Musical Quarterly* 39, no. 4 (1953): 576.

different rates. This in turn created a new spatial awareness in which to situate parishioners, unifying them to their surroundings and to the cosmos in a new compositional style which became known as Venetian Polychoral. Today, scientific work is being conducted in the field of Heritage Acoustics as painstaking methods are employed to electronically recreate some of the acoustic spaces that helped define this era of musical experimentation, with notable modeling being done of the once grand but now decrepit St. Mary's Abbey in York, abandoned during the Dissolution of the Monasteries under Henry VIII, and more recently the fire damaged Cathedral of Notre Dame, among others.[26] While modern-day researchers are hoping to digitally reconstruct these sonic spaces and gain insight into the harmonic fingerprint of medieval music, interest in the construction of the harmony itself likewise resurfaced in the twentieth-century, with new tools to aid researchers and artists.[27]

"Some new properties of strings will always be found if one takes the trouble of examining them in all possible ways."
\- Marin Mersenne, 1636 CE

It must be stated here that musical tuning is a complex and multi-faceted concept which cannot be encapsulated in the scope of this paper, and generalizations will be made. In different times and different cultures tuning conventions have been understood in radically different ways. While tuning theory should be considered as a dynamic and malleable field, one constant that is generally agreed upon is the universal recognition of the octave as a consonant, stable interval. Thus a tuning system can generally be considered by the way in which it divides the octave, and constructs harmony by sounding together two or more tones with some degree of mathematical precision. (Although even that has been occasionally disputed.)[28] Dividing the octave is typically an easy task even for those lacking musical

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26 "Recreating the sound of a sixteenth century abbey in York," University of York, May 11, 2015, https://www.york.ac.uk/research/themes/sixteenth-century-acoustics/

27 Inbal Shapira Lots and Lewi Stone, "Perception of musical consonance and dissonance: an outcome of neural synchronization." *Journal of the Royal Society* 5, no. 29 (2008): 1429-34.

28 Elena Renken, "Perceptions of Musical Octaves Are Learned, Not Wired in the Brain," Quanta Magazine, Simons Foundation, October 30, 2019, https://www.quantamagazine.org/perceptions-of-musical-octaves-are-learned-not-wired-

training, but for non-musicians issues of tuning theory can become obfuscated by musical terminology and the underlying mathematical formulas, so efforts will be made to keep the explanations concise and accessible.

Dating back to the ancient world certain matters of musical harmony were not strictly the domain of musicians, and were more often debated across scientific disciplines. Whereas today an inquiry may fall to a specialized branch of science, in antiquity advancements of tuning theory were made in the realms of philosophy and mysticism. At the start of this paper there was a description of the harmonic series and an explanation of overtones, but that is not what is generally tuned to in modern Western musical settings. The prevailing tuning system is that of twelve-tone equal temperament (12TET) which divides the octave into twelve equally spaced tones, a method which maintains the consonance of the octave and offers its own conveniences, but is considered to compromise all other harmonic relations.[29]

1/1   196/185   55/49   44/37   63/50   578/433   99/70   433/289   100/63

- approximate equal temperament ratios, for illustrative purposes only[30]

If one were to attempt to tune a twelve note piano, for example, for use in the key of C using only the harmonic series to construct intervals the resultant spacing of the notes would only be useful to the key of C, and would need to be reset for other key signatures. Most tuning methods seek to "temper" out these differences by dividing the octave equally, so that all of the intervals are slightly impure but as a whole remain usable across keys signatures and still approximate the harmonic series. It's important to reiterate here that these issues of musical temperament have primarily been relevant to the development

in-the-brain-20191030/ ; Bernhard Wagner et al, "Octave equivalence perception is not linked to vocal mimicry: budgerigars fail standardized operant tests for octave equivalence," Behaviour 156, no. 5-8 (2019): 479-504.

29 The applicable formula is $f=fo\times(21/2)n$

30 Harry Partch, *Genesis Of A Music*, (Boston: De Capo Press, 1979), 101.

of music in the West. In Middle Eastern, Indian, and Asian cultures a much greater effort has been made to maintain the pure harmony of intervals at the expense of the labor required to retune, and the constraints of key modulation. This will be discussed more later. In the Western canon, musical theory can be indirectly traced to theoretical approaches argued by many of the well-known Greek philosophers.[31] Whereas music and acoustics have today been spun off into their respective fields, in antiquity music was considered as much a science as an art, and mathematical theories often had an ethical and sensual correlate[32]. One figure that stands out early in musical history is Pythagoras, whose study of tuning was highly influential, not just on the science of sound but on how musical harmony was to be performed.[33] Although much of Pythagoras' own history is shrouded in myth one of the many lasting contributions he made to the field of music was the Pythagorean tuning system, which was modeled on his conception of celestial motion and constructed from stacking perfect 5th intervals. While useful in its time this ultimately resulted in something known as the Pythagorean comma, which is a dissonance inherent to the formula as one attempts to repeat the equation twelve times, and reaches an irrational number seven octaves higher where one would expect a consonance.

1⁄1 9⁄8 81⁄64 4⁄3 3⁄2 27⁄16 243⁄128 2⁄1

- a major scale in Pythagorean tuning[34]

Pythagorean tuning was one component of a number of musical innovations at the time considered to be sacred knowledge of the universe, and was protected by a cult of followers who charged that this

31 Stuart Isacoff, *Temperament: How Music Became a Battleground for the Great Minds of Western Civilization*, (New York: Vintage, 2003), 5.

32 It's important to note here that while use of the term "natural" has been problematic throughout history it is employed here in relation to mathematical consonance, regardless of any ethical correlates, which were frequently implied."Pure" in a musical sense does not mean better.

33 There are many important philosophers and theorists who made significant contributions to the field of musical tuning, this survey will by necessity be brief and unfortunately leave many of them unmentioned.

34 Harry Partch, *Genesis Of A Music*, 101.

dissonance was a discordance of the natural world, to be illuminated upon initiation into the cult's pure understanding. This strict quasi-religious adherence to Pythagorean theory would have a surprising lifespan, and continue to be propped up by church leaders well into the Renaissance.

After Pythagoras' death Plato would take up the issue of tuning, arguing that harmonious music was indeed a matter of divine importance. Portraying it as a manifestation of universal beauty accessible through mathematics, he believed that musical intervals should reflect the orbits and cycles of the natural world. For Plato, harmony should be understood as corresponding to the development of mankind, and its evolution should be a primary concern of political leaders interested in the mental and physical well-being of their society.

This model of Pythagorean tuning remained predominant in the west until medieval times, as from the fifth-century BCE onwards successive schools of philosophy frequently took on the issue of musical tuning and advocated for their own unique system, which likewise offered advantages and disadvantages in efforts to minimize the dissonances that occur when formulating a temperament. Picking up on these efforts Ptolemy, in his second-century CE treatise *Harmonics,* argued that musical intervals should be based on the simplest ratios in order to avoid a harsh clashing of tones. Along with Pythagoras these two philosophical approaches were in general terms the basis of the competing theories to come.

1/1 9/8 5/4 4/3 3/2 5/3 15/8 2/1

- Ptolemy's intense diatonic scale[35]

Nearly 1000 years after its inception, Pythagorean tuning was given new life in the sixth-century CE by the Roman statesman and philosopher Anicius Manlius Severinus Boethius, a devotee, who

35 Ibid., 165.

likewise promoted a theory of universal harmony, arguing in his treatise *De institutione musica* that musicians should follow the dictates of Pythagorean tuning conventions to maintain order:

> "These were music's concordances—the covenants that tones form under heaven's watchful eye. For the Pythagoreans...the importance of these special proportions went well beyond music. They were signs of the natural order, like the laws governing triangles; music's rules were simply the geometry governing things in motion: not only vibrating strings but also celestial bodies and the human soul."[36]

This deference to the earlier Greek philosophies on tuning would serve to stoke the debate well into the Enlightenment as the issue roiled European theorists. It's worth briefly noting here, and it's often overlooked, that Boethius had also posited that the intellectual study of music was superior to that of composition and performance, a point that notably contradicts one of Platos' other assertions that music, as with any endeavor, is most beneficially approached by both the body and mind working in tandem. It's worth noting because this oversight in the matter of theory versus practicality would later become much more important to the developments of tuning and harmony as the concepts evolved and decisions regarding standardized tuning systems were made at the end of the Enlightenment.

As English influence spread across Europe at the close of the Hundred Years' War so too did English triadic harmony. With John Dunstable and other leading composers making use of the imperfect 3rd it became clear that the Pythagorean method of tuning, which Boethius had strongly advocated for, would need to be altered to accommodate the shift in tastes among nobility. This widespread use of the imperfect 3rd, considered dissonant in Pythagorean tuning, would reignite arguments both sacred and profane.

This era in tuning history is often misrepresented, and I hope to clarify it here.[37] Pythagorean tuning had been prevalent into the Middle Ages, due in large part to the writings of Boethius. As previously noted, at the turn of the millennium Ptolemy had already advocated for a method of tuning

36 Stuart Isacoff, *Temperament*, 38.
37 Likewise please note the index entry for "Ramis de Pareja" in Partch's *Genesis of a Music*, p.513

based on smaller, just ratios: he promoted greater consonance in the 3rd and 6th intervals. However, Boethius was devoted to the Pythagorean school, and in his canonical writings had misrepresented the work of Ptolemy to a degree. By the fifteenth-century, as composers were pursuing greater explorations of harmony, a leading theorist of aristocratic descent by the name of Franchinus Gaffurius had taken up the issue. Like Boethius, Gaffurius was devoted to Pythagorean philosophies of harmony, and continued the tradition of promoting them in his own work, unaware of the errors in Boethius' own writing.[38] However, another theorist and mathematician, Bartolomé Ramos de Pareja had read Boethius and arrived at different conclusions. In 1482 Ramos paid deference to the work of Boethius but proposed a practical tuning method of just intonation, similar to Ptolemy's diatonic tuning model.[39] This was vigorously opposed by Gaffurius and others, and even after he had encountered a faithful reproduction of Ptolemy's work in translation (this being absent from Boethius' writings) Gaffurius could not bring himself to break with Pythagorean tradition.[40] Nevertheless, in short time the methods of Ptolemy would come to be known through Ramos' advocating. "Gaffurio's opponents…grasped at this ancient authority and not only confronted him with it but started a groundswell that eventually led to the adoption of Ptolemy's 'syntonic' or 'intense' diatonic tuning as the ideal system," which would later be adopted into the "most widely read musical textbook of the sixteenth-century."[41]

"You can't criticize geometry it's never wrong." – Paul Rand

Just ratios are what the ear and voice naturally gravitate towards, and what is observable in the harmonic series. But to break with the predominate metaphysical philosophies of Pythagoras' conception of harmony was considered sacrilegious, and, somewhat ironically, was seen as a reflection

38 Claude V. Palisca, *Music and Ideas in the Sixteenth and Seventeenth Centuries* (Champaign: University of Illinois Press, 2006), 140-142.
39 Claude V. Palisca, "Humanism and Music," in *Renaissance Humanism, Volume 3 Foundations, Forms, and Legacy*, ed. Albert Rabil Jr.. (Philadelphia: University of Pennsylvania Press, 1988), 460-461.
40 Ibid.
41 Claude V. Palisca, *Music and Ideas in the Sixteenth and Seventeenth Centuries*, 142.

of the science of music deteriorating into the profane. This was ironic because where conservative thinkers had admonished the break from Pythagoras just intonation was, mathematically speaking, actually in greater accordance with nature than its predecessor. Where Pythagorean tuning maintained the consonance of the octave, 4th, and 5th the system of just intonation went one step further tempering out additional intervals of the 3rd and 6th. There remained however the problem of key modulation on fixed pitched instruments, which were cautiously being adopted into church music and putting into stark relief the problems inherent to both just intonation and Pythagorean tuning.

1/1 16/15 9/8 6/5 5/4 4/3 64/45 3/2 8/5 5/3 9/5 15/8 2/1[42]

- chromatic scale based on Ramos' *Musica practica*

Whereas for Greek theoreticians practicality in music was often secondary to theory, by the fifteenth-century matters of practicality were being brought to the fore as specialized workers were making available fixed pitch instruments at an increased rate, and often wading into the debate inadvertently: as arguments continued to unfold temperaments were being employed as a matter of convenience. There exists a theoretically infinite number of temperaments, as many ways as there are to divide the octave or comma, and leading intellectuals made their deliberations known. The father of Galileo Galilei, Vincenzo Galilei was a rare early advocate of equal temperament, and composed collections of music demonstrating consonant use of a range of key signatures and extended chord voicings. Tuning all intervals to be slightly dissonant was one option, but another option was to tune so that some intervals were pure and some dissonant. In equal temperament the pythagorean comma of 24 cents was essentially divided up and removed from the 5th to keep semitones an equal distance apart.

42 Diana Margarita Allen Schrader, "Altercatio musicorum: a discussion of the polemical reactions to Ramos de Pareja's Musica practica," (The University of Arizona, 1977). ; Bonnie J. Blackburn, "Music Theory and Musical Thinking After 1450," *Music As Concept And Practice In The Late Middle Ages*, ed. Reinhard Strohm and Bonnie J. Blackburn. (Oxford: Oxford University Press, 2001), 317.

Another type of comma, the syntonic comma, is defined differently but comes out to around 22 cents, and quarter-comma meantone was one popular temperament which divided the comma and likewise removed it from the 5th, leaving some intervals pure and some dissonant, which composers could then select for expressive purposes. Over the next hundred years a number of meantone temperaments would see widespread adoption, becoming the *temperament ordinair* as they represented a somewhat unendearing compromise between just intonation and equal temperament.[43] The meantone convention remained in use for sometime but was acknowledged to be equally problematic and was merely accepted as a practical solution.[44]

1/1   107/100   559/500   11963/10000   5/4   107/80   14311/10000   8/5   16719/10000   17889/10000   4673/2500   2/1

- approximation of 12-tone ¼ comma meantone ratios,

for illustrative purposes only [45]

As music became increasingly chromatic the issue of key constraint was becoming intolerable, and just intonation was likewise becoming impractical to modern instruments and musical tastes, even though theoreticians still favored it. Johannes Kepler, well known for his theories on orbital motion among a vast array of other scientific advancements, was an outspoken advocate of just intonation. In his five-part magnum opus *Harmonices Mundi* Kepler dedicated an entire section to theories of musical harmony and how they relate to the harmonic patterns of nature. In hindsight many philosopher-scientists throughout history had been overzealous in relating cosmic motion to musical harmony, and in this regard Kepler was no exception. To that end he had calculated the minimum and maximum

43 Meantone temperaments are a significant part of tuning history but will not be covered here in depth.

44 Noel David Hudson, "Abandoning nature: European philosophy and the triumph of equal temperament," (University of Massachusetts Amherst, 2007) 17.

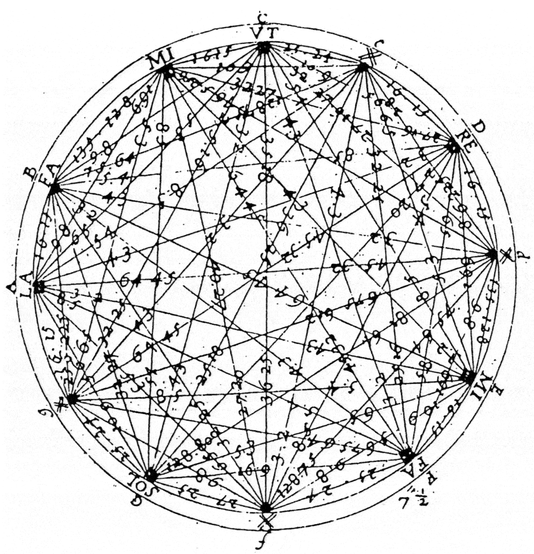
45 These ratios are approximations of ¼ comma meantone as many meantone intervals can only be expressed with irrational numbers, more formulas can be viewed here http://www.peterfrazer.co.uk/music/tunings/temperament.html

orbital speeds of planetary bodies and correlated them to just intervals.[46] It's worth noting here that in contemporary times this has contributed significantly to what can only be described as a subset of New Age pseudo-science advocating the sonic reorganization of everything from tonal harmony to the dial-tones of the telephone system. It's worth noting briefly for two reasons: the first is that many of Kepler's calculations contained errors or were likewise contextualized improperly.[47] If the oft-referenced *musica universalis,* or music of the spheres, were to be tied to a greater cosmic order one would expect it to be precise. This is not meant to dismiss or denigrate the hypothesis of universal harmony, just to clarify that even Kepler, who succeeded in bridging the works of Copernicus and Newton, was himself prone to error and capable of making clumsy analogies of the divine. But whether or not mathematically pure harmonic intervals were reflected in the heavens meant increasingly little to mankind and earthbound music. While Kepler would continue to advocate for the use of just intonation he ultimately acknowledged that temperaments for fixed pitch instruments were a "mechanical" inevitability, though he cautioned that they would be "ruinous" to man.[48]

Far less accepting of the proliferation of equal temperament was René Descartes. While Kepler's views on just intonation have remained more notable in contemporary times for the aforementioned reasons, Descartes likewise believed temperament to go against natural law, and even took on the issue in his very first book, *Musicæ compendium,* comparing it to the geometry of a building whose architect made compromises that may not be noticed by laypersons but were wrong and dangerous all the same. This sentiment would find unlikely support after his death in the work of Jean-Philippe Rameau. Known in France as the "Newton of Music," Rameau was actually a proponent of equal temperament. But in his efforts to discern a natural rationale for harmony he conducted experiments which would demonstrate that indeed nature favored just intonation. By positioning a vibrating string near

46 Stuart Isacoff, *Temperament*, 154-155.
47 Ibid., 133, 160.
48 Noel David Hudson, "Abandoning nature," 19.

sympathetic strings Rameau would conclusively demonstrate the importance of overtones on what he termed the "sonorous body," a fact that had been posited going back to ancient times. The sympathetic strings resonated with the fundamental and rang out at intervals of a 3rd and a 5th, and the mysteries of consonance began to unravel. The work of Marin Mersenne and Joseph Sauveur would scientifically describe harmonics and provide proofs in support of a number of others who had sought ways of explaining the clashing, "beating" dissonance of imperfectly tuned intervals and their effect on the timbre of a sound.[49] They would each devise their own preferred methods of tuning and harmony, but henceforth just intonation could be considered a basis of harmonic consonance, often referred to as the "chord of nature," and Sauveur would coin a term for the scientific study of sound: *acoustics*.[50]



- Mersenne's diagram of harmony, 1648 (fig. 8)[51]

The remainder of this paper could easily be spent dissecting the competing theories, systems, contradictions, discoveries and debates that followed, but for our purposes it's sufficient to make note of the attendant controversy and leave off there. The preceding history has mainly highlighted

49 Thomas Christensen, *Rameau and Musical Thought in the Enlightenment*, (Cambridge: Cambridge University Press, 2004), 135-136.

50 Sauveur preferred a 43EDO scale similar to 1/5 comma meantone.

51 Kellen Griffiths, "Decoding Music," Scalar, University of Southern California, May 5, 2015, https://scalar.usc.edu/works/decoding-music/patterns-that-we-like

convenient pivots in the evolution of tuning in the Western world, and left out the at times lengthy and vitriolic exchanges of the aforementioned figures. Further mathematical proofs and acoustic demonstrations would be presented in the seventeenth and eighteenth centuries by leading mathematicians and theorists of the era, and the question of temperament would thereafter be one of practicality and aesthetics. Concepts of pure intonation and previous harmonic theories had been justified according to natural behaviors witnessed in the overtone series. But in spite of this, just intonation as a tuning method remained nevertheless impractical for the needs of seventeenth-century musicians.

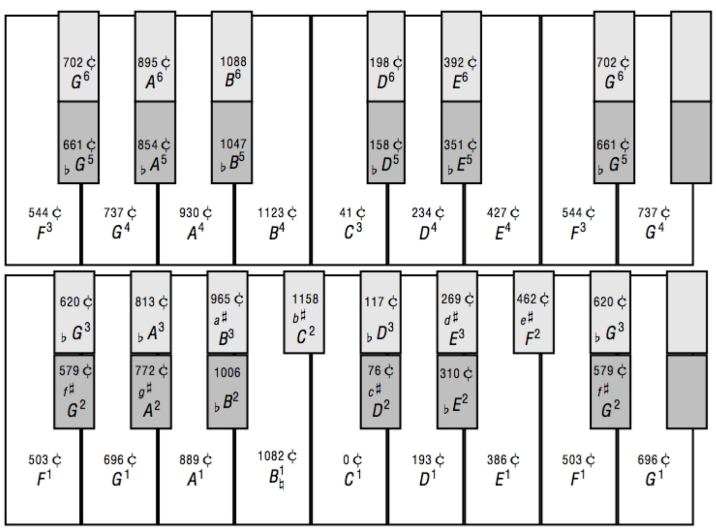
With the proliferation of temperament practicality would carry the day. Johann Sebastian Bach would compose one of the most famous works in the Western canon, *the Well-Tempered Clavier*, a collection of keyboard pieces in each of the twenty-four major and minor keys, demonstrating the power of temperament[52]. With its success, public exposure to alternative methods of tuning was rapidly narrowing at the end of the Enlightenment.

- example of a 19EDO keybed (fig. 9) [53]

"Abstract and manmade harmonic conventions regarding the tonic key-centers had a physical embodiment in meantone temperaments. By 1800, this physical embodiment was gone."[54] The conveniences and proliferation of twelve-tone equal temperament allowed the complexities of harmony

52 "Well-temperament" typically represented some degree of custom temperament.
53 Grant O'brien. "The Single-Manual Italian Harpsichord In The Royal College Of Music, London, Cat. No. 175: An Organological Analysis," Claviantica, 2008, http://www.claviantica.com/Publications_files/Guarracino_RCM175_files/Guarracino_RCM175.htm
54 Noel David Hudson, "Abandoning nature," 51.

to be forgotten, and to the general public equal temperament would no longer be understood as an artificial construct, a dissonant compromise or work in progress, but would be considered the de facto tuning standard. It would fundamentally shape the music of the next 200 years, making chromaticism possible in ways unprecedented. “Whereas thinkers from Pythagoras to Descartes had first codified the just proportions of nature and then used these as a prescription for musical practice […] Rameau began with the question of what humans need to do with music […] In Rameau's theory of temperament, the needs of artistic man had overcome the dictates of nature.”[55] One can imagine a pantheon of philosophers, astronomers, religious figures, and composers contextualizing this as a fall from grace, but their arguments had been laid to waste by the inevitable rationalization of labor, which was producing fixed pitch instruments at a scale previously unimaginable, and the ensuing democratization of musical practice.



- example of historical enharmonic keybed (fig. 10)[56]

55 Ibid. 36.
56 Lunlunta99, *Archicembalo en Cents.jpg*, 2007, Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Archicembalo_en_Cents.jpg

Historic keybed designs abandoned after equal temperament

- 31EDO Guido Trasuntino keybed design (fig. 11) [57]

- 53TET keybed (fig. 12)[58]

- Archicembalo (fig. 13)[59]

- enharmonic organ (fig. 14) [60]

57 Frederick Hammond, *Trasuntino instrument*, Girolamo Frescobaldi, accessed May 1, 2021, https://girolamofrescobaldi.com/11-frescobaldis-instruments/

58 *Bosanquet's Enharmonic Harmonium*, Science Museum Group, accessed May 1, 2021 https://collection.sciencemuseumgroup.org.uk/objects/co5865/bosanquets-enharmonic-harmonium-musical-instrument-harmonium

59 *Tonraum30.11-14 1.jpg*, Wikipedia, accessed May 1, 2021, https://en.wikipedia.org/wiki/File:Tonraum30.11-14_1.jpg

60 J. Robson and Co, *Keyboard for General Thompson's enharmonic organ*, Science Museum Group, accessed May 1, 2021 https://collection.sciencemuseumgroup.org.uk/objects/co5873/keyboard-for-general-thompsons-enharmonic-organ-component-musical-instrument

At this point in our survey it's worth noting two things. The first is what we haven't covered. Absent from this study has been any consideration of the evolution of tuning theory as reflecting a change in outmoded conceptions of ethics and morality as being intertwined with science; nor has the convention of using twelve notes per octave been examined; nor a suitable history of meantone, enharmonic or pitch standards; likewise the supposed duality of major and minor keys; nor alternative developments in instrument making outside of the Western sphere of influence. This has been a brief overview of some of the key concepts informing my own interests and motivations, and has been written in order to provide some background on my work and thought process, constraints of time and space have dictated what has been included here. The second thing to note is that this is where many surveys of tuning and temperament conclude, often with some reference to the soaring chromaticism of Richard Wagner's *Tristan und Isolde* (1865), the dissonance of Igor Stravinsky's *The Rite of Spring* (1913), or the twelve-tone work of Arnold Schoenberg. On the contrary our examination will continue on and offer a brief appraisal of what I would call a twentieth-century renaissance in microtonality, and highlight some work in a lineage akin to my own.

> *"Whoever, in the pursuit of science, seeks after immediate practical utility may rest assured that he seeks in vain."* - Hermann von Helmholtz, 1862[61]

Although many professional ensembles continued to use a variety of temperaments for historically accurate performances, and the debates regarding tuning continued on, by the end of the nineteenth-century the issue had mostly been relegated to a subset of musical theorists with few exceptions.[62] But by the 1920s the matter would come to the attention of one young composer who would reject equal temperament unconditionally and set the course for a renewal of interest in tuning methods. Harry Partch, who became convinced of the primacy of just intonation after reading

61 Frederick E. Brasch, "History of Science," *Science* 55, no. 1410 (1922): 408.

62 Daniel K. S. Walden, "Emancipate the Quartertone: The Call to Revolution in Nineteenth-Century Music Theory," *History of Humanities* 2, no. 2 (2017).

Helmholtz's wide-ranging scientific tome on acoustics and music, would turn his focus to exploring alternative tunings for the next several decades. In that time Partch embraced a 43-tone division of the octave which became a hallmark of his work, further devoting considerable amounts of time to building his own instruments, a massive collection of microtonal instruments which had become key to his performances. His unique, singular vision would serve as an inspiration for later generations, and his enormous professional output is something that is difficult to comprehend having often served as an itinerant worker and later surviving on grants. Partch's work remains an entry point for many into the world of microtonality, myself included.

Working within the constraints of equal-temperament, the French composer Olivier Messiaen (1908-1992), in his extended chromaticism and focus on harmonics and acoustic resonance, was likewise a personal entry point to the world of sound that exists between the notes of fixed-pitch instruments. His use of tone clusters and quarter tones, along with the work of Charles Ives (1874-1954) and Thelonious Monk (1917-1982), was an early inspiration. The composers Henryk Górecki (1933-2010) and Krzysztof Penderecki (1933-2020) were highly influential to my early interests in drone, sonorism, sound mass, and proto-spectral music, along with a long list of others. While the influence of these composers may not seem apparent at first listen I am including them here for that same reason. A list of early twentieth-century composers whose work influenced my thinking would be theoretically never ending.[63] But as for the work of these composers, their unique sonic explorations within the confines of equal-temperament served as something of a gateway to the wider world of microtonality. Long before I had encountered anyone else doing microtonal drone work similar to my own these sounds served as an inspiration for exploring overtones and resonance.

Moving into the 1960s a number of artists and composers stand out whose work more closely aligns with my own. The influence of both electronics and non-Western developments in music were

63 For such a list you can tune into WKCR 89.9FM Monday afternoons from 3-6PM.

becoming more apparent post-World War Two. In the realm of acoustic instruments, the American gamelan movement was exploring Indonesian musical conventions. As noted earlier in this paper, outside of Western society the issue of tuning was dealt with very differently. In the Javanese tradition of gamelan metal and bamboo instruments were crafted with the intention of exploiting inharmonic partials as a fundamental part of the musical practice. Adapted in the West, the American gamelan ensembles organized by Lou Harrison and William Colvig (among others) were likewise embracing this harmonic dissonance, with the beating of sound waves allowed to create washes of microtonality.

The proliferation of electronics at this time was also broadening the sonic palette of Western musicians as tape machines, electric organs and tone generators were becoming widely available. The Columbia-Princeton Electronic Music Center, the San Francisco Tape Music Center, and Mills College were all early sites of electronic experimentation. As Dr. Robert Moog and Don Buchla engineered and popularized the synthesizer electronic tones became more commonplace in musical settings, and offered microtonal timbres that were impossible to achieve on acoustic instruments.

Individual pure tones, sine waves such as my work relies on, would become an indispensable tool to some sound practitioners, and allowed for crafting justly intoned harmonic structures with a degree of precision that was unprecedented. One such composer, La Monte Young, had explored serialism, indeterminacy, and abstract performance art before ultimately focusing on minimalist techniques of composition. Along with an implementation of microtonal tuning practices on acoustic instruments, by the mid-1960s he and a number of others were incorporating electronic tone generators into their work. Within the revolving cast of the Theater of Eternal Music, Young, Marian Zazeela, Tony Conrad, Terry Riley, and many others were presenting long-form improvisatory performances of free jazz motifs mixed with sustained tones, where the focus was less on altering pitch and more on the manipulation of timbre. Conrad, who studied mathematics at Harvard, has been credited with introducing concepts of just intonation and harmonic consonance to the group.[64]

By the 1970s Western musicians were taking inspiration from the world of Hindustani music, with Conrad, Young, Riley, and many others incorporating traditional Indian music techniques into their own repertoire. Hindustani classical music offers a large variety of resonant instruments which serve to highlight the overtone series. Among them the *veenam, sarod, and sitar* are very different instruments from one another but share in common the use of sympathetic strings which resonate with and accentuate the overtones. Especially notable is the *tanpura*, which in some traditions is considered the most important instrument of an ensemble. It consists of four strings, typically tuned at octaves and a 5^{th}, and the performer plays a single drone, altering the harmonics throughout the course of a performance. There is a corresponding concept in classical Hindustani music (as well as other eastern traditions) known as the *jivari*, which formalizes the focus on overtones as an outsized component of the performance when compared to Western musical traditions. Likewise the style of singing known as *Kirana gharana* places special emphasis on precise intonation. The musician and teacher Pran Nath, who had grown up in Pakistan and later resided in India, came to the attention of Young and others who ultimately brought him to New York and became his pupils in the 1970s. From that point on Young's music became much more focused on drone without any of the melodic trappings of past work. Likewise Terry Riley would begin producing albums exploring alternate tunings, hiring a technical assistant to modify his electric organs and Prophet synthesizers to achieve just intonation.[65]

Microtonal drone music was becoming more widely practiced at this time, as rock and roll's increasingly uniform musical tropes of the 1960s and 70s wore on, coalescing around familiar conventions, and new electronic techniques were being developed to explore alternative sounds. In

64 Tony Conrad, *Writings*, (New York: Primary Information, 2019), 358-369. ; Kyle Gann, *American Music*, (New York, Schirmer, 1997), 189.

65 Mark Prendergast, "A Composer For Our Time," *mu:zines*, August 1989, http://www.muzines.co.uk/articles/a-composer-for-our-time/5636

Paris, Éliane Radigue had been a student of *musique concrète* before developing a drone music practice utilizing tape machines and sound synthesis. Her recording of *Adnos I* in 1973 was the first of many to focus heavily on interference patterns and difference tones. The year prior a collective of German musicians, Tangerine Dream, recorded their album *Zeit* in 1972, combining droning string arrangements with electronics and organ in a meditative exploration of timbre. 1975 saw the first iteration of Gavin Bryars' masterpiece of minimalist harmony, T*he Sinking of the Titanic*, and in 1977 Alvin Lucier would conceive of his electro-acoustic performative drone installation *Music on a Long Thin Wire*. That same year Randall McClellan would begin giving his improvisatory performances which would later be collected as T*he Healing Music of Rana*. A founding member of the electronic studio at the Eastman School of Music, McClellan's practice was informed by his doctoral studies and explored raga-inspired vocal techniques accompanied by two synthesizers, tanpura, tape loops, and custom designed drone instruments. By the beginning of the 1980s we start to see some of these musical motifs branch off with the development of New Age and ambient music, which typically had a greater focus on large washes of sound as opposed to precise microtonality. A common theme within these genres involves some vague reference to Indian, Asian or Middle Eastern modalities. Beginning with the Beatles' highly publicized visits to India in 1968 it became fashionable in certain sectors of the art world and society-at-large to associate oneself, however superficially, with eastern beliefs and manners of comportment.[66] This is something that I find highly questionable not only as a student of Buddhism and practitioner of the arts, but as I feel it represents some degree of Orientalism.[67] Drone music especially, in its combination of science and art and its history in eastern musical traditions, tends to attract an audience infatuated with mysticism. There is nothing inherently wrong with this, but it can be expressed in ways which I find to be problematic, and harkens back to the incurious cultic era

66 Philip Goldberg, *American Veda: From Emerson and the Beatles to Yoga and Meditation – How Indian Spirituality Changed the West,* (New York: Harmony, 2013), 7-8.

67 Anyone unfamiliar with the concept should read Edward Said's 1978 book *Orientalism*.

of Pythagoreanism and the stifling dogmatic traditions of the medieval church. It can furthermore result in a backlash, where anyone working in this mode gets placed into a veritable box. Where practitioners of this music have gained notoriety in the later twentieth-century and beyond it is more often than not in association with some degree of affectation. A manner or self-styled presentation that in another country may be considered modest but when transplanted to the west becomes flamboyant. That these musical practices have moved from an iconoclastic realm at the start of the twentieth-century to one ultimately filtered through the twentieth-century culture industry is not notable in and of itself, but begs the question of whether it can thrive without a cult of personality, which is something Tony Conrad had harshly criticized Young for perpetuating.[68] In any case it's worth differentiating the branching off of ambient music as these are issues which are still at play in contemporary times.

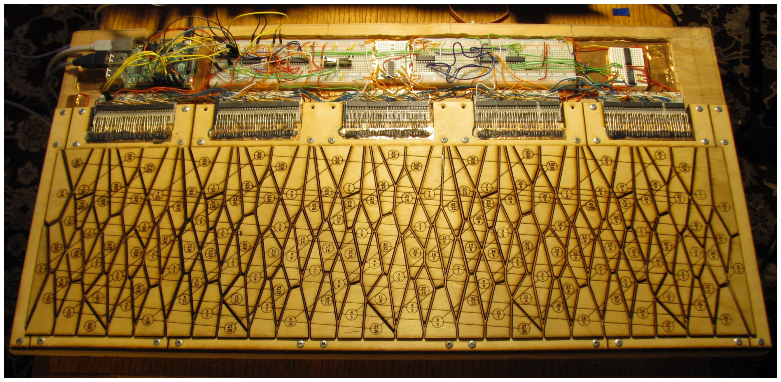
While "ambient" music flourished in the atmosphere of the 1980s a number of landmark microtonal and timbral works were likewise incubated. Beginning in 1977 and throughout the 1980s the Estonian composer Arvo Pärt contributed significantly to renewed public interest in pre-Rennaissance harmony with his move away from 12-tone techniques. Likewise Henryk Górecki began to transition away from serialism and modernism and would soon begin work on his droning minimalist string quartets. By the end of the decade Pauline Oliveros, a veteran of Mills College and the San Francisco Tape Center, had joined with Stuart Dempster and Peter Ward to form the Deep Listening Band, performing music with a focus on resonant spaces and just intonation, such as on their premiere, eponymous 1989 recording. In that same year Éliane Radigue would record what has generally come to be considered her electronic masterpiece of microtonality, *Trilogie De La Mort*. I should reiterate here that the short preceding list is just a personal overview of musical developments, and in many cases the works were released into relative obscurity. In any case by the 1980s the

68 Tony Conrad, *Tony Conrad's Response to An open letter to La Monte Young and Tony Conrad*, Buffalo, September 2000. https://static1.squarespace.com/static/56d5b65df850827e476cb1f9/t/5770ca2de3df287500cad57e/1467009581976/Tony+Conrad+Response.pdf ; Brian Duguid, "Tony Conrad Interview," *Table of the Elements*, (1996): http://media.hyperreal.org/zines/est/intervs/conrad.html

freedom that sound synthesis could offer musicians who were interested in exploring alternative harmony was unparalleled. In an interview from 1986 synthesist pioneer Wendy Carlos described her own work with just intonation and microtonal tunings, work made possible through the use of synthesizers. Commenting on the legacy of Harry Partch and his labor intensive practice, she noted her satisfaction at living in an age when she was able to easily and precisely control the harmonic content of her arrangements, lamenting only the mechanical and cost limitations preventing her from realizing a scale based on the full overtone series.[69]

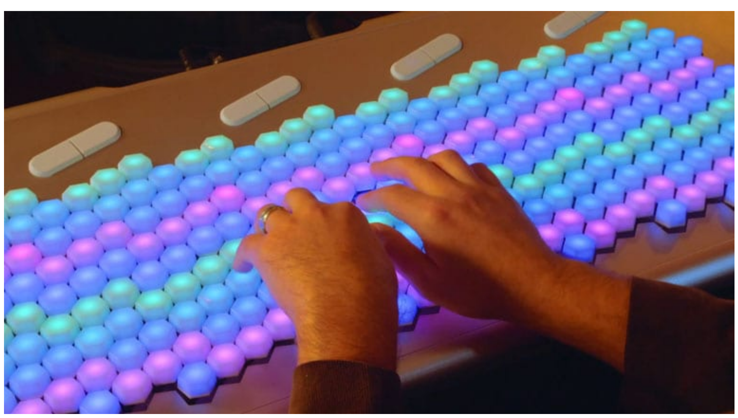
Indeed music technology was developing rapidly and becoming increasingly user friendly. While acoustic designs likewise evolved, digital innovations throughout the 1990s and into the twenty-first century have made microtonal music accessible in ways unprecedented. Today there exists a large and diverse range of synthesizers, plug-ins, apps, and midi instruments designed for microtonal composing. Scala, a free software application, allows for the creation of custom tunings and temperaments which can then be exported to a variety of file standards. One of the latest iterations of the Prophet synthesizer, which had required customization when first employed by Terry Riley in his search of alternative harmony, now includes by default a selection of historic tunings, such as many of those described throughout this paper. There is additionally Cycling ‘74’s *Max* programming environment which offers users the conveniences of visual programming to facilitate design of virtual custom instruments.

69 Dominic Milano, “A Many-Colored Jungle of Exotic Tunings,” Keyboard, (1986): 64-64.



- Jim Snow’s 31EDO keyboard (fig. 15)[70]

- Tonal Plexus (fig. 16)[71]



- Lumatone’s isomorphic keyboard (fig. 17)[72]

70 Jim Snow, On the Design and Construction of a Just Intonation Keyboard, accessed May 1, 2021, http://jsnow.bootlegether.net/jik/keyboard.html

71 H-Pi Instruments, Tonal Plexus, accessed May 1, 2021, https://hpi.zentral.zone/tonalplexus

72 Lumatone Isomorphic Keyboard, Lumatone, accessed May 1 2021, https://www.lumatone.io/

The proliferation of music technology has in turn contributed to a significant expansion of the microtonal community. That being said, there are not many contemporary artists who have successfully transitioned these practices to the commercial realm. There are few notable exceptions, as social scenes have occasionally coalesced around some of the characters previously mentioned, or when a critic has written an advocating survey of the field. But the study and advancement of microtonality, especially in the context of drone music, remains for the most part in the domain of a small community of amateurs, which by my own informal and unscientific observations consists equally of audiophiles and technicians as it does professional musicians and academics.

To many practitioners, especially working in the context of just intonation, it can be a guiding philosophy, the scaffolding of a musical practice reflecting a religious experience, dependent origination, the primacy of sound, psalmody of the desert fathers, or abstract notions of cosmology and universal harmony. To others it can be a tech fetishism, with expensive and ostentatious instruments becoming class signifiers, and performers often speaking nonsensically about the dubious math underpinning their work—Theodor Adorno’s incipient culture industry made manifest on some small scale.

The proliferation and refinement of digital technology has likewise given rise to an element of high-EDO fetishism. Whereas these matters were originally questions of mathematical soundness and mechanical practicality there is now a hyper-specific focus on composing work built on precise, arbitrary frequencies. On the whole I would suggest that explorations of dissonance are a good thing whatever form they take. But the practice of creating music based on some supposedly critical geometric frequency, while employing it in the context of equal-temperament and regardless of intervallic relationships, has itself become a cliché and is unfounded.

Drone music especially has been put through these motions in the past few years, often being implemented as a promotional term for musical performances and festivals which feature electronic dance music with some droning element buried in the composition, further obscuring categorical analysis by genre. In the twentieth-century the concept of drone music has become difficult to encompass in an era of ready-made electronic music devices. La Monte Young immodestly (and ahistorically) credited himself as the originator and offered his succinct definition as "the sustained tone branch of minimalism."[73] I think that is generally agreed upon as a satisfactory, if broad, definition. I also think it's worth incorporating the xenharmonic framework in any attempts to define music concerned with microtonality.

Xenharmonic is a term that was coined by the composer Ivor Darreg (1917-1994), a contemporary of Harry Partch. Darreg published a newsletter consisting of writings relevant to the study of microtonal music, and the journal has in some sense been expanded into the various forums and wikis which have taken on the name. The Xenharmonic wiki page offers the following distinction: "music which can be performed in 12-tone equal temperament without significant loss of its identity is not truly microtonal." The word "significant" is of course the operative qualifier here, but I find it to be a definition that captures the spirit of xenharmonic and microtonal practices, where intonation and precise intervallic relationship of tones are of critical importance.

I would additionally critique the field in noting that while the matter of aesthetics is highly subjective I find that the philosophy can be employed haphazardly. I would argue that approaching just intonation or any other alternative tuning system does not entail composing music using the same tropes one would employ in equal-temperament and then adjusting the product for an alternative tuning, as can often be the case. Each tuning method is unique and anyone looking to work in an alternative tuning should consider their motivations and manner of implementation. Likewise I feel it's important to move away from the practice of anthropomorphizing intervallic relationships, which is common in Western musical history and practice, and has resulted in an oversimplified happy/sad,

73 La Monte Young, *Notes on The Theatre of Eternal Music and The Tortoise, His Dreams and Journeys*, Mela Foundation, 2000, https://www.melafoundation.org/theatre.pdf

dark/light musical binary. Notions of inherent key characteristics, which have been inherited from meantone conventions, are typically unjustified, and have no doubt played a role in perpetuating these stereotypes.[74]

Additionally, the microtonal field can be fraught with hyperbolic self-promotion. Organizations have been known to offer weeklong retreats and "Deep Listening® certificates" which I think are, as with any offer to fundamentally realign ones cognizance in seven days, best approached with a healthy degree of skepticism. Similarly problematic can be the issue of naming conventions, such as La Monte Young's "Magic Chord" which was supposedly kept "secret" for over a quarter century, during which time I can only assume no one ever attempted to examine it using a spectrum analyzer, or even just a band-pass filter. Ecstatic reviews of his corresponding spatialized installation are likewise suspect in their description of the experience as one providing an effect that is in truth contingent on the physical placement of the sound source and could be achieved using arbitrary frequencies.[75] But again I will reiterate that the community is small and there are no formalized conventions, with forum and wiki contributors often taking the liberty to name musical scales after themselves, or obsequiously crediting their "invention" to a well-liked artist. As such, a significant amount of the material to be found in the forums, social media groups, and wiki pages can be didactic and unreliable.

On the matter of categorization in general, tuning methods are not scales nor musical genres and I think that any attempt at classification should remain agnostic to stylistic heritage or popular implementation. As regards drone music specifically, I would propose that if a composer has detailed control of the harmonic content of a sustained tone and is intentionally manipulating it or altering the interference patterns in service of the piece I would consider those hallmarks of drone music. Conversely, a musical composition which utilizes extensive fx processing I would classify under the

74 See: Rita Steblin's *A History of Key Characteristics in the 18th and Early 19th Centuries*.
75 William Duckworth and Richard Fleming, *Sound and Light: La Monte Young and Marian Zazeela*, (Lewisburg: Bucknell University Press, 2009), 187.

equally dubious umbrella term of “ambient music.” This is a useful distinction to make in as much as any attempt at musical classification is useful, as the two styles are regularly conflated, with the former occasionally presented as an approximation of the latter.[76] Equating microtonal drone music, my own for example which is based on a small number of sine waves (typically two to three), limited analog modulation, and filtering, with music created by way of complex algorithms, granular processes, or spatialization effects, would be baseless and misleading. I find this to be a recurring theme in popular music criticism and analysis, and it is significantly flawed. Another common refrain from those encountering this music is the phrase “difficult listening.” As in, “the piece is excellent, but it’s difficult listening.” There is without a doubt a trend of composing microtonal music as some sort of provocative performance art, and likewise appreciation of any art form is highly subjective and the world of microtonal music is no different in that regard. But while it is true that alternative tunings and drone music can require a brief period of acclimation, the preceding is a phrase which gets regular use in the writings of even the most steadfast music journalists, and of all the art criticism tropes that get passed around I would like to see this one put to rest. To that end I would offer the following advice: if you find it to be difficult listening, don’t listen.

If on the contrary you find this music to be engaging you will be pleased to discover a limitless palette of diverse sounds existing just beyond the scope of traditional Western tonality. Carl Sagan found the concepts intriguing enough to include a recording from synthesist Laurie Spiegel on the Voyager satellite’s Golden Records. Spiegel’s piece is a sonification of the astronomical harmonies referenced in Kepler’s *Harmonices Mundi*. Etched onto a pair of phonograph records launched into space in 1977. The included sounds and images from earth are intended as a sort of calling card to any extraterrestrial life that might be out there.

76 Nikolsky Aleksey et al, “The Overlooked Tradition of ‘Personal Music’ and Its Place in the Evolution of Music,” 1.

I myself encountered these concepts in a different manner altogether. As stated previously my initial investigations into microtonality were by way of what can generally be termed mid-century Eastern European sonorism. It was not until later that I discovered through personal research many of the figures in drone music which I listed above. At that point I had still not formed a significant practice of microtonality or tuning. Several years later I was completing my undergraduate degree at Columbia University and in the evening attending public talks at the Pupin Physics Laboratory and Rutherfurd Observatory, a series which is part of an ongoing public outreach program of the astronomy department. I became convinced that there was some way to correlate my interests in timbral music and harmony to orbital resonance, and I felt the sensation that comes with making grand, unfounded assumptions about the universe. I discovered Kepler's writings on harmony and started researching historical tuning practices. I spent a semester learning about gamelan practices while studying East and Southeast Asian music under a musicologist who had played a role in the conservation of Harry Partch’s instrument archive. Prior to studying just intonation and microtonal practices I had been interested in the concepts, but not as a performer. Wendy Carlos had criticized contemporary microtonal compositions which move too quickly, stating that they don’t leave enough time to appreciate the tuning system, and I likewise feel that the harmony of a tuning method serves a different role in rapid melodic sequences than in the type of harmonic and gamelan work that I became especially interested in. The practice I’ve developed over the past several years is one of long form microtonal drone composition. In years prior there have been unrelated conversations about whether or not to call this type of work “music.” While I wish that I had something erudite to add to this conversation the truth is I don’t care. To me “music” best describes some type of song, a melody supported by harmony. By that definition what I do wouldn’t be considered music as such, but I nevertheless think of it as drone music or timbral music. I think some practitioners are fearful of losing the title “music” and see its loss as a disservice to the art form, while others actively avoid cosmic allusions or mathematical descriptions. I'm comfortable with my audio work being considered a technical demonstration of psychoacoustic phenomena. Whatever story people want to tell themselves about the work is fine, up to and including New Age notions of universal harmony. The only distinctions I am concerned with are the ones outlined above.

How my specific practice differs from that of others is in the various ways that I construct harmony. Whereas much of what has been discussed utilizes acoustic instrumentation, digital effects, or large numbers of sound waves, I look for ways to work within my own arbitrary analog limitations. What I create could mostly be accomplished in the digital domain, and with a higher degree of precision, but that being said there are two considerations. The first issue is the debate of digital versus analog waveforms. Whereas analog waveforms are a smooth, continuous expression, the stepped sample rate of digital waveforms can affect the timbre and result in sonic artifacts. If one is producing content that maintains a pure analog signal path it can be argued that the difference is significant. The second point to consider is that analog components generally produce more pleasant harmonic distortion when overdriven, a point likewise relevant to conversations regarding vacuum tubes and transistors, but these are questions of aesthetics. Manufacturers of electronic instruments often incorporate these nuances into their designs, and I often find them to be useful in my own work.

My process typically begins with a single sine wave. Depending on the context and setting I will make adjustments to the frequency. Recording and performing live are two different modes of working. If I'm performing live or recording in a space I'll typically try to find an architectural resonance and either use it to build harmony, or in the worst case avoid it. If I'm recording to tape or to a computer the frequencies I work with are wholly subjective. In my opinion there is only one frequency standard that is worth defending: if you are working with oscillations the simple process of beginning with 1 cycle and using the power of 2 until you reach a desired pitch is the only formula that I subscribe to and one that I arrived at early on. While I was unaware that this is considered to be "scientific pitch" and has an interesting history all its own, including Joseph Sauveur himself promoting it, the convention seems to be commonsense to me, though not widely known. As it regards tuning methods, I don't use a 12-tone system of organizing pitches, but rather a 16-tone system based on the harmonic series, so the naming conventions are made additionally superfluous, but in terms of scientific pitch the note C is considered to be at 256 Hz.

In terms of technique, that varies greatly. I typically employ some combination of the following, for which I've provided general definitions as they apply to my personal practice:

> Fixed filter bank: a series a band-pass filters allowing me to isolate the harmonics of a sound source.
>
> Wavefolding: a method of distorting a waveform to emphasize or minimize certain harmonics.
>
> Amplitude modulation: as a method of combining audio-rate waveforms to create sideband harmonics.
>
> Frequency modulation: as a method of combining audio-rate waveforms to create sideband harmonics.
>
> Phase shifting: used to create notches in the frequency spectrum to emphasize or minimize certain harmonics.

These are typically used in order to achieve some degree of comb filtering, phase cancellation, harmonic sidebands, difference tones, and/or interference patterns of the sound wave. The tools have been around for decades, and while the techniques that I have developed provide me with unique opportunities to create complex harmonies from just two to three sine waves it's important to note that the clashing of harmonics and beating of the tones is not something that I avoid, but rather actively exploit. The ability to derive harmony from a sound source by modulating its amplitude or frequency with that of another sound source is a concept that likely could not have been conceived of or understood throughout the preceding history of Pythagoras, Boethius, Kepler, etcetera and is a technique that I find to be highly effective for my purposes. While my work can be compared to that of previously mentioned figures in some regards the only composer whose practice included a significant focus on attaining harmony through audio-rate modulation would be Eliane Radigue. In terms of my tuning methods, as referenced previously the only standard I employ regularly is what is sometimes known as an octave repeating mode 16 of the overtone scale. This is a just intonation scale I developed of my own accord without any reference, and I would argue that it could be considered a basis for truly consonant harmony. This involves dividing the octave linearly in Hz and using it as an interval of repetition for a logarithmic scale. It can be further divided down linearly as desired. Wendy Carlos approximated this scale in something she called a super just intonation harmonic scale which she employed in her just intonation work in the 1980s, but by her own account mechanical and cost limitations forced her to leave out some of the tones that I include.[77]

1 /1	3/2
17/16	25/16
9/8	13/8
19/16	27/16
5/4	7/4
21/16	29/16
11/8	15/8
23/16	31/16
	2/1

- 16-tone overtone scale

All else being equal, this tuning method merely serves as a framework of consonance for me. The tension and release that dissonance enables is an elemental concept of music and not something that I

77 Dominic Milano, “A Many-Colored Jungle of Exotic Tunings,” *Keyboard*, (1986): 64-64.

avoid on theoretical grounds. In my frame of reference all other tuning methods are arbitrary, just as all other pitch standards are arbitrary, but arbitrary should not be understood as being bad or undesirable. On the contrary I am inclined to agree with Helmholtz who argued that “Rameau was correct in seeking a natural basis for harmony,” but as Robert Cunningham points out:

> “Helmholtz does not regard physical nature with the same reverence as Rameau; in reference to inharmonic partials, for instance, he remarks that Rameau ‘might have heard many a perfectly dissonant chord’ if he had listened to a wider array of sonorous bodies. To infer harmony from nature requires a broader view of nature … Moreover, Helmholtz (unlike Rameau) brings to this investigation a thorough understanding of scientific method and a keen appreciation of the difference of viewpoint between artist and scientist.”[78]

My feelings are that preferring any tuning standard over another, aside from what I’ve outlined here, is purely subjective. As previously mentioned, the range of frequencies that I work with are oftentimes based on the physical environment I am in, as sound propagation and standing waves are taken into consideration. In a previously referenced article the authors discuss how certain frequencies resonate inside the Hagia Sophia and spread out everywhere, giving the sense of an omnipresent sound, and that is typically what I aim for in my performances.[79] The architecture and reverberations are fundamental components of a live performance. To that I end I spent a considerable amount of time performing and recording at the Park Church in Brooklyn, a cavernous Lutheran church built at the turn of the century where I helped curate musical programming for several years along with a number of others. In environments such as this the work that I have described and included in recordings becomes a physical sensation well beyond the reduced aural version of the material presented here. In general terms microtonal music can be uniquely experienced in large settings such as this, and there is a useful Wikipedia page devoted to cataloging churches of North America which house organs tuned to

78 Robert Cunningham, “Helmholtz’s Theory of Consonance,” Robert Cunningham, 1995, 2-3. https://robertcunninghamsmusic.com/academic-papers/

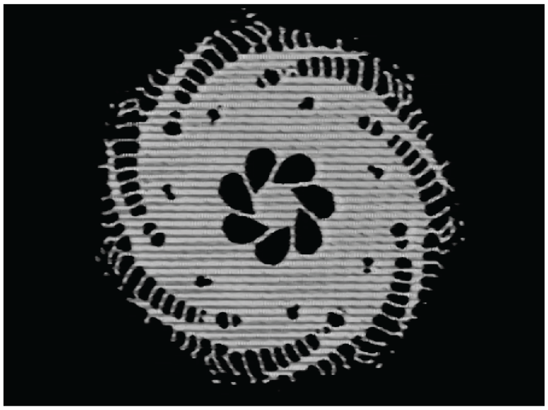
79 Adrienne Lafrance, “Hearing the Lost Sounds of Antiquity,” The Atlantic, February 19, 2016, https://www.theatlantic.com/technology/archive/2016/02/byzantine-angel-wings/470076/

alternative meantone temperaments.[80] If in some distant future meantone conventions were to once again become the prevailing tuning method one can imagine contemporary times in Western music being viewed as a dark age of tuning, when fixed pitch instruments were cheap and plentiful but all sounded the same.

80 "Meantone organs in North America," Wikipedia, accessed May 1, 2021, https://en.wikipedia.org/wiki/Meantone_organs_in_North_America

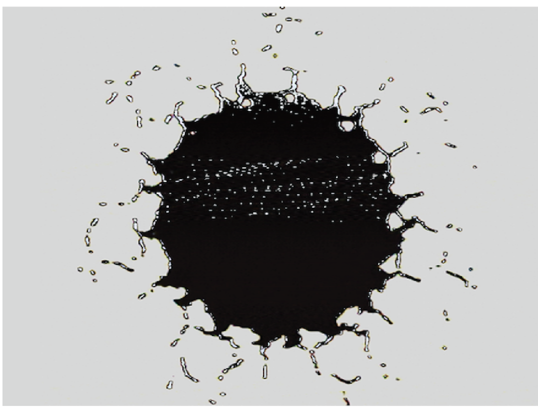
List of Works

www.dylanmarcheschi.com/signaltonoise



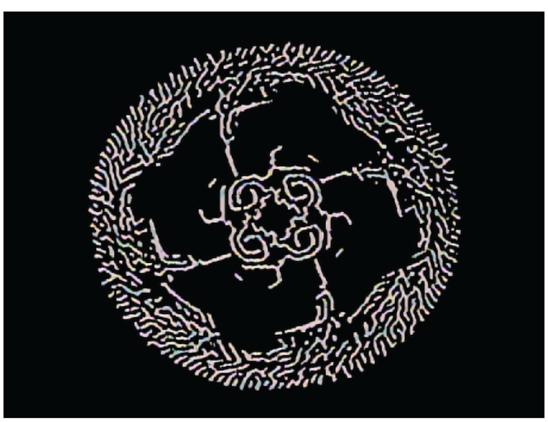
BWC-42. The sound is composed of two saw waves at ~49 Hz and ~65 Hz. By utilizing a fixed filter bank to isolate the partials I'm able to create just harmonies of the constituent sine waves, and by using these frequencies I'm able to derive the II, VII and Pythagorean VI for added dissonance. Wave multiples and divisions are used to accentuate the harmonics.

ƒ=67 : 1 /1 9/8 5/4 11/8 3/2 13/8 7/4 15/8 2/1
ƒ=49 : 1 /1 9/8 5/4 11/8 3/2 13/8 7/4 15/8 2/1



40-70P-IC. The sound is primarily composed of two sine waves and amplitude modulation. By utilizing ring modulation sidebands are created up to the 25th harmonic, allowing for a narrow IV, augmented IV, augmented V and tridecimal neutral VI. Wave multiples and divisions are used to accentuate the harmonics.

Y=400 : 1/1 9/8 21/16 11/8 25/16 7/4
X=300 : 1/1 19/16 4/3 3/2 13/8 7/4



M17. The sound is primarily composed of three sine waves and amplitude modulation. By utilizing ring modulation, with a Z input providing an alternate phase relation from the X input, I'm able to achieve finer control over the timbral quality of the sound. Asymmetric distortion provides for additional tonal characteristics. Throughout the piece the wave frequencies are altered. Wave multiples and divisions are used to accentuate the harmonics.

X=46, 64, 114
Y=178, 242, 310

- *Signal to Noise* stills (fig. 18)

“Media, by altering the environment, invoke in us unique ratios of sense perceptions. The extension of any one sense alters the way we think and act—the way we perceive the world. When these ratios change, men change.”

- Marshall McLuhan[81]

“The basis of the subdivision of the intervals of our keyboard instruments...has an extensively dulling effect upon the delicacy of listening ability.”

- Max Weber[82]

Perhaps by virtue of being unable to close our ears there is a significant distinction between what is most easily termed as the passive behavior of hearing versus the active behavior listening. The field of studies encompassing selective auditory attention has been active for over half a century but it remains an experimental and evolving science (with fascinating correlates in the study of artificial intelligence). R. Murray Schafer, in his landmark 1977 book *The Tuning of the World*, advocates for more active listening, and criticizes sonic noise and pollution as being allowed to propagate without due consideration. To that end he pioneered the field of Acoustic Ecology to study sound as a mediating factor in the relationship between humans and their environment. In one series of tests Schafer documented how test subjects in musical exercises identified intervals of 60 Hz as a tonal center, the frequency of the alternating current of our electric system, which in the 1970s still caused many appliances to buzz audibly at 60 Hz. He likewise documented a reciprocal tendency at 50 Hz in European subjects.[83] It would be worthwhile to conduct these tests again in modern times and observe the outcome, but it is well-documented that animals internalize the sounds they are exposed to, and that this in fact forms a basis of our conception of tonality.[84] Schafer additionally published a number of

81 Marshall McLuhan, *The Medium Is the Massage: An Inventory of Effects* (New York: Bantam Books, 1967), 41.

82 Max Weber, “Rational and social foundations of music,” *The Routledge Reader on the Sociology of Music*, ed. Kyle Devine and John Shepherd. (New York: Routledge, 2015), 43.

83 R. Murray Schafer, *The Soundscape: the Tuning of the World*, (Rochester: Destiny Books, 1993), 99.

84 Peter M. C. Harrison and Marcus T. Pearce, “Simultaneous Consonance in Music Perception and Composition,” *Psychological Review* 127, no. 2 (2020): 216-244.

other studies and teaching guidebooks suggesting exercises and methods of intervening in that relationship towards developing a critical framework.[85]

At a minimum my work can be understood in the context of providing exercises in listening. While that can be said of most any music that is created with the intention of being heard I have shown throughout this paper that the vast majority of Western audiences will only ever encounter music created within the fixed tuning system of equal temperament, and never experience alternative harmonies, or those of pure consonance. Over the past several decades acoustic ecology has documented the effects of the soundscape on biological processes. Similarly the fields of evidenced based music and sound therapy are now established science and have shown benefits in a wide variety of rehabilitation and neuropathology treatments. Pain management has repeatedly been shown to correlate to the perceived consonance of harmonic intervals, with the author of one study noting that further research on the attenuation of pain would likely require forms of sound production which are dissimilar to traditional approaches of musicality.[86] Anecdotally, in 2018 the IEEE and Engineering in Medicine & Biology Society published an article by Professor Emeritus Max Valentinuzzi, a celebrated doctor of physiology, biophysics, and biomechanical engineering. In the article Valentinuzzi described music therapy as possessing untapped potential for biomedical engineering, while likewise musing on the aforementioned topics covered in this paper and invoking Kepler’s notion of just harmony.[87]

I am not a scientist, and although I read a lot of scientific studies I cannot claim to understand all of the nuances and intricacies of many of them. But I do understand that our cells function as autonomous circadian oscillators, regulating behavior, hormone levels, sleep, body temperature and metabolism.[88] In 2017 Jeffrey C. Hall, Michael Rosbash and Michael W. Young were awarded the

85 R. Murray Schafer, *The Soundscape*, 208.
86 Ibid., 36-46.
87 Max Valentinuzzi, “Music Therapy and the Planets’ Consonances,” *IEEE Pulse, IEEE Engineering in Medicine & Biology Society*, July/August 2018, https://www.embs.org/pulse/articles/music-therapy-and-the-planets-consonances/
88 The Nobel Assembly at Karolinska Institutet, “Press release,” The Nobel Prize, October 2, 2017, https://www.nobelprize.org/prizes/medicine/2017/press-release/

Nobel Prize for documenting the molecular mechanisms of protein creation and destruction which periodically tune that biological clock of the cell.[89] Key to cellular health and well-being is keeping these clocks properly in sync, in tune, and not sending mixed signals, as messing with those clocks can cause all types of health problems and disease.[90] It's been said that what they're doing for medicine is akin to what Einstein did for physics.[91]

As an artist extrapolating my own meaning and understanding from the data, one question I have is in regards to harmony and noise. I feel it would be shortsighted to not further extrapolate from patterns observed in nature, such as those similar to Zipf's Law which opened this paper. Our eyes are outgrowths of brain tissue and are part of the central nervous system, our ears are merely delivery mechanisms for sound, and the act of hearing is a cognitive function. What unknown effects do inharmonic pressure waves have on both a mental and biological level? It is well documented that noise alters the stress levels and physiology of mammals and other creatures.[92] There are likewise many studies documenting the use of noise as a weapon.[93] Stephen Dubner, co-author of the best selling *Freakonomics* book, seeks to reveal the hidden cost-benefit analysis of things that get taken for granted in modern society. In an episode of his podcast from 2020 he presented an in-depth consideration of noise pollution, and the webpage for the episode cites several case studies, including the landmark *Munich Airport Noise Study* which documented significant cognitive impairment in a group of children residing near an airport site.[94] In addition to the unaccounted sound therapy implications posited above,

89 Ibid.
90 Ibid.
91 Allison Aubrey, "How Messing With Our Body Clocks Can Raise Alarms With Health," NPR, October 2, 2017, https://www.npr.org/sections/health-shots/2017/10/02/555054483/how-messing-with-our-body-clocks-can-raise-alarms-with-health
92 Ron Chepesiuk, "Decibel Hell: The Effects of Living in a Noisy World," *Environmental Health Perspectives* 113, no. 1 (2005): 34-41. ; "Noise Pollution," National Geographic, accessed May 1, 2021, https://www.nationalgeographic.org/encyclopedia/noise-pollution/ ; Graeme Shannon, "How noise pollution is changing animal behaviour," The Conversation, December 17, 2015, https://theconversation.com/how-noise-pollution-is-changing-animal-behaviour-52339
93 Steve Goodman, *Sonic Warfare: Sound, Affect, and the Ecology of Fear*, (Cambridge: The MIT Press, 2012).
94 Stephen Dubner, "Please Get Your Noise Out of My Ears (Ep. 439)," Freakonomics, Novermber 11, 2020, https://freakonomics.com/podcast/noise/

I think a worthwhile undertaking would be to create a noise map of New York City and look for correlates in literacy and graduation rates.

In his various media analyses Noam Chomsky has been highly critical of the frequency of advertising breaks in media, which I addressed in a paper I on wrote on the subject several years ago, documenting the negative effects of non-linear media on aggression, ADHD and empathy.[95] This rapid fire media is often marketed as what people want, but it is in fact a tactic to shoehorn into a program as many advertising commercial breaks as possible. While this practice of "media concision" no doubt contributes to the dumbing down of complex discussions, in the world of mobile media with random advertisement breaks interrupting the linearity of narrative content (and with even greater frequency) I wonder what further psychological and physiological effects this might have. What does the simple act of viewing/listening to rapidly changing media do to the audience member whose attention is constantly being diverted and redirected? Furthermore, screen-time and the rapid consumption of online media are now well-known to have severe consequences for physical well-being and the way in which they impair sleep and raise stress levels, a biological fact supported by the cellular clock proofs of Hall, Rosbash, and Young. While these issues are salient and I would like to address them in greater depth, this is again moving further into the realms of science as I am attempting to conclude this paper. In some sense I hope that by placing my long-form audio-visual compositions in an ecosystem such as this they would serve as a counter-force to the prevailing trend of media concision and its corresponding effects. It's worth noting here that starting in 2009 a phenomenon in Norway described as "slow tv" endeavored to broadcast unedited footage of mundane events in their entirety, often lasting for several hours without interruption. The series subsequently became a smash hit and was adopted across European stations.[96] It should be clear why a series pilot was never tested in America, where advertising buy-outs dictate much of what is aired.

95 Dylan A. Marcheschi, "On Empathy in the Media," 2015.
96 "Slow television," Wikipedia, accessed May 1, 2021, https://en.wikipedia.org/wiki/Slow_television

"To create solid and stable convictions in the minds of the uncultured masses, there must be something that appeals to the eye."
- Pope Nicholas V[97]

Translating my audio work to a recorded medium presents its own challenges and opportunities. Whereas in an architectural environment the slight shifts in tones may produce dramatic resonant effects, in a recording the changes may be more subtle and muted. Several years ago I began to consider how people can have difficulty hearing the microtonalities of the music and I began using audio-reactive video techniques as a sort of visual aid. While I initially found them aesthetically pleasing, over time the practice took on a life of its own.

In my past I have worked as a filmmaker and animator, and have utilized a number of techniques to visualize my audio work. Early on I would employ an oscilloscope to show the waveforms in a one-to-one representation of what was being heard. I spent some time experimenting with software for this, but since my audio work is analog it was an undesirable process, one of attempting to translate analog control voltage to digital midi signals. While commercial video synthesis tools have existed since the 1960s, in modern times they largely exist within academic studios or in small scale projects of DIY technicians. Many of the designs have been made available but I never had much interest in the process of cloning them, or in the glitch effects that can be achieved through circuit bending more affordable video mixers and processors. When working with video I typically focused on utilizing a waveform display and generic video feedback. Then starting in 2008 two analog video enthusiasts, Lars Larsen and Ed Leckie, endeavored to make analog video tools available to artists on a larger scale with their hardware and DIY kit offerings through LZX Industries. Since my work is created in the analog domain the voltages controlling the sound and constituent sources are easily translated to the 1V video standard employed by LZX. The varying degrees of audio-reactivity present in my video work are

97 Stuart Isacoff, *Temperament*, 109.

derived directly from the control voltage and sound sources of the corresponding piece. As stated previously, I often use very narrow band-pass filters in my work to isolate partials, and LZX offers a similar workflow with their own band-pass filter device. Although the bandwidth is much broader, it enables me to construct video signals which reflect the harmonic content of the audio. This is just one technique of many which I employ, but it is one that is typically present in most of my work. In addition to breaking up the constituent audio into discrete bands, I'm able to send the control voltage that I may apply to wave folding or filtering on the audio side to control the brightness, contrast, or hue of the corresponding video signals. In terms of my video process, the fundamentals have not change all that much from when I was a child pointing a camera at the screen and watching the feedback create a hall of mirrors effect. The aesthetic is one that I remain transfixed by and I frequently discover new techniques, but by combining it with the analog audio and video tools made available by LZX I am able to take that generative video process into more complex territory. Camera and screen selection are critical to this process. While newer digital technology is better in the sense that it offers higher fidelity and a clearer image, it's not necessarily better in terms of its use as an artistic tool. I find that old monitors and cameras employing cathode-ray tubes have a certain unique quality that can't be replicated. CRT technologies go back to the turn of the twentieth-century, and employ what is known as an electron gun. A monitor's incoming video signal will be directed through a circuit which fires electrons down the tube and through an electromagnetic field. The electron beam is made to scan across the screen and as it excites the phosphor coating the image is reproduced. Utilizing this technology can limit the scan line resolution of my work, but I find it to be a worthwhile trade off, providing a level of control over image fluidity and gradation that can be difficult or impossible to achieve in the digital domain.

In my work I try to capture feedback while using the corresponding audio to guide its evolution, and one is able to witness a phenomena that feels like something along the lines of watching a flower that is perpetually blooming. I think one element that sets my video process apart from other similar work is that I don't apply any typical fx processing such as mirroring or perspective shifting of the image, and the evolution appears to unfold more organically, likewise devoid of the aliasing and sampling artifacts of digital image processing. In terms of aesthetics, I find that this process can inadvertently resemble a variety of natural mathematic processes, from cellular automata in Conway's Game of Life, to Mandelbrot set iterations, standing waves made visible through cymatics, planetary orbital patterns, the mineral skeletons of radiolaria, the cross-sections and phyllotactic spirals of plants, and prehistoric art motifs. While these resemblances would not be difficult to create if one were so inclined, I frequently arrive at them by virtue of the audio-reactive process alone.

Video feedback has experienced periods of popular usage in the art world, and was employed throughout the 1960s and 70s with various artists such as Nam June Paik and Steina and Woody Vasulka making notable use of the technique. Likewise writers and commentators from Alan Watts to Douglas Hofstadter have remarked on video feedback as a fascinating effect and useful metaphor resembling the corridors of consciousness and recursive sense of self, a theme which has found favorable reception in modern times as well.[98] In my private correspondence I have had older video artists write me to say that they had previously enjoyed working with feedback but were taught that it could not be considered an art form and that it was too simplistic. I find it to be a useful and engaging technique, and I feel that any former hesitation towards labelling it an art form reflects the historical hesitation of labelling photography an art form. As time passes and people grow more familiar with a technology they become more comfortable with the idea of it being employed in an abstract sense. I think that can also partly account for the limited presence of abstract video art in the gallery and museum art environments, along with the ephemeral quality of video art and difficulties of commodification. In an effort to help raise the visibility of such work I recently began a collaboration

98 Robert Pepperell, "How a Trippy 1980s Video Effect Might Help Explain Consciousness," Neuroscience News, December 21, 2018, https://neurosciencenews.com/consciousness-80s-video-10386/

with the multimedia arts organization Harvestworks in New York City to produce a video series focused on contemporary international abstract video art and expanded cinema. The semi-regular series is broadcast on Manhattan public access Channel 4 and archived on Harvestworks' website for later viewing. Throughout the process I have sought to invite guest curators who in turn help to document the diverse emerging video art communities that they are member to.

In terms of the future direction of my work, aside from those questions which I have raised throughout this paper, I hope to pursue alternative avenues for this work, not just in further single and multi-channel video compositions, but also in audio-visual installations, tactile and remote experiential projects, biofeedback devices, and spatialization and ambisonic translations. I also feel that some degree of outreach is necessary, and would like to pursue teaching of acoustic ecology courses offered at the community and academic levels, something that is still lacking by most measures. One of the benefits of technological advancements is in the tools it offers to reconsider past assumptions, and in this regard notions of tuning and harmony are no different.

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