Sine Waves and Simple Acoustic Phenomena in Experimental Music - with Special Reference to the Work of La Monte Young and Alvin Lucier

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Statement of Authentication

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

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Abstract

This thesis explores a series of relationships between music and acoustics in order to develop a basis for discussing and critiquing aesthetics in post-Cagean experimental music. Specifically, it examines the acoustic and aesthetic theories that inform the practice of American composers La Monte Young and Alvin Lucier. One particular theme - the sine wave - emerges, both as a prominent feature in the work of these two composers, and also as a nexus point between music and acoustics. Pursuing this theme, the thesis begins by looking at issues in the science, technology, and ideology of acoustics in relation to the study of musical sound in the late nineteenth century. It then aims to situate the sine wave historically, culturally and technologically within a range of scientific and aesthetic practices in operation in the first half of the twentieth century. Finally, it explores the deployment of concepts from the field of acoustics by artists of the avant-garde, and considers what contribution these factors played in broadening the developing discourse of sound within the arts. These discussions then inform detailed investigations into the work of both Lucier and Young, examining their use of sine waves to explore and produce simple acoustic phenomena.

Introduction: Simple sounds, simple shapes, complex notions

> It's ... stopping people in their tracks so that they can pay attention to that phenomenon which they otherwise don't pay any attention to or they miss. I don't mean it just as an exercise in perception. You know, that wouldn't interest me; to me that's sort of a dead end. Instead, it's putting people into a beautiful relationship to those phenomena. - Alvin Lucier[1]

This assertion from American composer Alvin Lucier exemplifies a specific approach to composition that arose within the context of the experimental arts and music milieu of the 1960s. This context could itself be seen as a set of responses to the provocations of that prototypical musical experimentalist, John Cage. The key components of Cage's attempts to disassemble the edifice of traditional musical language - through the use of chance operations, indeterminacy, and a reappraisal of the material aspect of sound on its own terms - informed the work of a large number of artists across a range of disciplines during this era. However, while the interrogation of form, structure and purpose implicit in Cage's writing and compositions cleared the ground for others looking to reconfigure the arts, it also created a crisis: if sounds were, as Cage had decreed, to be allowed to 'be themselves,' how were artists to involve themselves in both producing and representing sound without simply re-enacting Cage's own methodology?[2] As composer, violinist and film-maker Tony Conrad simply asked: "What was the composer to do?"[3]

The work of the two artists who provide a key focus for this thesis - La Monte Young and Alvin Lucier - constitute approaches to music making that incorporate both an investigation into the nature and behaviour of sound, and an exploration of the interactions between sounds and space. In other words, what these two artists share is a practice that involves the realisation and elucidation of specific *acoustic phenomena*. This thesis aims to detail the aesthetics of a compositional practice focused on producing these phenomena, and to examine the role that acoustic phenomena play in the account of perception (in the form of hearing), attention (in the form of listening), and of sound itself, that the works of Lucier and Young present.

Acoustic phenomena surround us. They are the natural physical actions and interactions of every sound event that occurs in the air or is transmitted through other solid, liquid or gaseous media. Therefore, the sound of any and all music is, of course, on at least a scientific level, comprised of a complex of different acoustic phenomena. What distinguishes the work of Young and Lucier is the aim to utilise only one or two types of acoustic phenomena as the subject of a given work, and that the generation of specific kinds of phenomena, and the subsequent audition of those specific effects by an audience, comprise the very subject matter of a composition. These phenomena are often the result of the propagation of sound in space: acoustical beats, echoes, standing waves, diffraction effects and combination tones. As such they can be categorised as basic or *simple* acoustic phenomena, which in turn are the foundation for an array of more complex acoustic interactions.

That these simple types of natural acoustic phenomena should, in the wake of Cage, form the basis of new musical compositions may not in some ways be unexpected. The employment of natural sonic occurrences in music surely finds a thematic precedent in the incorporation of quotidian and ambient sound running through the arts in the first half of the twentieth century, from Luigi Russolo's 'Art of Noises' through to Cage's own *4'33"*. Like worldly sound, acoustic phenomena resist any simple textual representation in the form of a musical score. Similarly, as they result from the natural, physical behaviour of sound in space, acoustic phenomena take place irrespective of aesthetic considerations. As with Cage's compositions, the use of simple acoustic phenomena as the subject of compositions equally required an attentive audience keyed into listening for aesthetic experience in sounds beyond the instrumental. Therefore, the notion of a music which attended to these natural sonic interactions was dependent on the kind of shift in focus that Cage had previously enacted within western art music - from composition as a form of utterance to composition as an act of audition.[4]

However, despite the fact that acoustic phenomena are natural events in themselves, an aesthetic that emphasised only one or two of these simple acoustic phenomena established an altogether different relationship between artist and materials than that proposed by Cage. This did not necessarily mean that composing with simple acoustic phenomena contravened Cage's dictum by drawing hard and fast distinctions between different types of sounds, or even classifying sounds. The importance would rest not in the sounds 'in themselves', but *in the range of acoustic effects that a given sound or sounds might exhibit or elicit*. These effects were realised through the physical interaction of two or more sounds with each other, and through the interaction of sound with the environment in which it was both made and heard: it was music-making by way of the careful selection and presentation of natural sonic behaviour.

That there was already in existence specific terminology that could define and describe these kinds of acoustic phenomena signifies that Young and Lucier were not working in some hitherto uninvestigated area of sound. In their explorations of the physical aspects of sound, both artists drew heavily on a range of theories and techniques from the field of acoustics - the scientific investigation into the formation, behaviour and audition of sound.

Signs of sines

Case studies of the art of La Monte Young and Alvin Lucier form the bulk of this thesis. The examination of their aesthetic involves exploring the significant role that sine waves have played in the realising of acoustic phenomena in their compositions and installations. Unlike the naturally occurring acoustic phenomena, the sine wave represents a specific model of sound; one that is reductive, abstract, theoretical, and, in its technological manifestation, synthetic. The term sine *wave* is an ambiguous one: it conflates the mathematical sine *curve* - a two-dimensional graph of the equation y = a *sin* x, with the acoustical sine *tone* - a sound containing a single frequency. The popular notion of the sine wave as the fusion of sound and waveform rose to prominence within the theories of musical sound popularised in the late nineteenth century by the work of experimental scientists such as Herman von Helmholtz, John Tyndall and John William Strutt (Lord Rayleigh). Accompanied by an incipient technology for both the explanation and the creation of harmony extrapolated from J.B.J. Fourier's *Analytic Theory of Heat*, the sine wave was the most 'perfect' of the range of other irregular waves realised by acousticians in the late nineteenth century, and became the building block from which a model of musical sound was constructed.

In the wake of the application of Fourier's theorem to the question of the composition of musical sound, two specific and interdependent claims were made of sine waves. As the exemplar representation of simple harmonic motion, the sine wave became the *simple* sound, the basic unit of musical sound production. The decomposition of complex waveforms into an arrangement of individual regular periodic motions (or frequencies) also effectively cast the sine wave as the musical *harmonic* or *partial*. Sine waves then were held to be both the most basic unit of sound in and of itself, and also the component parts of more complex and meaningful *musical* sounds.

Once identified and explained, the significance of the sine wave seemed to be exhausted, and so was left aside in pursuit of more interesting and complex acoustical phenomena. As such, the sine wave seems a *fait accompli* - a given, containing no real interest in and of itself, except for what might be constructed from multiple sine waves. However, this nineteenth century definition of the sine wave presents a simplified and therefore problematic case for the structure of musical sound, let alone sound in general. The sine wave was the end product of a reductive procedure for determining the basic components of musical sound. However, as philosopher Michel Serres has suggested, an assumption of indivisibility in investigative science is often illusory:

> We are as little sure of the one as the multiple. We've never hit upon the truly atomic, ultimate, indivisible terms that were not themselves, once again, composite. Not in the pure sciences and not in the worldly ones. The bottom always falls out of the quest for the elementary. The irreducibly individual recedes like the horizon, as our analysis advances.[5]

Following Serres, this work identifies the sine wave as an *aporia* - something that cannot possibly shoulder or contain all the conflicting attributes bestowed upon it. Despite being just one product of the reductive process of the decomposition of complex waveforms by Fourier analysis, conceptually speaking each sine wave is expected to represent the ur-musical 'simple' sound, the musical harmonic, and the rendering of the mathematical sine curve into sound. This last attribution is particularly problematic, as it requires abstract mathematical functions to be manifest in the physical world. In order to unpack this aporia, this thesis aims to situate the sine wave historically, culturally and technologically through a critique of the work of Herman von Helmholtz and other early acousticians and experimental scientists in the late nineteenth century. The analysis is centred on the role sine waves played in their conceptualisation of the physical and cognitive aspects of listening to musical sound. Of course, both Fourier analysis and the sine wave have been very useful tools in acoustics. However, the generalised models they have produced of sound have underplayed the importance of empirical observations, which has in part served to abstract the definition of musical sound from processes of listening. Again, to quote Serres, "to exclude the empirical is to exclude differentiation, the plurality of others that mask the same," so in order to understand its subject, this thesis investigates the difficulties and vicissitudes that surrounded these early scientific attempts to hear and produce sine-like sounds, in order to generate a different trajectory for understanding sine wave sound.[6]

Acoustics, aesthetics, and transduction

A reappraisal of the sine wave is crucial to the study of acoustic phenomena in the work of Young and Lucier, as the sine wave marks a *nexus* point between the fields of music and acoustics, both in that it forms a connection or link associating the fields of music and acoustics, and that it is the investigative centre or focus of this inquiry into the aesthetic deployment of simple acoustic phenomena. Where acoustics relies on the regular oscillations of the sine wave to establish a boundary line between notions of sound and noise, music theory confers to sine waves the role of the construction of timbre through harmonic interaction. In the application of Fourier analysis by Georg

Ohm to the question of musical sound, the sine wave was placed right at the juncture where acoustic descriptions of the structure of sound and rhetoric or aesthetic commentary on the regularity of musical sound intersect. If considered as neither wholly musical nor wholly scientific, the sine wave becomes a useful conceptual tool for probing the musical and scientific claims made of it, and for exploring the experimental and aesthetic conditions in which it is invoked.

While identifying the sine wave as a nexus between music and acoustics has some application, it is, of course, subject to a definition of the field of acoustics. Although it has its roots in the study of music and vibration, the operation of the ear and voice, and the propagation of sound through the air, the field of acoustics has over time expanded to embrace an ever-widening range of disciplines. In the preface to his authoritative history of the origins of the study of sound, Frederick Hunt lays out his definition of acoustics:

> Acoustics is a 'crossroads' subject - it bears its richest fruits when regarded as a synthesis of other classical disciplines rather than when pursued in textual isolation... the historical origins in acoustics at any rate are not, for the most part, to be found in the state of acoustics in a preceding era, but in the antecedent history of mathematics, mechanics, heat, and a handful of other disciplines that contribute in a two-way intellectual exchange with the content of modern acoustics.[7]

By the 1960s, the decade in which the artists covered by this thesis realised their creative endeavours, the ambit of acoustics had expanded across the breadth of contemporary science. According to R. Bruce Lindsay's graphical portrayal, the field of modern acoustics finds its unity in the investigation of "mechanical radiation in all material media," as performed across an array of scientific and aesthetic endeavours.[8] In his diagram, Lindsay placed this phrase at the hub of his 'wheel', and with each successive step away from its centre depicted how the field of acoustics was applicable across a range of interrelated subjects - psychoacoustics, electroacoustics, communication, musical sound, shock and vibration, underwater sound, and so on - with radii extending out into each of the four basic areas of arts, earth sciences, engineering science, and life sciences. Both Hunt's and Lindsay's accounts show acoustics to be best appreciated as an interdisciplinary field, which consequently provides a proliferation of points of contact between science and aesthetics in the study of musical sound - and there is an abundance of these points in the works of Young and Lucier that explore simple acoustic phenomena. As a result, selecting the sine wave as a trope serves to focus an investigation of these points of contact, and it provides a constant reference against which a broader reading of these exchanges can proceed.

Arguably, acoustics has its biggest cultural presence in the scientific study of musical sound. Therefore, an investigation of the cultural origins of acoustics in part requires a critical examination of its statements and assertions on musical sound on the one hand, and an interrogation of its modes of investigation on the other. As numerous histories of musical inquiry since the time of Pythagoras show, the use of number has been both a defining and delimiting factor in the study of musical sound. However, the investigation of musical sound as performed by acoustics can be described as the combination of two important epistemological distinctions: abstract, *a priori* reasoning, exemplified by the application of mathematical operations such as Fourier analysis; and the *a posteriori* evidence-based or factual knowledge of the natural sciences, where understanding is dependent on sensory experience. Each approach continually informs the other: for example, the application of a theoretical model to a physical process is contingent on the perception of the process under investigation. It is this interplay between these two positions that informs scientific method, and produces meaningful observations on musical sound (however, this is not to say that this interplay dissolves the disparity between the abstract perfection of the sine curve, and the physical realities of producing a single frequency sound).

This relationship between the deductive and the inductive finds some resonance within aesthetics. On the one had, in etymological and philosophical terms, aesthetics refers to sensory perception. Yet aesthetics also refers the history and study of artistic knowledge, practice, and its relationships to aesthetic experience. Of course, this comparison is not made to imply that artistic knowledge is in some way necessarily divorced from sensory experience, or that aesthetic experiences are wholly sensory: as in acoustics, perception involves conception, and vice versa. It is only to acknowledge that ideological and philosophical positions play a role in aesthetics, and also in the determining of aesthetic experience. Rather than becoming hamstrung by the irreconcilability of the abstract and the empirical, it can be said that aesthetics and science each generate meaningful statements on musical sound through exchanges between these two positions.

Acoustics can be used as a hermeneutical frame for exploring the connections between aesthetics and science, as it forms a link between these two domains. In fact, a history of the scientific inquiry into musical sound cannot be divorced from a history of musical aesthetics, and acoustics draws its aesthetic consideration of sound from the realm of music. Therefore, acoustics does not necessarily offer independent reflection on the status of music, and any assumption of the objective character of acoustics in regard to questions of musical sound must be called into question. As mentioned above, the field of acoustics is far broader in scope than simply the study of musical sound, and there are many instances where one 'spoke' on the acoustics wheel may be brought to bear in critiquing claims made of musical sound.

Identifying these nexus points between aesthetics and science might be construed as a convenient process for constructing a number of simple binary oppositions. Instead, they are perhaps better understood as complex sites, places where information is not simply oscillated between one field and another unchanged but is instead subject to *transduction* - the process by which energy received from one medium generates related energy in another medium. In this way, the concepts and practices motivating one domain of knowledge are translated into a different form within another domain (for example, where the aesthetics of music informs acoustics). Identifying, exploring and expanding upon this diverse series of interconnections establishes a basis for critically addressing both the rhetorical and experimental categorisation of musical sound in an act of restoration - not by aiming to somehow renew the 'empiricism' of empirical science, but by sifting through and critiquing what has been excluded from these accounts of sound due to processes of reduction and refinement. In other words, to locate and situate those other sounds, concepts and meanings that were dissipated in the heat of formulation.

The acoustic and the auditory

The appeal to transduction forms the basis of a sensory-based methodology for investigation, making the ear the primary site for examining both the experiments and demonstrations of Helmholtz and Tyndall, and the compositions of Young and Lucier. This metaphorical transduction mimics the reception of sensations by the sensory organs, such as the ear, the eye, and the skin, through which processes of perception occur.[9] With this in mind, employing a sensory model considers the sound, the sonic, and the audible as its first priorities. For this thesis, it means beginning with the sound of sine or sine-like sounds as they occur in either composition or experiment (be that literally or conceptually), and working outwards in two directions: on the one hand following the sound toward the listener, addressing issues of perception, attention and cognition, and on the other tracing the sound back to the concepts and intentions of the artist or experimenter. As transduction also plays a large part in the physical and technological means for generating, recording, amplifying and reproducing sound, this approach can hopefully address the role that both the material and technical aspects of working with sound play in these schemes without the danger of displacing the important themes of listening, attention, and perception that are its central concerns.

This methodology is underpinned by a certain hermeneutic of reversibility. It uses sine waves and simple acoustic phenomena as tools for examining the work of Young and Lucier, and vice versa; the exploration of Young and Lucier's work are used as a means for generating a range of observations on sine waves and simple acoustic phenomena. In its negotiation of the links between aesthetics and acoustics, it aims to reflect on each side of that relationship to provide an account of sound that reverberates between both positions, rather than simply a reading of one through the other. This reversibility is a way of exploring what the investigation of sine waves and simple acoustic phenomena by artists reveals about musical sound and listening, and how an examination of listening practices relating to music provides information on simple acoustic phenomena.

Providing an account of the role the senses play in the intersection of acoustics and aesthetics also achieves one the aims of this thesis, which is to enrich and enliven a discourse situated within a broader field of sound and audition. This has been prosecuted by writers, researchers and theorists across a wide range of disciplines, in recognition of what ethnomusicologist and anthropologist Veit Erlmann has described as "the need for the cultural and historical contextualisation of auditory perception."[10] This study of sound, called *auditory culture*, or simply *sound studies*, has an ambit to rival acoustics.[11] In its examination of the cultural status of sound and listening, auditory culture has attempted to address the visual bias, or ocularcentrism, of western post-enlightenment culture.[12] However, in doing so, contemporary writers in the field have not aimed to re-enact a hierarchy of the senses by replacing sight with hearing.[13] Instead, their methodology has been to attend to sound, hearing and listening on its own terms - be that cultural, social, historical, technological, physical, physiological, and psychological. Nor does this mean that the study of sound is or has been undertaken in sensory isolation. Hearing is one amongst the senses, and exploring the connections between sight, touch, smell and taste have been crucial in works that aim to 're-listen' to sound, both in the body and in culture.[14]

As this thesis examines notions of the sensory within acoustics and music, it cannot avoid addressing the significant role that processes of visualisation have played in the scientific investigations of sound and hearing, and also how similar procedures appear in the work of Lucier and Young. Historian Lynn Gamwell has cited the role that scientists of the late nineteenth century played in revealing "hitherto abstract invisible realms", not just through the microscopic world of biology, or the unconscious of experimental psychology, but in the visualisations of sound and otological work performed by natural philosophers such as Helmholtz.[15] Michel de Certeau holds that this new representational capability of science, with its "indefinitely extensible field of optical investigations", marked an epistemological shift, where that which was made visible became synonymous with the real, producing what he calls a belief in vision, the "identification of the seen with what is to be believed."[16] For de Certeau, the 'real', previously the realm of other sensory modes has since then been increasingly subsumed by vision.

Whether the work of Helmholtz, Tyndall and others involved an encounter with the 'real' is a matter of conjecture, but experimental procedures for the visualisation of sound did provide what they considered to be important and convincing forms of verification of their theories on the structure and behaviour of musical sound and vibration. This served to give sound an ontological foothold in the ocularcentric scientific environment of the late nineteenth century. The rendering of the physical vibrations of sounding bodies into graphic representations of sound provided a means by which the transient phenomenon of sound could be apprehended and made the object of visual scrutiny as to its form and dimension. Visualisation also plays a similar verification role in the work of Lucier, and to a lesser degree with Young, where visual cues would be helpful for locating and highlighting specific acoustic phenomena, such as providing cues to the behaviour of sound in space.[17]

Experimental science and music each frame aural experiences in a different way, and aim to construct listening for their own ends: both activities select a range of sounds to be perceived, accompanied by an set of listening techniques and listening positions. Where hearing is understood as the perception of sound by the ear, listening is the act of directing ones attention to specific elements in the incoming sound stimulus. For example, to listen to music is different from hearing all the ambient sounds which might occur in a space while a radio is playing, just as to listen only to the vocal harmonies in a given song is different to listening to the vocal parts and instrumental accompaniment as a whole. *Attention* plays a crucial role in the reception of sensory input: it is the focused awareness of activity in the world that transforms curiosity into interest, and turns concentration into absorption. It has been characterised a number of different ways: sometimes attention is simply a synonym for concentration, at other times it refers to a state of vigilance or detection, or the ability to select and sort a piece of incoming stimulation for further analysis.[18] Regardless, in listening, attention turns hearing from a perceptual fact into a conscious act.

Listening in experimentation, technology, and music

That attention, and listening in particular, can be directed or focussed means that it can be harnessed in the investigation of acoustic phenomena by acousticians and musical experimentalists. Helmholtz attempted to utilise listening as a crucial part of empirical scientific verification by focussing attention onto the smallest parts of musical sound in order to confirm its component structure. Attention would play a more ambiguous role in the listening scheme proposed by Young and his sine wave compositions, where it would become synonymous with a mensuration that would in turn produce psychological effects. However, artists or experimenters who wished to control or direct attention needed to negotiate its subjective character, problematising moves to employ the ear in systems of verification in science, and for the auditing of specific sonic effects in music. In fact, the subjective nature of attention has challenged attempts to study attention itself. For example, Michael W. Eysenck notes that one of the major limitations to attentional research has been the ability of subjects to oscillate between attending to the *external* environment and their own personal *internal* environment.[19] Exploring how listening is constructed both within and by these experimental and aesthetic schemes requires an examination of how attempts to control this oscillation between the interior self and the physical world limit, delimit or enhance opportunities for demarcation and discrimination within the auditory domain.

The history of sound and listening in the twentieth century - in both science and art - has been paralleled by the development of the mechanical and electronic means for recording, distributing, storing, transforming and replaying sound. Therefore an investigation of these related technologies is a key consideration for a study of audition in that period. However, rather than regarding technology as a range of science-based artefacts (which might then in turn be hinged to notions of sophistication), this work considers technology to instead be the organising principles that relate to systems of practical knowledge. As Stuart Macdonald indicates, technology can be regarded "simply as the way things are done, and technological change as the adoption of what are thought to be better ways of doing things."[20] In practical terms, this means particular technologies can be considered as representing particular methods for doing things, or as a series of techniques related to a specific purpose. Therefore, exploring the role of technology in acoustics, and in the work of Lucier and Young, becomes an investigation into the historical deployment of a structure of related techniques, as they relate to experimental and aesthetic concerns, rather than a progress narrative about equipment. For Macdonald, technology is "really the sum of knowledge - of received information - which allows things to be done, a role which frequently requires the use of machines, and the information they contain, but conceivably may not."[21] Although it unnecessarily posits technology as the sum of knowledge (in that the use of a given technique need only draw on part of that knowledge), Macdonald's definition of technology is applicable in this discussion, given that schemes for the verification and identification of acoustic phenomena in both the sciences and the arts invariably incorporated the ear. Within these schemes, techniques of listening became linked to the mechanical and electronic processes for generating and reproducing sound, at times producing a technologised form of listening.

The range of technologies employed by both experimenters and artists in their investigation of sound often involved the deployment of existing techniques and artefacts in a new context, rather than the development of wholly new instruments or equipment. For instance, Fourier's harmonic analysis, which provided the mathematical basis for the analysis of the structure of musical sound, was initially formulated to explain the dissipation of heat. The history of many early electronic instruments also involves a kind of reconceptualisation, where it was as much a question of determining new contexts for the sounds generated by an existing apparatus or system than designing new instruments from scratch.[22] In the case of Lucier and Young, the field of acoustics and scientific investigation itself constituted a kind of 'technology' that could be brought to bear in their compositions. It was not only the source of the sine wave - the benchmark sound of the acoustics laboratory - it was also the source of processes for the production, classification and identification of simple acoustic phenomena.

One discipline to which this thesis obviously relates is the study of music, and although its theoretical ambit overlaps in part with the concerns of musicology, musicology's resources are insufficient for a study such as this one, and its concerns are at a tangent to those presented here. Historically, the study of music has deflected attention away from questions of the sonic and instead fixated on the textual analysis of the score. Recent movements within musicology have diversified to include performance practices, audience reception and cultural readings, but still tend to shy away from its transient, temporal subject - sound. As stated above, this thesis takes sound as its starting point, and encounters musicology as only one of a number of relevant aesthetic and scientific disciplines that can inform a broader study of sound, be that physics, performance studies, mathematics, or neurobiology.

The continued reliance on the score within musicology suggests not only a reluctance to consider sound on its own terms, but a reticence to take into account the different roles listening plays in aesthetic experience. This has hampered the ability of musicology to reflect on much sound- and listening-based Post-Cagean experimental composition, let alone discuss the use of sound in other art forms (such as cinema, installation or radiophonic work). The centrality of the role of listening in the compositions of Lucier and Young acts to destabilise textual readings of their work; instead it requires an attention to the physical, spatial and environmental factors that reside within their compositions. Placing an importance on listening also unravels the objectification implicit in a singularly styled ‘audience,’ instead revealing a collective of listeners whose positions and experiences are comparable but by no means identical.

This thesis - like musicology - is engaged in extensive discussions on various definitions of musical sound. However, in addressing the compositions of Young and Lucier, the sonic component of those works needs to be understood as possessing all the physical and material properties, behaviours, and understandings attributed to any kind of sound in the most general sense, rather than restricting it to the definition ‘musical sound’. This position is also required to be reversible, in that where these artists are concerned, any sound is seen as being available for employment within the context of art, or indeed music. Composition is consequently understood as the result of listening to, and making use of, the attributes of sound in order to make new music. Therefore, it can be said that the centrality of the role of listening in the work of Lucier and Young allowed sound to break away from the immediate concerns of music, in order to participate in a revitalisation of musical practices.

Outline of thesis

This thesis has been structured in two parts. Chapters One and Two aim to provide an historical context for the study of sine waves and simple acoustic phenomena in the work of Alvin Lucier and La Monte Young. The first of these chapters takes the form of an account and selective critique of the work of acousticians and experimental scientists in the late nineteenth century. It discusses how the application of Fourier analysis to the question of musical sound by Georg Ohm conflated classical and contemporary definitions of musical sound around the figure of vibration, and in the process produced an artefact in the form of the sine wave. The analysis then proceeds to document how this account of musical sound was subsequently investigated by experimental scientists such as Herman von Helmholtz, John Tyndall and Baron Rayleigh, and popularised through their writings and lectures on music and on sound in general. Lastly, it investigates the ramifications of rhetorical and experimental attempts to define, produce, and hear these 'simple' sounds, and examine the metaphor of the wave and its relationship to these definitions of musical sound.

Chapter Two attempts to establish a context for the works produced by Young and Lucier in the experimental music milieu of the 1960s and 1970s that were aimed at the investigation of simple acoustic phenomena, predominantly with the use of sine waves. It examines firstly the means by which a range of sine and sine-like sounds were generated - initially as a fixed sound for the purpose of scientific investigation, then as the sound of early electrical musical instruments. This is followed by an examination of the relationship between sine wave (or sine-like) sound and the call for the expansion of musical resources within the European and American *avant-garde* of the first half of the twentieth century, as proposed by composers such as Ferrucio Busoni, Luigi Russolo, Edgard Varèse, Henry Cowell, John Cage, Harry Partch and Carlos Chavez; a rejuvenation of music that took place alongside the social and cultural proliferation of technological means for producing sound, such as radio and phonography. In doing so it traces the influence of theories drawn from the field of acoustics on these composers, and how it applied to moves to utilise *extra-musical* sounds - such as the noises of everyday life - as musical materials. While not aiming to provide a definite account of the era, it instead depicts a range of aesthetic responses to acoustics, from antipathy to adoption. Whatever their stance, all of these composers displayed a tendency towards establishing a more expansive sonic discourse than that decreed by orthodox musicology, whether that be the *noise-sound* of Russolo, the *infinite gradation* of tone of

Busoni, or the *all-sound* of Cage. The work of Lucier and Young would be founded on, and also contribute greatly to, this broader understanding of sound within music.

The four chapters that comprise the second part of the thesis present in-depth case studies of the work of La Monte Young and Alvin Lucier. Each of these studies is spread across two chapters. The first chapter of each case study presents an examination of the work of one composer up to the introduction of sine waves in their oeuvre. Although these chapters examine works that are 'pre-sine', they establish the aesthetic and historical basis for their work with simple acoustic phenomena, and map the development of conceptualisations of sound and listening in their artistic practice. The second chapter of each case study offers an investigation of the period where sine waves came to play a significant role in their aesthetic as a distinctive sonic component, and as an important conceptual tool for devising, and for explaining, the effects of their compositions. Sine waves were also a primary means by which the influence of acoustics - both in notions of the structure of musical sounds, and of the behaviour of sound in space - would make its effects felt. These two case studies document the role acoustical theories played in their conceptualisation and realisation of musical works, and examines problematic aspects of this association, specifically in relation to the work of Young, where the imperatives of intersubjective verification, on which inductive science depends, came in contact with his personalised aesthetic programme.

The first case study documents the work of Minimalist composer La Monte Young. Chapter Three explores the origins of the long tone in Young's early works and the development of his concept of listening 'inside a sound', before tracking the progressive alterations to this concept implied by each of his compositions. After documenting the influence of his childhood experiences of sound on his musical development, the chapter presents an examination of Young's early compositions, from *Trio for Strings* (1958) and *2 sounds* (1960), the conceptual works that parallel his involvement in the formative days of the Fluxus movement, his work with rule-based improvisations, and ends with the formation of the Theatre of Eternal Music. It identifies the sources of several characteristics of Young's work that were to significantly influence his formulation of sound and listening: extended duration; the employment of whole number ratios as a compositional tool; the influence of natural and environmental sounds; conceptual sounds; the music of India and Japan; and the early stages of his employment of electronic technology.

Chapter Four covers the period from 1966 until 1974, and investigates Young's extensive use of sine tones for realising his compositions. This chapter begins with a tracing of the theoretical and conceptual origins of the two primary works from this period: the 'sine-tone installation' *Dream Hous*e and his composition *Map of 49's Dream The Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery* (1966-present). The analysis then proceeds to investigate in some detail the relationship between these two works, and focuses on the formal, physical and conceptual role that sine waves played in their realisation. It also examines Young's notion of a sonic environment, and its relationship to the sounds of technology and the sounds of nature. Lastly, it presents an examination of Young's attempts to enact specific relationships between number and musical sound with sine waves, and how this formulation impacts on his notions of sonic spatiality and perception.

The second case study investigates the work of experimental composer Alvin Lucier. Chapter Five concentrates on the period from the early 1960s until 1972, and examines those early works that explore the presentation of natural acoustic phenomena in musical composition. Lucier considered that his works that used simple acoustic phenomena as their subject capable of drawing attention to what he considered the disregarded or overlooked aspects of sound and its behaviour in space, which he conceptualised in the phrase "making the inaudible audible". The analysis then proceeds to examine how this strategy corresponded with a programme of depersonalisation or distanciation, which served to place emphasis on acoustic effects rather than personal expression. The development of these two concepts within Lucier's aesthetic - revealing the hidden aspects of the sonic landscape and depersonalisation - is traced through a discussion of the series of works Lucier instigated during this period, and explores how these two concepts relate to notions of musical language, scientific experimentation, and technology, and to notions of environment and space. This chapter employs the tropes of repetition and reverberation in charting the progressive extension of the duration of sounds in these compositions. In doing so, it documents how Lucier's use of environmental acoustics, and his utilisation of electronics and technology (such as amplification, sound recording and synthetically produced sounds in a live performance context), extended the duration of sounds - setting a precedent for his later work with sine waves.

Chapter Six examines the scope of Lucier's sine wave pieces from 1973 until 1984, focussing specifically on the range of works that Lucier regarded as exploring the "spatial characteristics of sound itself", beginning with the initial version of *Still and Moving Lines of Silence in Families of Hyperbolas* (1973-74) and ending with the later, revised version from 1984. This chapter discusses how these works marked a significant change in Lucier's sound resources and compositional imperatives, and saw him negotiate a new series of relationships between the spatial and the sonic. Also, it considers the significance of a range of concurrent compositions that explored the theme of sound visualisation, which had begun with *The Queen of the South* (1972), drawing out Lucier's relationship to the history of acoustics, and identifies how these works influenced his conceptualisations of sound in space. In following these themes, this discussion identifies both the practical and theoretical aspects of sine waves as important aspects of

Lucier's compositional practice, and provides a means for investigating how notions of sound, technology and the environment function in his work during this period.

In choosing to examine the role acoustics has played in experimental compositions that employed sine waves to explore simple acoustic phenomena, this thesis charts an interdisciplinary (and perhaps somewhat idiosyncratic) path. It attempts to provide a new reading of instances where the meaning of musical sound was formulated by re-examining the context of those formulations and re-evaluating the findings or conclusions they produced. In doing so it aims to identify a range of possibilities for understanding the wider questions of the sonic and the auditory as they occur within contexts that might otherwise be simply considered to be 'about' music.

To some, a study such as this one - that surveys a set of sonic relationships between art and science - might be thought to occupy an uncomfortable position, straddling a theoretical divide between two disparate and dissimilar discourses on the subject of sound, and its composition, organisation and effects. One defensible reason for occupying such a position is that this is the very place the artists, scientists and natural philosophers whose work is surveyed are themselves to be found, even though they may have come to occupy this position from one particular side. In its execution, this work attempts to recount through narrative, analysis and critique, the claims each side - art and science, or perhaps aesthetics and experiment - makes for the other, and in the process endeavours to tease out the what, the how and the why of sine waves and simple acoustic phenomena as they relate to musical aesthetics.

[1] Robert Ashley, "Landscape with Alvin Lucier," in *Music with Roots in the Aether: Interviews with and Essays About Seven American Composers*, ed. Gisela Gronemeyer & Reinhard Oehlschlägel (Köln: MusikTexte, 2000), 81.
[2] A general discussion of John Cage's aesthetic is neither the aim of this thesis, nor (as the remainder of the introduction will illustrate) within its ambit. For a perceptive critique of Cage see Frances Dyson, "The Ear That Would Hear Sounds in Themselves: John Cage 1935 - 1965," in *Wireless Imagination: Sound, Radio and the Avant-Garde*, ed. Douglas Kahn and Gregory Whitehead (Cambridge: MIT Press, 1992).
[3] Liner notes, Tony Conrad, *Four Violins (1964)* (Table of the Elements, 1996), LP record.
[4] Douglas Kahn, *Noise Water Meat: A History of Sound in the Arts* (Cambridge: MIT Press, 1999), 158.
[5] Michel Serres, *Genesis*, trans. Geneviéve James & James Nielson (Ann Arbor: University of Michigan Press, 1995), 3.
[6] Michel Serres, *Hermes: Literature, Science, Philosophy*, trans. Ilya Prirogine and Isabelle Stengers (Baltimore: Johns Hopkins University, 1982), 68.
[7] Frederick V. Hunt, *Origins in Acoustics: The Science of Sound from Antiquity to the Age of Newton* (New Haven: Yale University Press, 1978), xiii - xiv.
[8] R Bruce Lindsay, "Proceedings of the Conference on Education in Acoustics," *Journal of the Acoustical Society of America* 37 (1965): 361.
[9] Strictly speaking, the sense organs are the source of *exteroception*, the perception of mechanical and electromagnetic energy fields in surrounding space. The body has two other major sub-classes relating to other types of transducers in the body. *Proprioception*, the perception of the orientation and action of the body in space is based on the information provided by the proprioceptors, such as skeletal muscle spindles, tendon organs, and joint strain receptors. Interoceptors, such as stretch receptors of the atria and carotid arteries, chemoreceptors of the carotid sinus and mechanoreceptors in the skeletal muscles, form the basis of *interoception*: the central neural representation of the blood vessels and visceral organs. This is not to say that sound is only experienced through exteroception. For example, very loud and very low sounds can result in full body sensory experiences, only part of which is perceived aurally. B. R. Dworkin, "Interoception," in *Handbook of Psychophysiology*, ed. John T. Cacioppo, Louis G. Tassinary, and Gary G. Bernston (Cambridge: Cambridge University Press, 2000), 482.
[10] Veit Erlmann, "But What of the Ethnographic Ear? Anthropology, Sound, and the Senses," in *Hearing Cultures: Essays on Sound, Listening and Modernity*, ed. Veit Erlmann (Oxford: Berg, 2005), 3.
[11] A number of significant texts can be said to fall within a field called 'auditory culture', without making any specific claims that these works either constitute the field, or indeed were formulated within it, apart from perhaps *The Auditory Culture Reader*, ed. Michael Bull & Les Back (Oxford: Berg, 2003). However, all of them respond to the imperative suggested by Erlmann. A number of writers have provided readings of sound and aurality from a variety of historical positions, such as *Hearing History: A Reader*, ed. Mark M. Smith (Athens: University of Georgia Press, 2004); Alain Corbin, *Village Bells: Sound and Meaning in the Nineteenth Century French Countryside*; Trans. Martin Thom (New York: Columbia University Press, 1998); John M Picker, *Victorian Soundscapes* (New York: Oxford University Press, 2003), and Mark M. Smith, *Listening to Nineteenth-Century America* (Chapel Hill: University of North Carolina Press, 2001). The significance of the auditory across social, cultural and anthropological contexts is examined in works such as *Hearing Cultures: Essays on Sound, Listening and Modernity*, ed. Veit Erlmann (Oxford: Berg, 2005); Jonathan Sterne, *The Audible Past: Cultural Origins of Sound Reproduction* (Durham: Duke University Press, 2003); Steven Connor, *Dumbstruck: A Cultural History of Ventriloquism* (New York: Oxford University Press, 2000); Emily Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America 1900-1933* (Cambridge: MIT Press, 2002), Paul Carter, *The Sound In Between: Voice, Space, Performance* (Sydney: NSW University Press, 1992) and Steven Feld, *Sound and Sentiment: Birds, Weeping, Poetics, and Song in Kaluli Expression* (Philadelphia: University of Pennsylvania Press, 1990). Issues of technology, sound and cultural

practice are surveyed in *Sound States: Innovative Poetics and Acoustical Technologies*, ed. Adalaide Morris (Chapel Hill: University of North Carolina Press, 1997); Friedrich Kittler, *Gramophone, Film, Typewriter*. Trans. Geoffrey Winthrop-Young & Michael Wutz (Stanford: Stanford University Press, 1999); Mark Katz, *Capturing Sound: How Technology has Changed Music* (Berkeley and Los Angeles: University of California Press, 2004); James Lastra, *Sound Technologies and the American Cinema: Perception, Representation, Modernity* (New York: Columbia University Press, 2000). Two works have been influential in extending a history of sound in the arts beyond the domain of music: *Sound by Artists*, ed. Dan Lander & Micah Lexier (Toronto: Art Metropole; Banff: Walter Philips Gallery, 1990) and Douglas Kahn, *Noise Water Meat: A History of Sound in the Arts* (Cambridge: MIT Press, 1999) to which this present work owes a great debt. Other works in the aesthetics of sound include *Radio Rethink*, ed. Dan Lander & Daina Augaitis (Banff: Walter Phillips Gallery, 1994); Penelope Gouk, *Music, Science and Natural Magic in Seventeenth-Century England* (New Haven: Yale University Press, 1999); *Wireless Imagination: Sound, Radio and the Avant-Garde*, ed. Douglas Kahn & Gregory Whitehead (Cambridge: MIT Press, 1992); and Christoph Cox and Daniel Warner, eds., *Audio Culture: Readings in Modern Music* (New York: Continuum, 2004).This is merely a brief survey of works, and should in no way be considered definitive.

[12] A thorough account of the ocular bias of western culture is given in Martin Jay, *Downcast Eyes: The Denigration of Vision in Twentieth Century French Thought* (Berkeley: University of California Press, 1993).

[13] It has at times been customary for writers on sound to step into the breech and defend sound and hearing from the visual bias of western culture. In decrying the dominance of the visual in western cultural forms, there has been a tendency for writers from certain critical positions to recount a series of binary distinctions that serve to define the differences between sight and hearing (for example: sight is directional, perspectival, objective, exterior, spatial; sound is spherical, immersive, subjective, interior, temporal, and so on). Historian Jonathan Sterne has referred to this list of comparisons as the 'audiovisual litany'. In his critique of the litany, Sterne locates its origins in Christian spiritual traditions that idealise hearing and aligns the voice with the spirit - ascribing a kind of 'pure interiority' to auditory experience. As Sterne indicates, the interiorised and individuated account of aurality provided by this litany can act as an impediment to cultural readings of sound. This is not to necessarily give credence or to find fault with either reading. However, Sterne's critique is helpful in picking apart these somewhat romanticised and idealised notions of sound and listening. For his lucid discussion of this subject, see Jonathan Sterne, *The Audible Past: Cultural Origins of Sound Reproduction* (Durham: Duke University Press, 2003), 15-19.

[14] For more on the significance of an interrelated understanding of listening, hearing and intention in historical and cultural investigations, see Paul Carter, "Ambiguous Traces, Mishearing, and Auditory Space," in *Hearing Cultures: Essays on Sound, Listening and Modernity*, ed. Veit Erlmann (Oxford: Berg, 2005), 43-63.

[15] Lynn Gamwell, *Exploring the Invisible: Art, Science, and the Spiritual* (Princeton: Princeton University Press, 2002), 152-57. See also Jennifer Tucker, "Photography of the Invisible," in *Nature Exposed: Photography as Eyewitness in Victorian Science* (Baltimore: Johns Hopkins University Press, 2005), 159-93.

[16] Michel de Certeau, *The Practice of Everyday Life*, trans. Steven Rendall (Berkeley: University of California Press, 1984), 187.

[17] These themes of the visualisation and representation of sound will be more thoroughly pursued in relation to late nineteenth century science in chapter one, and in the work of Alvin Lucier in chapters five and six.

[18] Neville Moray, *Attention: Selective Processes in Vision and Hearing* (London: Hutchinson Educational, 1969), 5-6.

[19] Michael W. Eysenck, *Principles of Cognitive Psychology* (Hove: Lawrence Erlbaum Associates, 1993), 43.

[20] Stuart Macdonald, "Technology Beyond Machines," in *The Trouble with Technology: Explorations in the Process of Technological Change*, ed. Stuart Macdonald, D. McL. Lamberton, and Thomas Mandeville (London: Frances Pinter, 1983), 27.

[21] ibid.

[22] Similarly, much of the laboratory apparatus used by Heinrich Hertz in his experimental work on the theories of James Clark Maxwell were considerably older than Maxwell's question of electromagnetic waves itself. See "Technologies of sine-sound (and sight)" in chapter two.

1. Creating a wave in the nineteenth century: from sound into sine

This chapter seeks to trace a history of the sine wave, locating its origins in the fertile period of acoustics in the nineteenth century. During this time new techniques of mathematical analysis were brought to bear on the question of musical sound. These techniques were accompanied by new technological means for the observation, audition, and production of sound. Together they formed basis for acoustic investigation in this era. The sine wave appeared as a product of the combination of the theory for the analysis of heat developed by French mathematician and physicist Jean Baptiste Joseph Fourier (1768-1830), and its application to the question of musical sound by German physicist Georg Ohm (1787-1854) in the first half of the nineteenth century. However, the expansion and popularisation of this and other ideas pivotal to the development of contemporary acoustics occurred in the latter half of the nineteenth century, many of which stem from the experimental research and publications on sensation, perception and musical sound by German anatomist and physicist Hermann von Helmholtz (1821-1894).

Central to Helmholtz's inquiry into sound was the observation that any given sound event was not singular, but composite. The application of Fourier analysis to the problem of musical sound gave acousticians of the late nineteenth century a means by which they could explore the composite nature of sound. It provided them with the ability to analyse sound - to break down, or *decompose*, a given sound into its individual frequencies. A principle aim of this chapter is to investigate some of the ramifications of analysing sound in this fashion. In doing so it aims to explore how the application of Fourier's theory for decomposing musical sound into its component parts introduced the concept of a simple sound that would have only one frequency component, construed as the musical harmonic. It will also examine various attempts by Helmholtz to hear these sounds in isolation - as separate elements within a matrix of sound.

The successful application of Fourier's theory would also depend on closely defining its subject by drawing both rhetorical and physical demarcations between musical sound and noise. In identifying the points where these distinctions came to inform theories about the sound of music and the sense of hearing, this chapter will explore what role these factors played in investigations into the physiology of the ear. It will also examine how these definitions contributed to the aesthetic discussions that took place within acoustics in the late nineteenth century in relation to musical sound.

Defining and decomposing musical sound and noise

In 1822, French mathematician and physicist Jean Baptiste Joseph Fourier published *Théorie Analytique de la Chaleur* [*Analytic Theory of Heat*]. Although the work did not contain any acoustic theory *per se*, it was to have a profound effect on the field of acoustics, providing what has become one of the key mathematical techniques for the analysis of sound. Fourier's theory demonstrated "that a finite and continuous periodic motion can always be decomposed into a series of simple harmonic motions of suitable amplitudes and phases," implying that any manner of complex wave phenomena could be mathematically broken down into an interrelated series of simpler waves for the purposes of scientific examination.[1] As Robert Bayer has noted, this concept was readily adopted by Georg Ohm, who in 1843 asserted in his laws of acoustics that Fourier's model was not only an accurate representation of musical sound, but offered a complementary description of the process of aural perception. Ohm considered the ear itself performed its own Fourier analysis, and was capable of disassembling a musical tone into its separate component simple tones. Ohm applied Fourier's theory to musical sound before the technological and scientific means had been developed such that this kind of analysis of an actual sound was possible. However, it provided a conceptual framework for understanding the component nature of sound once an actual waveform could be measured.[2] In anticipation of this eventuality, Ohm represented a pulse of sound with a series of sine and cosine curves, showing the fundamental frequency and the higher harmonics, the frequencies of which were all multiples of the fundamental.[3]

There are a variety of terms for describing the component part of a given sound, the three most common being the *overtone*, the *harmonic*, and the *partial*. While the three terms ostensibly describe the same phenomena, each represents a different descriptive model of sound. Although within music these terms are often used interchangeably, in the field of acoustics the definition between partials and harmonics relates to the nature of the intervallic relationships between the components under examination.[4] The term harmonics usually is restricted to describing frequency components that have a simple whole number relationship (for example, 100, 200, 300 Hz.), whereas partials designates the relationship between frequency components of one complex tone that do *not* have a simple whole number relationship (100, 180, 225 Hz.). Additionally, the term overtone, the "erroneous translation" of Helmholtz's *obertön* (literally 'upper tone'), carries within it the implication of a vertical construction for sound, with the lowest frequency component designated the fundamental.[5] However, what all these designations share is their common reference to frequency, measured in cycles per second, or hertz (Hz).

Ohm posited that the prevailing notion of a 'sound wave' - characterised as a regularly fluctuating disturbance or vibration in the air - could be represented graphically as a *complex periodic waveform*: complex in that the shape of one oscillation was not sinusoidal, but periodic insofar as each oscillation was considered identical. By then performing Fourier analysis on particular types of complex periodic waveforms the makeup of musical sound could be determined, not just by showing its component parts, but through describing the mathematical relationships *between* those parts. In doing this, Fourier analysis also served to contract ideas about sound - not just the relationship between musical sound and the sense of hearing, but; the radiation of sound in physical space (a moving wave of sound); the production of sound in vibrating strings; and the intervallic relationships of harmony. Most importantly, however, was Ohm's suggestion that the ear also analysed sound in this manner, as this allowed Fourier's' theory to provide a mathematical link between physics and physiology on the question of musical sound. It would be Helmholtz, following in the wake of Ohm, who would initiate a comprehensive investigation into this relationship between sound and hearing.

In the mid nineteenth century, as historian John Picker has noted, the field of acoustics lacked a foundational set of principles, a "summa acoustica that could simplify and connect the disparate areas of sound production, transmission, and what was most complex of all, perception."[6] Helmholtz's acoustic investigations were duly aimed at rectifying the lack of unity across the scientific disciplines in relation to musical sound, aiming to "connect the boundaries of two sciences, which, although drawn towards each other by many natural affinities have hitherto remained practically distinct – ... the boundaries of physical and psychological acoustics on the one side, and ... musical science and aesthetics on the other."[7] In fact, the integration of different disciplines had been central to developing Helmholtz's initial interest in acoustics in 1852, after he had identified and corrected mathematical errors in the studies of wave propagation made earlier by John Challis.[8] According to Helmholtz, the study of musical sound would be aided by an interdisciplinary approach that incorporated physics, philosophy and aesthetics, in order that this problem be "thoroughly considered and advanced towards its solution."[9]

Helmholtz had been a student of physiologist Johannes Müller (1801-1858) at the Royal Friedrich-Wilhelm Institute for Medicine and Surgery in Berlin, and had been exposed to Müller's materialist theories of perception.[10] Müller proposed that each sense organ produced nerve impulses in response only to one kind of input - what he called 'sense specific energies' - which might vary in intensity but not in kind.[11] He considered it was the specificity of this relationship between stimulus and sense organ that accounted for the way in which the senses produced individual perceptions from the broad spectrum of information provided by the physical world.[12] Helmholtz in time became a member of the Berliner Physikalische Gesellschaft [Berlin Physical Society], established by former students of Müller, which proposed that all phenomena could be accounted for by physical principles, including neural and mental phenomena.[13] In line with these influences, Helmholtz's subsequent work sought to explain perception as a series of material processes which could be investigated through experimentation.

Although a medical doctor by training, Helmholtz initially made his name through his work on the principles of the conservation of energy. Studying the role of heat in muscle action, he moved beyond documenting empirical phenomena to derive more fundamental laws; this resulted in his concept of potential energy.[14] From here he began substantial studies into optics. These included the development of the theory of complex colours, studies of the eye and acuity, and invention the ophthalmoscope - culminating with the publication of his *Handbook for Physiological Optics* in 1856.

This publication formalised Helmholtz's empirical or cognitive theory on the material processes of the sense organs. Theo Meyering has indicated in his study of Helmholtz's role in the history of cognitive science that this thesis overturned existing ideas about the nature of perception. As Meyering describes, Helmholtz's theory states that "the very material in the afferent nervous system for the subsequent formation of perceptions of reality does not copy external reality but constitutes a *naturally given system of symbols* which the human organism must *learn* to interpret for the development of adaptive patterns of behaviour" (emphasis in original).[15] Helmholtz's theory effectively proposed a division of the sensory process into discrete physical, physiological, and psychological stages.[16] He contended that perception was not immediate, and not wholly determined by sensory input in the manner that Müller's theory described. It was instead the mediated product of a combination of sense data, the reception of that data through the material structure of the sense organs, and higher mental processes - where nerve impulses induced by external stimuli constituted a kind of code which the human brain must learn to interpret in order to receive information about the physical world.

Influenced no doubt by his background in physiology, Helmholtz commenced his investigations into musical sound from the standpoint of sensation. Despite the fact that he considered all processes of perception to be the product of physiological mediation, he made a special case for the perception of music, stating that it stood "in a much closer connection with pure sensation than any of the other arts." In his comparison of visual contemplation with musical audition, Helmholtz explores the aesthetic value of this relationship between music and sensation:

> It is only in painting that we find colour as an element which is directly appreciated by sensation, without any intervening act of the intellect. On the contrary, in *music*, the sensations of tone are the material of the art. So far as these sensations are excited in music, we do not create out of them any images of external objects or

> actions. Again, when in hearing a concert we recognise one tone as due to the violin and another to a clarinet, our artistic enjoyment does not depend upon our conception of a violin or clarinet, but solely on our hearing of the tones they produce, whereas the artistic enjoyment resulting from viewing a marble statue does not depend on the white light which it reflects into the eye, but upon the mental image of the beautiful human form it conjures up.[17]

Helmholtz's contention that music constituted a 'special case' seems predicated, in part, on his comparison of the sensations of tone by the ear in music with the sensations of colour experienced with the eye in painting. He found that where the sensation of colour in a given painting cannot exist independently of its physical manifestation as stretched canvas and pigment, the tones that stimulate the ear are *immaterial*. The idea that sound in this description seems to arrive immediately and unmediated, moving through time, revealing nothing but itself, creates a problem for Helmholtz's own theory of mediated perception. However, the most important aspect of this description is on aesthetic pleasure, which is thought to be derived solely from perceiving the *sensations* of tone, not the tones themselves (let alone the instruments). Given this framework, determining the nature of this encounter between sense and sensation and its relationship to aesthetic experience would therefore depend on both an understanding of tone as the active element of musical sound and an understanding of the function of the ear. Investigations into musical sound would therefore require a mechanism for the extraction and identification of individual tones, and the definition of their role in relation to individual sensations. Correspondingly, in order to better understand its inner workings, musical sound would need to be halted in its flow, fixed in time and place, and so being effectively converted from physical sensation into an object for scientific investigation.

Given his earlier work defining fundamental principles in optics and energy conservation, it is not surprising that Helmholtz would, in following the lead of Ohm, be drawn to Fourier analysis as a basis for his research in acoustics. He considered Fourier analysis to be central to any adequate theory of sound, due to its ability to reduce complex phenomena such as sound waves into a series of simple phenomena.[18] As Ohm had indicated, it provided a principle that tied together the invisible phenomena of sound and the minute and hidden activities of the ear. At the same time, it presented sound as a collection of components held together in harmony by whole number ratios. This representation of musical sound as whole number ratios seamlessly incorporated Fourier analysis into a tradition of sonic investigation that extended all the way back to ancient Greece, where Pythagoras in the sixth century BCE is reputed to have discovered that harmonic relationships between notes are expressible as ratios of simple whole numbers (for example, 3:2 for the interval of a fifth).[19] All at once, Fourier analysis seemed to offer Helmholtz a heuristic that allowed him to visualise, rationalise and historicise his conception of musical sound as a physiological effect.

Along with the writings and public lectures of John Tyndall (1820-1893), and the work of John William Strutt (Lord Rayleigh) (1842-1919), Helmholtz's work came to define the field of acoustics in the late nineteenth century. His book *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik* [*On the Sensations of Tone as a Physiological Basis for the Theory of Music*] was first published in 1863 and became an influential text for both scientists and musicians.[20] Tyndall's work *On Sound* appeared in 1867, and was based on his lectures and demonstrations. Unlike Helmholtz's book, which covered only music, Tyndall intended his work to survey all areas of acoustics. Likewise, Strutt's two-volume work *The Theory of Sound*, published in 1877-8, was also an attempt to cover all facets of the scientific study of sound.

The publication of *On the Sensations of Tone* had exerted an enormous influence on the work of both Tyndall and Strutt. Tyndall states in the introduction of *On Sound* that there are numerous references to Helmholtz to be found in own his book, but that they "fail to give an adequate idea of the thoroughness and excellence of [Helmholtz's] work".[21] Strutt goes so far as to credit Helmholtz's work as triggering his own interest in acoustics. There was a great degree of correspondence and mutual respect between the three theorists, with Tyndall undertaking the first translation of *On the Sensations of Tone* into English, and Helmholtz returning the favour by translating *On Sound* into German. Helmholtz reviewed both volumes of Strutt's *The Theory of Sound* for *Nature*, deeming it "a complete and coherent theory of the phenomena of sound" and complementing its extensive and rigourous use of mathematics.[22]

Aside from the widespread interest in its subject matter, one of the abiding reasons for the popularity of *On the Sensations of Tone* was its accessibility to the general reader - especially those with an interest in music. Helmholtz placed the more complex mathematical and experimental procedures in appendices at the end of the book, "in order to facilitate the use of the book by readers who have no special knowledge of physics or mathematics".[23] The mathematical formulation of sound via Fourier analysis was still central to his reading of musical sound, but Helmholtz was careful to apply it only after a demarcation of musical sound had been conducted. Before making claims for its ability as a Fourier 'analyser', he would need to define the ear as the site for aesthetic discrimination.

Helmholtz began his tome by formulating a distinction between noise and music. He is not alone in classifying natural, mundane, and quotidian sounds as noise (although he does, however, allow for noises and musical sounds to intermingle, and to "pass insensibly into one another, but their extremes are widely separated").[24] However, for Helmholtz the defining factor in discriminating between music and noise is the relationship between stimulus and the organ of perception. A noise can be determined by "a rapid alternation of different kinds of sounds: ... rapid, irregular, but distinctly perceptible alternations of various kinds of sounds, which crop up fitfully".[25] Predictably perhaps, a musical tone strikes the ear "as a perfectly undisturbed, uniform sound which remains unaltered as long as it exists, and it presents no alternation of various kinds of constituents".[26] This emphasis on the 'striking of the ear' (as in the instantaneous recognition of the sound of the violin in the example above) means that distinctions between music and noise were deemed to be determined physiologically by the ear of the listener at the time of hearing. Deferring to the experiments of unnamed physicists, Helmholtz states that these regular "oscillations, vibrations or swings, that is, up and down, or to and fro" must be necessarily periodic, with a periodic motion being "one which constantly returns to the same condition after exactly equal intervals of time."[27] Hearing musical sound is eventually reduced to this simple distinction: "The sensation of a musical tone is due to a rapid periodic motion of the sonorous body; the sensation of a noise to non-periodic motions."[28]

While Helmholtz contended that musical sound could be differentiated from noise by the ear due to its periodicity, the observations of John William Strutt showed that this distinction was not always so straightforward:

> The extreme cases will raise no dispute; every one recognises the difference between the note of a pianoforte and the creaking of a shoe. But it is not so easy to draw the line of separation. In the first place few notes are free from all unmusical accompaniment. With organ pipes especially, the hissing of the wind as it escapes at the mouth may be heard beside the proper note of the pipe.[29]

To a far greater degree than Helmholtz, Strutt allowed that there be some interplay between musical sounds and noises, with some noises found to be "not entirely unmusical, and notes ... not quite free of noise." There was, however, no confusion as to which was the simpler phenomenon: "There is a certain smoothness and continuity about the musical note. Moreover, by sounding together a variety of notes - for example, by striking simultaneously a number of consecutive keys on a pianoforte - we obtain an approximation to a noise; while no combination of noises could ever blend into a musical note."[30] According to Strutt, noise could not be used to make music - but a surplus of musical sound could approach the condition of noise. Therefore, Strutt's definitions of musical sound were not only used for useful for defining the subject of his inquiry, but for holding noise at bay.

This model of the periodic nature of musical sound had not been proposed by Helmholtz and others in order to force musical sound to conform to the demands of Fourier analysis. Studies of musical sound through the centuries had aligned musical sound with a sense of regularity, from the Pythagorean notion of whole number ratios to seventeenth century discussions of harmony and consonance by Francis Bacon, which explicitly contrasted musical sound against the perceived irregularity of noises.[31] However, the confidence and specificity with which his definitions were presented seems to suggest the conviction Helmholtz had in the relevance of periodicity and the kind of epistemological opportunities and possibilities it presented. Conflating musicality with regularity, a "simple, regular kind of sensation" brought about by the "regular motion of the air, continuing uniformly," boded well for applying schemes of mensuration and mathematical formulation. The recasting of musical sound as regular waveforms abstracted it from the world of quotidian sounds, effectively isolating it even from the kinds of noise Strutt found lurking within music; further, such a recasting had the advantage of providing a subject for analysis that was consistent and uniform.

Defining musical sound as complex periodic waveforms therefore was not just a form of abstraction but an idealisation, in that it represented musical sound as a perfect, regular set of waveforms, totally free of noise. Fourier analysis not only provided a mathematical representation of musical sound, it also subjected the individual components within musical sound to mathematical theorisation. With Fourier analysis the harmonics within a sound in the ear became the sine and cosine functions of a complex periodic waveform on a graph. Both Ohm and Helmholtz had decreed that the harmonic was in fact a simple tone with one frequency component: a sine tone.

Sine waves: some mathematical considerations

The sine has its roots as a trigonometric function and was introduced by Indian mathematical astronomers in the *Surya-Siddhanta*, an Indian astronomical text circa 400 AD. Used for the linear measurement of angles, the sine was understood as half the chord of double the given arc.[32] Sine was further systematised by Islamic mathematicians, who drew from both Indian and Greek trigonometry. In the *Almagest*, a tenth century mathematical text, Abu' al-Wafa (940-997 or 998 AD) related the various functions of sine to the variety of horizontal shadows (or *zill*) cast by a *gnomon* onto the circular face of a sundial.[33] He used these observations to unite a range of trigonometrical functions, which in turn provided important mathematical tools for use in astronomy. The linear measurement of angles was used for determining the angle of the ecliptic, the right ascension of rising and setting of heavenly bodies, the evaluation of distances, and for determining crucial events such as the hour for prayer.[34] The Arabic term for the chord of an arc - *jaib* - became known as sine, from the Latin *sinus* (literally 'curve').

As an abstract mathematical expression, a sine curve, rendered in the two-dimensional Cartesian coordinate system, can express only one specific value along the vertical y-axis. However, along the horizontal x-axis, it is infinite in both directions. The length of a single oscillation - that is the distance between the adjacent peaks in the waveform - can be of any magnitude. Each oscillation of a sine curve is identical. This kind of modular repetition makes sine curves an example of what mathematician Brook Taylor described in 1712 as an "endless power series curve," in that even though a sine curve extends infinitely in both directions along the x-axis, one single oscillation effectively represents its entirety.[35]

In definitions of musical sound, the decomposition of a complex periodic waveform into a related series of individual sine waves has two specific consequences. The first is that it implies that the constituent parts of a given sound - its harmonics or overtones - are individual sounds with one frequency component, and that the visual representation of such a sound is a sine curve. Helmholtz describes these, according to Ohm's formulation, as simple vibrations or simple tones "since they cannot be analysed into a compound of different tones."[36] The second consequence is that the lowest in frequency of these simple tones – the fundamental – determines the overall pitch of a musical sound, as all of the other components are related to it by whole number ratios.

Perhaps influenced by the overtone structure depicted via Fourier analysis, a two-dimensional graph has often been used to examine two of the primary classical concerns of music: the vertical y-axis is used to denote the vertical, intervallic relationships of harmony (pitch space), and is static. The horizontal x-axis becomes the domain of temporality, with changes registered along that axis relating to notions of melody. However, privileging as it does a periodic stasis, Fourier analysis decodes only the vertical construction of musical sound, not the successive fluctuations of melody.

Given that it seeks to describe the composition of sound through the interactions of sine waves, Fourier analysis has to contend with infinity along two axes.[37] As already mentioned, the first of these is the horizontal infinity of sine curves. The second is the chain of successively shortening sine and cosine waveforms arranged vertically along the positive arm of the y-axis. This ascending movement is anchored by the waveform with the lowest frequency of the series, designated the fundamental.

To move from the mathematical abstraction of the Cartesian plane to the exigencies of an actual sound in space and time requires an examination of these apparent infinities, as defining a given musical sound of finite duration through a series of infinitely sounding components is problematical.[38] The question of infinites was one considered by Aristotle, who formed a distinction between *potential* infinities and *actual* infinities. He allowed that potential infinites could exist. For example, the set of positive integers can always have 1 added to the last number in order to produce a new number. However, it was the very notion of incompleteness implicit in that process of infinite addition that lead Aristotle to conclude that actual infinites could not exist.[39] A means of analysing the notion of actual infinites came from the work of Bohemian priest, philosopher and mathematician Bernard Bolzano (1781-1848), who proposed that a set of elements (called, for example, ‘S’) can be said to be actually infinite if the elements in a subset of itself (called ‘s^1’) can be put into one-to-one correspondence with the elements of ‘S’.[40] This was later expanded upon by Georg Cantor (1845-1918) in his work on infinite sets. Cantor posited that a set is actually infinite if its members can be put into a one-to-one correspondence with the natural numbers: this means it is a *denumerable* set.[41] Of course, any subset of an actually infinite set is therefore also denumerable. This is one paradox that suggests actual infinites are purely mathematical.

As plotted on a Cartesian graph, a sine curve could be said to be an example of an actual infinite. At best (and given that it could somehow be maintained infinitely) a sine *tone* could in some ideal situation be considered an example of a potential infinite, in so far as it could continue indefinitely. However, any real world sine tone sound would necessarily be of finite duration. Although theoretically any sound is potentially infinite, the number of oscillations contained in a *potentially* infinite sine tone could still not be put into one-to-one correspondence with the number of oscillations of an *actually* infinite sine curve of the same frequency (or any other for that matter).

Perhaps then, in the absence of an actual infinite, it is still reasonable to consider the case of what might be termed sine-like sounds, and their importance in the study of musical sound. These would still be sounds conceived of as having only one frequency component, but would be spared the necessity of being infinite in duration.

Resonators, isolation, and machines for visualising sound

Having determined that musical sound had a component structure based on sine tones and was dependent on physiological factors for its reception, Helmholtz embarked on experimental strategies aimed at uncovering the behaviour of sound both in open space and in the ear. Helmholtz stated that the regular vibrations emitted by a sound source were transmitted to the eardrum by way of a shared "atmospheric vibration". He posited that there was an indexical relationship between the pattern and quality of vibration derived from a physical disturbance of a given 'sonorous body' - be that a note played on a violin, a snare drum beat or a struck tuning fork - and the corresponding vibrations on the tympanum in the ear. These vibrations were then transferred to the ossicles and then on to the cochlea.[42] He defined this relationship between the object being heard and the apparatus of hearing as being one of 'sympathetic vibration' or *resonance*, which became the basis for his theory of hearing.

This notion of the indexicality finds an expression in the work of nineteenth century logician Charles Peirce (1839-1914). In his work "On the Algebra of Logic," Peirce defines the index as kind of sign, a "pointing finger" which "denotes without describing," as that which connects symbols (or *tokens*) to their meanings.[43] Peirce states that these tokens alone "do not state in general terms what is the subject of discourse; and this can, in fact, not be described in general terms; it can be only indicated. The actual world cannot be distinguished from a world of imagination by any description. Hence the need of pronouns and indices."[44] Helmholtz's theory of 'sympathetic vibration' constituted a kind of indexical system in line with his material conception of perception. It served to indicate, to convey the impression of the presence of sound in the physical world and cognition of that sound as sensation, without conveying sound itself.

However, despite the sense of equation or unity that the term 'sympathetic vibration' seems to imply, Helmholtz sought to show how the theory of resonance could enable the breaking down of a musical sound into its constituent parts. If musical sounds were to be composed of simple, regular sensations (irrespective as to whether sine or sine-like tones truly exist), this scheme of sympathetic vibration needed to be able to show how individual sonic components could be isolated and heard on their own. Resonance, acoustically speaking, is a phenomenon that occurs within structures and between structures, be they rooms, throats, ears, walls or musical instruments. By using resonance (from the Latin *re-sonus: 'to sound again'*) as a heuristic, musical sound would need to be 'sounded again' within the confines of the laboratory.

Helmholtz acknowledged that musicians were already familiar with the composite nature of sound and had been able to hear out and produce individual harmonics for centuries. However, he noted that the phenomenon of hearing individual or specific harmonics was often regarded as an effect or illusion.[45] Instead, what

Helmholtz sought to establish was the compound nature of sound as an objective fact. This required a means by which sound could be examined after it had been broken down into the simple harmonic motions from which it was formed. To confirm his theory that sound was a sensation in the ear, irrespective of its source, Helmholtz not only needed to hear out these components of musical sound, but to hear them divorced from the idiosyncratic tonal qualities of any given instrument. His aim was not to produce these sounds, but to hear them in the ear.

The opening statements of John William Strutt's *The Theory of Sound* describe the important role that the ear played in acoustic investigation in the late nineteenth century. The individuality of sound, and his designation of its independence from the other senses, served as its qualification as a legitimate area for study: "The sensation of sound is a thing *sui generis*, not comparable with other sensations. No one can express the relation between a sound and a colour or a smell. Directly or indirectly, all questions connected with this subject must come for decision to the ear, as the organ of hearing; and from it there can be no appeal."[46] However, the ability of the ear to perform with the rigour and to the standards set by science is immediately called into question:

> But we are not therefore to infer that all acoustical investigations are conducted with the unassisted ear. When once we have discovered the physical phenomena which constitute the foundation of sound, our explorations are in great measure transferred to another field lying within the domain of the principles of Mechanics. Important laws are in this way arrived at, to which the sensations of the ear cannot but conform.[47]

Efforts to hear isolated simple tones occurred alongside attempts to not only explain how the ear functioned from a physiological perspective, but to understand the limits and the veracity of perception. This questioning of the reliability of the sense organs was implicit in the mediated model of perception that Helmholtz had devised, in that the sense organs conveyed the impression of the presence of sound in the physical world indexically through sympathetic vibration. For Jonathan Crary, this shift in the understanding of physiological processes in the late nineteenth century is directly attributable to the scientific work of Helmholtz, alongside experimental psychologist and physiologist Gustav Fechner and many others, who "defined the contours of a general epistemological uncertainty in which perceptual experience had lost the primal guarantees that once upheld its privileged relation to the foundation of knowledge."[48]

This epistemological uncertainty had two significant outcomes in regard to investigating the properties of musical sound. The first was an "uncertainty and vagueness about the nature of attention" which interfered with other more quantifiable understandings of perception.[49] In Helmholtz's case, his theory of sympathetic vibration could describe the physiological mechanics of how the ear functioned, but this, of itself, was insufficient in explaining the phenomenon of hearing, which had an unavoidable subjective element.

The second concerned the role of the ear in scientific discovery, and the increasing technologisation of the subject in line with the aims of scientific enquiry. Helmholtz, following Ohm, had surmised that the ear operated in the same manner as Fourier's theory. If musical sound was to be comprised of simple tones, the ear had to be found capable of performing a disassembly procedure of this kind. The technological apparatus Helmholtz developed for hearing out individual simple tones not only involved the use of the ear, they also served as models of the ear's design and function. In this way, the ear's own physiology provided the ontological basis for the apparatus used to explore its function. Despite this, the ear ranked as just one of a number of instruments for investigating partials, and as such, became a piece of perceptual apparatus - a tool for analysing sound.

Just as Fourier analysis provided a graphic visualisation of the composite makeup of sound, Helmholtz experimented with procedures for visualising the patterns of vibrations caused by sounds in the air. Initially he experimented using a glass bottle with its bottom replaced by a stretched membrane made from a pig's bladder.[50] In order to show how a note produced at the mouth of the bottle could register as a vibration on the membrane, a small piece of wax was suspended on a cord from the rim of the bottle (mounted horizontally), coming to rest in the centre of the membrane. When a note was blown across the bottle mouth, the changing air pressure in the bottle caused the taught membrane to vibrate 'sympathetically'. The dob of wax then acted as a pendulum, bounced into motion by the movements of the membrane.

Helmholtz then followed the renowned example of Ernst Florens Friedrich Chladni (1756-1827), whose work in visualising vibrational patterns formed the basis of his 1787 publication *Entdeckungen über die Theorie des zu Klanges* [*Discoveries on the Theory of Sound*].[51] Chladni used a violin bow to stimulate sheets of glass that had been spread with quartz dust. This caused the grains of dust to be bounced to the places on the glass sheet that vibrated the least. Chladni named these areas of stillness or low vibration *schwingungsknoten* (literally 'vibration knots', what are commonly referred to as nodes).[52] In order to observe the same effect, Helmholtz removed the pendulum from his apparatus, inverted the bottle, sprinkled sand across the membrane, and then blew a note across the bottle's open mouth. In one example, the bottle when blown produced the note $F^{\#}$, and the sand "heaped itself in a circle near the edge of the membrane." The result was repeated when the same note, and also its deeper octave, was played on an harmonium. Similar circles resulted from sounding a range of other harmonically related notes.[53]

This simple glass bottle resonator was by no means the only instrument Helmholtz had at his disposal for visualising sound. The phonautograph, invented by French scientist Edouard-Leon Scott in 1857 (and later improved by Rudolph Koenig) also produced a visual representation of sound through partially imitating the structure of the human ear. It channelled sound through a conic funnel to vibrate a small, thin membrane. Attached to this was a stylus, which 'wrote' the pattern of vibrations from the membrane or *diaphragm* by scratching them onto a rotating cylinder covered in lamp-blackened paper.[54]

The phonautograph and the glass bottle resonator were both modelled on the ear, and also served as models of the ear, with the membrane a substitute for the eardrum (or *tympanum*). Although they were devices that rendered sound into a series of images, each provided entirely different results. The inscription on the blackened paper by the phonautograph's stylus revealed a complex, changing waveform, one traced along an axis of time. However, the formations of sand grains on the membrane of the glass bottle, as with the steel plates of Chladni a century earlier, displayed static and symmetrical patterns of vibration, isolated from time.

For Helmholtz, the images formed by the grains of sand on the bottle's stretched membrane confirmed the objective nature of partials: "The pendular vibrations into which the composite motion of the air can be analysed, here shew themselves capable of producing mechanical effects in external nature, independent of the ear, and independently of mathematical theory."[55] With the aid of the glass bottle resonator, these simple tones could now also be apprehended visually, independent of the temporal flow of sound, and independent from the ear.

The job of actually hearing simple tones could not be left to a pig's bladder. While the stretched membrane across the glass bottle provided the "great advantage of being independent of the ear," it proved insufficiently sensitive, and did not provide the ability to incorporate or enhance audition (even though the use of the ear would later reintroduce issues concerning the vagaries of perception).[56] Helmholtz explored a number of options, initially using "any spherical glass vessel that came to hand, as the receivers of retorts, and inserted into one of their openings a glass tube which had been adapted to my ear."[57] He also investigated resonators constructed as 'double cones' of tin or pasteboard. These proved to be useless as they reinforced all the partials of their fundamental tone at the same time. The pasteboard resonators also proved unwieldy to use, with each having a length about the same as an organ pipe of the equivalent pitch.[58]

The resonators Helmholtz found best for his purposes were glass spheres with one opening to permit the entry of sound, and another opening of smaller diameter with a short funnel-like neck for insertion into the ear. He had Rudolph Koenig, a designer and manufacturer of acoustical instruments in Paris, construct a series of these glass spheres "properly tuned", and later replaced them with a further set made from brass.[59] The advantage of the resonator's spherical design was that all the other resonant modes present in the sphere (what Helmholtz named its 'proper tones') were distinct and distant from the 'prime tone' - the particular note to which the resonator had been specifically tuned. They also gave a very powerful resonance, aiding audition.[60] However, this isolation of the prime tone from the proper tones was concurrent with two other acts of isolation or separation. Firstly, there was the isolation of the initial sounds emitted from a source on the outside of the resonator from the new, mediated, scientific sounds heard inside the resonator. Secondly, there was the physical separation of the ear from the space in which the source sound source was made as a result of the scientific apparatus installed in between.

To use the spherical resonator, a small amount of warm wax was pressed around the entrance of the ear. When the neck of the resonator was inserted, the wax created an airtight seal. The other ear was then sealed with wax so as to reduce interference from other sounds. The larger opening was then directed toward the sound to be examined. "Theoretically" Helmholtz reported, "this apparatus does not differ from the bottle with an elastic membrane, but its sensitiveness is amazingly increased by using the drum skin of the ear for the closing membrane of the bottle and thus bringing it in direct connection with the auditory nerves themselves."[61] With the eardrum replacing the pig gut membrane, the ear itself is fully incorporated into the apparatus of experimentation. In its relation to scientific history, Helmholtz's procedure here is not dissimilar to the experiments of Alexander Graham Bell and Clarence Blake, who in 1874 replaced the diaphragm from a phonautograph with the tympanum and ossicles extracted from human cadavers; however, with the Helmholtz resonator, the ear is kept *in situ*.[62] This procedure embodies a very specific model of hearing, an hermetically sealed system which excluded noises and the sounds of the outside world, therefore restricting non-musical considerations, and focussing attention onto the process of hearing as a form of analysis.

However, it wasn't just the ear that had to be modified for experimental purposes. Helmholtz's resonator was designed to amplify and separate the harmonics from only one particular musical pitch. Therefore, any sound that was to be analysed had to be pitched as closely as possible to the primary tone of the resonator. An interdependent relationship existed between the apparatus and the subject - the right sound had to find the right resonator. When this match occurred the effect produced by the resonators was considered by Helmholtz to be so distinct as to be axiomatic: "any one, even if he has no ear for music or is quite unpractised in detecting musical sound, is put in a condition to pick the simple tone, even if comparatively faint, from out of a great number of others."[63] He likened the resonator's ability to focus and isolate aspects of sound to the microscope:

> Resonators with a very narrow opening generally produce a much more considerable reinforcement of the tone, but then there must be a much more precise agreement between the pitch of the tone to be heard, and the proper tone of the resonator. It is just as in microscopes; the greater the magnifying power, the smaller the field of view.[64]

Helmholtz ascribed great importance to his resonators and the kind of listening they allowed him: "Without their help, indeed, I should scarcely have succeeded in making the observations… with so much precision and certainty as I have been enabled to at present."[65] The ability to identify the same harmonics through different investigative procedures also provided proof of the compound nature of sound as an objective fact: "The ear recognises without resonators the simple tones that the resonators greatly reinforce, and perceives no upper partial tone the resonator does not indicate"[66] Resonators were thereby designated by Helmholtz to be one of the most useful instruments for investigating musical sound. A properly tuned series of resonators could be used for "observations of the combination and upper partial tones, and a series of other phenomena… relating to chords."[67] Not only did it help the untrained isolate and hear these sounds, it provided those "trained musical ears" who had previously gained their experience through "strained attention" with an easier method for investigating various acoustic phenomena.[68]

However, resonators can be seen as offering a reduced sound field for examination. Having already decoded sound mathematically and graphically through Fourier analysis, the use of resonators further problematised the status of the ear in determining the nature of musical sound. Although Helmholtz posited that the ear did indeed disassemble sound in the manner of Fourier, it could not be *observed* doing so. By replicating the eardrum, and applying a specialised sound filter in the form of a resonator, physiological aspects of hearing could seemingly be isolated from mental or psychological ones. This foregrounded the ear's role as an organ of perception, while sidelining listening and attention into the category of the subjective - open to fatigue and closed to the separation and distance maintained through the scientific apparatus. With the aid of a resonator, the need to familiarise oneself with the compound nature of musical sound through an extended experience of listening is removed.

In employing resonators in his examination of sympathetic vibration, Helmholtz achieved the ability to hear the individual harmonic components within musical sounds. In line with his theory that sound was a physical operation of the ear, he considered that the resonators decomposed musical sound in such a way as to conform to Fourier analysis. The primary implication of this was not only that the harmonics of a musical sound were simple harmonic motions containing only one frequency component and therefore sine tones - a perfect auditory mirror of a trigonometric idealisation - but that under laboratory conditions these sine tones could be heard.

As has been previously indicated, mathematically speaking a 'true' sine tone cannot be said to exist, due to the single fact that any actual sound must be of a finite duration. However, it would be later investigations of resonance in musical instruments that would explain why the harmonic could not be considered to be a sound with only one frequency component:

> In musical instruments the partials originate as the vibrations of parts that are capable of vibration; according to the material of which they are made, these parts permit a larger or smaller group of vibrations per partial, according also to the degree of dampening in the resonant system. The envelope of the resonant vibration in the area of one partial is called the 'resonance curve'. The line spectrum is thus only a

> simplified representation of the real behaviour of vibrations. The steeper the resonance curve, that is, the sharper the resonance, the less damping there is.[69]

While there may be one overwhelming frequency component within an individual harmonic (indicated by the shape of the resonance curve), it is but one of a band of frequencies. The shape of the resonance curve is determined by the molecular characteristics of the material in which the vibrations occur, be they wooden instruments or human larynxes. This dispels - or should dispel - the notion that harmonics are sine tones.

The idea that the harmonic itself might be further investigated and disassembled seems in part to have been forestalled by Fourier analysis itself. Having decomposed musical sound once, Fourier analysis did not provide any possibility or motivation for further 'dissection'. Therefore, once Helmholtz heard individual harmonics, there was the assumption that they were single frequency sounds. The harmonic was in fact composite, but this was not reflected in the mathematics and did not appear in the resulting graph.

Water and waves

Water has provided some of the most enduring metaphors for describing the nature of sound and its propagation. In examining the course of experimentation into sound in the late nineteenth century, it is possible to trace a progressive 'drying out' of the aqueous metaphors that had provided so much of the initial descriptions for the behaviour of sound and definitions of noise. As philosopher Michel Serres has pointed out, noise and water share more than an etymological link through the word *nausea* (literally 'seasickness'). Serres connects the two through a relationship of sonic continuity: "We never hear what we call background noise so well as we do at the seaside. That placid or vehement uproar seems established for all eternity." Serres hears in noise the agitation of multiplicity, the possibility of a whirl of forms. From his perspective, the very persistence of noise contains a challenge for natural philosophers looking to reduce phenomena to simple action: "It is at the boundaries of physics, and physics is bathed in it, it lies under the cuttings of all phenomena, a proteus taking on any shape, the matter and flesh of manifestations."[70] Yet, ironically, it would be through the progressive refinement of liquid examples and metaphors of wave action that would aid the conflation of the concept of a sound wave into that of the abstract sine wave and complex periodic waveform, and in turn lead to practices for the abatement and removal of noise.

The aqueous wave metaphor for sound has a long history. One the most frequently cited examples from antiquity would be that of Vitruvius, who in the first century BCE cast a stone into a pond and compared the propagation of sound to the expanding ripples. In the late nineteenth century Helmholtz would throw his own stone into calm water:

> Round the spot struck there forms a little ring of wave, which, advancing equally in all directions, expands to a constantly increasing circle. Corresponding to this ring of wave sound also proceeds in the air from the excited point and advances in all directions as far as the limits of the mass of air extend. The process in the air is essentially identical with that on the surface of the water.[71]

John Tyndall also re-enacts Vitruvius' experiment, but in a far more Victorian fashion: from a rowboat in Cowes harbour (in "moderate weather," naturally). He observed the motions made by his oar as it lightly touched the surface of the water, noticing how "every wave and every ripple asserted its right of place, and retained its individual existence, amid the crowd of other motions which agitated the water."[72] Compared to the previous accounts it seems unusual that Tyndall chose this story of a single wave in a moving body of water, as it illustrates the motion of sound in a noisy environment, rather than a quiet one. He did later move to a still pond where he cast two stones, one at either end. Each stone formed a series of expanding circular waves, and the interactions of the two resultant wave patterns in the middle of the pond served as an example of the superposition of sonic vibrations. However, as with Vitruvius and Helmholtz, it was only the resultant waves, and not the stones that caused them, that were deemed to be of any interest in these examples.

Tyndall later brought these outdoor experiences inside to form part of the subject matter of his successful series of lectures and demonstrations, both at the Royal Institution of Great Britain (where he had been made professor of natural philosophy in 1853) and abroad.[73] These popular public lectures incorporated his own ideas with material and experiments of others to form an overview of the field of acoustics; as such, they provided what Jonathan Crary has termed a kind of "didactic entertainment".[74] His book *On Sound* is based on these lectures, and like them, was an attempt to canvas the entire field of acoustics as it stood at the end of the nineteenth century.

Moving away from ponds and harbours, Tyndall's demonstrations of wave motion became decidedly more contained:

> I have here a long and narrow vessel with glass sides: a copy, in fact, of the wave canal of the brothers Weber. It is filled to the level A-B with coloured water. By tilting the end A, suddenly, I generate a wave, which moves on to B, and there is reflected. By sending forth fresh waves at the proper intervals, I divide the surface

> into two stationary undulations. Making the succession of impulses more rapid I can subdivide the surface into three, four, or more stationary undulations, separated from each other by nodes.[75]

The waveform from the pond is now captured within the confines of a rectangular box. The stone that caused the disturbance is replaced by a sudden tilt. Rather than a model of random wave propagation in space, this experiment uses water to display a range of harmonic modes as divisions of a wave. In his experiment, rather than a pond, Tyndall has in effect a kind of liquid version of the acoustician's monochord, which yields "gross, but not unbeautiful mechanical vibrations."[76] In order to draw a comparison between wave motion and vibratory modes in strings, Tyndall later abandons the wet apparatus in favour of its dry equivalent.

Each of these demonstrations of sound propagation provides a different account of wave behaviour. The dimensionality of a wave of sound, the direction of its propagation, and the plane along which it travels, varies radically from one to the next, with different implications indicated by each. Tracking those changes reveals not just how each illustration reimagined the shape of a sound wave, but how it aligned with the kind of conceptualisation provided by Fourier analysis. The examples of Vitruvius and Helmholtz initially occur on a flat plane, although Helmholtz was quick to extend the analogy into the third dimension: "The principle difference consists in the spherical propagation of sound in all directions through the atmosphere which fills all surrounding space."[77] However, in the initial example - as with Tyndall's pond side experiment - sound is viewed from an all-seeing position overhead, with sound waves propagating equally as a circular ripple (that is, in all directions) across a horizontal plane. Although also located on a horizontal plane, the bobbing sensation of Tyndall's rowboat might well have suggested more of the vertical movements of wave motion.

However, having placed himself at the point of disturbance he had also removed himself from the position of being able to oversee all wave action. Observable wave motion would largely be in the form of waves moving away from his centralised point.

Tyndall's 'liquid monochord' produces a far more significant set of transformations. The position of the observer shifts decidedly from the initial one - looking down onto a surface and imagining its three-dimensional spherical equivalent. In this example the wave is lifted up out of the pond so that it can travel laterally along a vertical plane. Instead of wave motion observed from above, it is wave motion seen from the side. Rather than a ripple spreading out in all directions across a randomly shaped flat surface defined by the banks of the pond, the sound wave inside the 'liquid monochord' is rendered as vertical undulations along a horizontal line. This effectively restructures the wave metaphor for sound, directing it away from being an analogy for the propagation of sound in space, to being a model for the pattern of mechanical vibrations in two dimensions. Tyndall's 'liquid monochord' example forms a bridge between the metaphor of the sound wave and observation of vibrations within a taut string or membrane. Demonstrations of waves and vibration could now be handled by a conventional monochord, without further recourse to water.

Charting the progression of the water-based examples reveals a process of quelling some of the perceived 'noisiness' of water hidden inside the wave metaphor for sound, redirecting it towards a depiction of sound more in line with the prescriptions of musical sound. In line with the graphical representation of sound generated by Fourier analysis, any question of what caused or triggered these wave shapes does not arise. Instead, they provide an image of sound shorn of its noise: an abstracted, 'perfect', noiseless sound. As Douglas Kahn has noted, these practices are aligned with a tradition of noise abatement in the study of musical sound: "Whether a stone was thrown into water by Vitruvius in the last century BC or Helmholtz in the nineteenth century, it was in effect a noisy act of percussion graphically muted by the surface tension of the water and rendered in regular wave patterns."[78] With the focus of each of these examples being the shape and motion of the resulting wave, the noisy event - the initial disturbance that excited the wave motion in the first place - is ignored. The pebble descends to the bottom of the pond unnoticed, the oar retracted into the rowboat. By the time of Tyndall's 'liquid monochord' the stimulus is removed from the water altogether, with the disturbance applied externally in the form of a tilt. Our noisy pebble never enters the water.

Fluid in the ear

Waves and water, both conceptual and actual, posed other problems when it came to the question understanding the function of the fluid-filled inner ear, and the role it played in perceiving musical sound. The aesthetics of wave watching would come into play in the determination of which kind of wave patterns were most appropriate for providing an analogy for musical sound.

In his discussion on the aesthetic qualities implicit in the motion of sound, Helmholtz makes reference to Aristotle and his 27th problem. Aristotle asks, and then partly answers, his own query: "why do rhythms and melodies, which are composed of sound, resemble the feelings; while this is not the case for tastes colours and smells? These motions, i.e. rhythms and melodies, are active, and action is the sign of feeling' (Aristotle Prob. xix. 29)."[79] Helmholtz responds:

> Not merely music but other kinds of motions may produce similar effects. Water in motion, as in cascades or sea waves, has an effect in some ways similar to music. How long and how often can we sit and look at the waves rolling in to shore! Their

> rhythmic motion, perpetually varied in detail, produces a particular feeling of pleasant repose or weariness, and the impression of a mighty orderly life, finely linked together.[80]

Waves provide a model of regularity for both the contemplative mind and a well-ordered society. However, to do this adequately, Helmholtz argues, waves have to be of a certain magnitude: "When the sea is quiet and smooth we can enjoy its colouring for a while, but this gives no such lasting pleasure as the rolling waves. Small undulations, on the other hand, on small surfaces of water, follow one another too rapidly, and disturb rather than please."[81]

However, the motions of water are too coarse and worldly compared to that of sound, which Helmholtz characterised as the pinnacle of internalised expression:

> The motion of tone surpasses all motion of corporeal masses in the delicacy and ease with which it can receive and imitate the most varied descriptions of expression. Hence it arrogates to itself by right the representation of states of mind, which the other arts can only indirectly touch by shewing the situations which caused the emotion, or by giving the resulting words, acts, or outward appearances of the body.[82]

Watery wave motion, random and differentiated, lacked the refinement of musical sound. If water motion alone was allowed to rhetorically represent "states of mind" it might lead to an outpouring of disorder or haphazardness, barely capable of providing an orderly aesthetic experience. Even worse might be the possibility of the still waters of boredom.

Despite any problems that water waves might represent, Helmholtz returned to his still pond in order to provide an example of the process of hearing. After setting the water in motion with another stone a chip of wood is placed on the surface. The manner in which the waves reaching the chip set it bobbing up and down served as a model for how a wave of sound affects the ear:

> The process that goes on in the atmospheric ocean about us is of a precisely similar nature. For the stone substitute a sounding body, which shakes the air; for the chip of wood substitute the human ear, on which they impinge the waves of air excited by the shock, setting its movable parts in vibration.[83]

Again it is for Helmholtz a demonstration of hearing via sympathetic vibration. However, while wave action could serve as a suitable mechanism for conveying sound to the ear, it would become a different matter as Helmholtz contemplated vibrations inside the fluid-filled cochlea.

The intricacy of Helmholtz's physiological investigation of the middle and inner ear is quite astounding given the era in which it occurred. The engravings that accompany his descriptions of the ossicles of the middle ear (the malleus, incus and stapes) are remarkably detailed, as are the depictions of the structures of the inner ear: the labyrinth, cochlea and the organ of Corti.[84] He described the incus as resembling a "double tooth with two fangs" with tiny interlocking teeth joining it to the malleus, and likened the operation of the ossicles to a watch mechanism.[85]

Helmholtz surmised that the role of the ossicles in facilitating hearing is to "transform a motion of great amplitude and little force, such as impinges on the drumskin, into a motion of small amplitude and great force, such as had to be communicated to the fluid of the labyrinth."[86] Any movement of the tympanum is therefore amplified by the mechanical interaction of these small bones. Amplification is crucial for the transmission of vibrations to the fluid filled cochlea due to the difference in impedance between air and water.[87] The last bone in the sequence - the stapes - connects to the base of the cochlea via the oval window, a small opening covered by a thin membrane. Movement of the tympanum caused by a sound wave leads to a back and forth motion of the stapes on the oval window, which creates changes in fluid pressure inside the cochlea. It is by this mechanism that sound waves travel to the inner ear.

The fluid-filled cochlea is the organ that transforms vibrations into neural firings. It is a tapering tube approximately 35mm in length coiled approximately two and a half times, and resembles a small snail shell (after which it is named).[88] Helmholtz's diagrams are detailed enough to display the cochlea in transverse section, showing its roughly circular interior divided by the vestibular or Reissner's membrane, and the basilar membrane, thus creating three internal divisions.[89] Between the vestibular and the basilar membranes is the wedge-shaped cochlear duct, containing the complex structure called the organ of Corti (named for the Marchese Alfonso Corti, who identified it in 1851). The organ of Corti sits on the basilar membrane, and is covered by the tectorial membrane. Tiny hairs (or cilia) extend from the organ of Corti in two rows. The outer hair cells appear to be embedded in the tectorial membrane, while the inner hairs are not. Due to the fluid pressure in the basilar canal, movement of the basilar membrane causes a sideways 'shearing' motion in the hairs. The hair cells are connected to auditory nerve fibres, and it is this shearing effect that transfers the movements of the basilar membrane, caused by the fluid, into nerve impulses.[90]

Having identified all the component parts of the cochlea, what Helmholtz had to determine was the mechanism by which the motion of the fluid travelling through the canals of the cochlea activated the nerve cells within the organ of Corti, resulting in nerve impulses being transmitted to the auditory centres in the brain. Helmholtz noted that the basilar membrane was "a firm, tightly stretched, elastic membrane, striped radially, corresponding to its radial fibres. It splits easily in the direction of these fibres, shewing that it is but loosely connected in a direction transverse to them."[91] This suggested to him that the basilar membrane was "tightly stretched in the transverse direction... but can have only little tension in the direction of length, because it could not resist a strong pull in this direction."[92] Helmholtz proposed that due to the tension placed on these fibres that they be "approximately regarded as forming a system of stretched strings", and the membranous connection between the fibres acted as a fulcrum against the pressure of the fluid on these 'strings':[93]

> In that case, the laws of their motion would be the same as if every individual string moved independently of all the others, and obeyed, by itself the influence of the periodically alternating pressure of the fluid ... Consequently, any exciting tone would set that part of the membrane into sympathetic vibration, for which the proper tone of one of its radial fibres... corresponds most nearly with the exciting tone.[94]

The physiology seemed to reinforce Helmholtz's theory of sympathetic vibration, right at the point where sound vibration was transformed into nerve stimulation: vibrations that had been turned literally into movements through a liquid (rather than the fluid system of the atmosphere) find their final decomposition into individual frequency components by stimulating these string fibres of the inner ear. This in turn would indicate that a sound of a single frequency - a sine tone - could be both accurately sensed by the ear and conveyed as nerve impulses to the brain.

The contemporary understanding of cochlea function would not be reached until 1928. Corralling the fluid dynamic theories of Hurst (1895), Bonnier (1895) and ter Kuile (1900), Hungarian anatomist and physicist Georg von Békésy (1899-1972) questioned Helmholtz's formulation of the cochlea and the operation of its structures:

> Helmholtz assumed the presence of a series of resonators in the ear, each tuned to different frequency, and he thought he was able to explain Ohm's acoustic law according to which the ear tends to hear the individual components of a complex sound, regardless of their phase relations. The search for these resonators ran, however, into certain difficulties. According to Helmholtz, the cochlear partition has what might be called a "piano-chord" structure. This means there must be present a membrane characterised by a much larger tension crosswise than in longitudinal direction[95]

Békésy's research into the cochlea proceeded from an analogy with the concepts of fluid dynamics that had proved useful in studies of blood vessels. He found that the inward motion of the stapes against the membrane of the oval window gave rise to a "travelling wave along the cochlea partition."[96] Observing the eddy currents in the fluid of the cochlea, he noted that as a result of this travelling wave along the basilar membrane, a "reflection from the far end of the membrane will then give rise to standing waves, with a different standing wave for each frequency."[97] Eddy currents forming in the cochleal pond literalised the wave metaphor at the site of transduction from vibration to nerve impulse; nineteenth century experimental science could not totally dehydrate sound and hearing after all.

The condition of sine

The explorations into musical sound conducted during the last half of the nineteenth century were extremely influential in developing the modern field of acoustics. Writing in 1935, Dayton Clarence Miller considered that the work of Tyndall, Helmholtz and Rayleigh (along with instrument builder and experimenter Koenig and architectural acoustician Wallace Sabine) had provided "both the substance and the inspiration for the acoustic work of the last fifty years."[98] Their work also showed the expansion of acoustical concerns into other disciplines. Through a combination of analysis, rhetoric and experimental techniques, the study of musical sound extended beyond aesthetics and mechanical resonance and, through the influence of concepts such as Müller's specific sense energies, brought it into contact with contemporary theories of physiology and cognition.

Although the application of Fourier analysis had wider implications in the study of musical sound than those documented here (especially in discussions of harmony and tuning theory), this chapter has traced how sine waves emerged from the mathematical formulation and graphic rendering of musical sound by Fourier analysis. In doing so it has identified several important effects of this approach to investigating sound. Fourier analysis effectively implanted the idea of the sine tone into acoustics, declaring it to be the basic unit of musical sound production.[99] Although Helmholtz claimed that his investigation into musical sound dealt "only with the analysis of actually existing sensations" and sought to establish this theory as empirical fact, he did so by using Fourier analysis, which created an artefact in the form of the sine tone. More than simply a by-product of a process, Fourier analysis presented nineteenth century acousticians with an abstract, idealised waveform that they defined as harmonically simple (in that it had one frequency component), harmonically stable in that it was unwavering in pitch, and noise-free.[100] Application of Fourier's method for the decomposition of complex waveforms into a series of regular periodic motions (or frequencies) also effectively cast the sine wave as synonymous with the musical harmonic.

This figuration of the sine tone has proved to be untenable. As a sound consisting of single frequency, any actual, audible sine tone could never comply with the strictures of the mathematical curve from which it was derived, due to the impossibility of an actual infinite. Claims to having heard individual sine tones would be complicated not only by the techniques by which this was accomplished, but by later investigations into the resonant modes of instruments, which would show that the musical harmonic was itself a complex structure.

The sine tone played a role in the desire amongst nineteenth century acousticians to confirm ideas about the regular and even nature of musical sound. The reductive effects of Fourier analysis, combined with both a discourse of regularity and experimental technique, formed a strategy for taming any unruly behaviour found in the natural and aqueous metaphors used to describe musical sound. In transforming the sound wave into a complex periodic waveform through procedures of visualisation, Fourier analysis effectively separated orderly and desirable musical sound from the noisy and quotidian sounds of the world. This was accompanied by a shift from descriptions and observations of wave patterns and wave motion, to demonstrations of isolated wave action that attempted to quell the watery aspects of wave motion and its associated splashy noisiness. This would conclude with Helmholtz attempts to downplay the function of wave motion inside the cochlea, in favour of his theory of sympathetic resonance. However, in the absence of the anatomy to support this model of hearing, it would be the hydrodynamic theories of Békésy and others that would finally explain how the cochlea functioned.

[1] Robert T. Beyer, *Sounds of Our Times: Two Hundred Years of Acoustics* (New York: AIP Press, 1999), 44-45.
[2] ibid.
[3] ibid.
[4] Stephen Handel, *Listening* (Cambridge: MIT Press, 1989), 554.
[5] Translator's footnote; to explain the consequences, translator Alexander Ellis draws a dental analogy: "*oberzahn*, an 'upper tooth' i.e. a tooth in the upper jaw, with *ueberzahn*, an 'overtooth' i.e. one grown over another." Alexander Ellis, Translator's note, in Hermann von Helmholtz, *On the Sensations of Tone as a Physiological Basis for the Theory of Music*, trans. Alexander J. Ellis, Second ed. (New York: Dover, 1954), 25.
[6] John M Picker, *Victorian Soundscapes* (New York: Oxford University Press, 2003), 85.
[7] Helmholtz, *On the Sensations of Tone*, 1.
[8] Henry Margenau, Introduction, *On the Sensations of Tone as a Physiological Basis for the Theory of Music* by Hermann von Helmholtz, trans. Alexander J. Ellis, Second ed. (New York: Dover, 1954), np.
[9] ibid.
[10] Theo C. Meyering, *Historical Roots of Cognitive Science: The Rise of a Cognitive Theory of Perception from Antiquity to the Nineteenth Century* (Dordrecht: Kluwer Academic, 1989), 134.
[11] ibid., 136. This specificity of sound to the ear also has a history in the study of music. For example: "*Nature* has been so extraordinarily liberal in distributing her Favours, (which visibly demonstrates an *invisible Hand* in all her Works) that she has indulged every Sense with Variety enough for every One's Palate: But there is One, which is feasted in a different Manner from the rest; and that is, the *Sense* of *Hearing*; for whatsoever is an *Object* of the *Eye*, affects also the *Touch*, the *Smell*, and the *Taste*, *Sound* alone being proper to the *Ear* only, which has its full Gluttt with the others, in the infinite Variety that it is regaled with, by the beautiful Decorum of *Musical Cadences*." William Turner, *Sound Anatomiz'd in a Philosophical Essay on Musick* (New York: Broude Brothers, 1974; reprint, facsimile of the London 1742 edition), 2.
[12] Morton Hunt, *The Story of Psychology* (New York: Anchor, 1993), 111. Instances of Müller's theories find resonance across a range of fields. His assertion "nemo psychologus nisi physiologus" ('one is not a psychologist who is not also a physiologist') finds an echo in Merleau-Ponty's statements on the interrelatedness of theories of the body and perception. Michael W. Levine, *Levine & Schefner's Fundamentals of Sensation and Perception*, third ed. (New York: Oxford University Press, 2000), 1.
[13] Hunt, *The Story of Psychology*, 114. See also Frederic L. Holmes "The Role of Johannes Müller in the Formation of Helmholtz's Physiological Career" in *Universalgenie Helmholtz: Rückblick nach 100 Jahren*, ed Lorenz Krüger (Berlin: Akademie Verlag, 1994), 3-21.
[14] Margenau, Introduction, *On the Sensations of Tone*, np.
[15] Meyering, *Historical Roots of Cognitive Science*, 143.
[16] Stephan Vogel, "Sensation of Tone, Perception of Sound, and Empiricism: Helmholtz's Physiological Acoustics," in *Hermann Von Helmholtz and the Foundations of Nineteenth-Century Science*, ed. David Cahan (Berkeley: University of California Press, 1993), 285.
[17] Helmholtz, *On the Sensations of Tone*, 3. Helmholtz initially outlined his studies into musical acoustics in a lecture delivered in Bonn during the winter of 1857, later published under the title "On the Physiological Causes of Harmony in Music." In it he exhibited a slightly more combative attitude towards the perceived reluctance of music to yield to science (unlike other arts): "Music has hitherto withdrawn itself from scientific treatment more than any other art. Poetry, painting and sculpture borrow at least the material for their delineations from the realm of experience. They portray nature and man. Not only can their material be critically investigated in respect to its correctness and truth to nature, but scientific art-criticism, however much enthusiasts may have disputed its right to do so, has actually succeeded in making some progress in investigating the causes of that aesthetic pleasure which it is the intention of these arts to excite. In music, on the other hand, it seems at first sight as if those were still in the right who reject all "anatomisation of pleasurable sensations." This art, borrowing no part of its material

from the experience of our senses, not attempting to describe, and only exceptionally to imitate the outer world, necessarily withdraws from scientific consideration the chief points of attack which other arts present, and hence seems to be as incomprehensible and wonderful as it is certainly powerful in its effects." Hermann von Helmholtz, "On the Physiological Causes of Harmony in Music," in *Helmholtz on Perception*, ed. Richard M. Warren and Roslyn P. Warren (New York: John Wiley & Sons, 1968), 27.

[18] ibid., 152.

[19] Carl B Boyer, *A History of Mathematics*, Second ed. (New York: John Wiley & Sons, 1991), 54-57. Pythagoreanism has had a long history, connecting thinking in music, natural philosophy and metaphysics. For an account the enduring appeal and influence of Pythagoreanism on mathematics, music and cosmology. See Penelope Gouk, *Music, Science and Natural Magic in Seventeenth-Century England* (New Haven: Yale University Press, 1999).

[20] It wasn't just the subject matter that was influential. Helmholtz's interdisciplinary approach also found favour. For example by 1876 Professor Pietro Blaserna of the Royal University of Rome had produced his text *The Theory of Sound in its Relation to Music,* which states in its introduction that it follows the example of given by Helmholtz in "his now classical book" in trying to bring together "in a plain and simple form two subjects which have hitherto been treated separately." In a further bout of influence, the English publication also included illustrations from Tyndall's *On Sound.* Pietro Blaserna, *The Theory of Sound in Its Relation to Music*, English ed. (London: Henry S. King & Co., 1876), np. In his tome *The Analysis of Sensations and the Relation of the Physical to the Psychical,* Ernst Mach shows the scale of admiration for Helmholtz's achievements "There is no one but will cheerfully acknowledge the decided advances effected by Helmholtz in the analysis of auditory sensations" before providing an extensive catalogue of his achievements. However, Mach is more prudent in his praise than others. Writing only 24 years after the first German publication of *On the Sensations of Tone* he states: "The work of Helmholtz excited general admiration on its first appearance; but of late years it has been subjected to various critical attacks, and it almost seems to be as much underestimated now as it was originally overestimated." Ernst Mach, *The Analysis of Sensations and the Relation of the Physical to the Psychical*, trans. C. M. Williams and Sydney Waterlow, fifth ed. (London: The Open Court Publishing Co., 1914), 268.

[21] John Tyndall, *On Sound* (London: Longmans, Green, and Co., 1867), x.

[22] Herman Helmholtz, *Nature* 17 (Jan. 24, 1878), reprinted in Beyer, *Sounds of Our Times*, 419. It is not surprising that Helmholtz praised Rayleigh's mathematical approach to acoustics given his earlier pronouncements: "It always struck me as a wonderful and peculiarly interesting mystery, that in the theory of musical sounds, in the physical and technical foundations of music, which above all other arts seems in its actions on the mind as the most ethereal, evanescent, and tender creator of incalculable and indescribable states of consciousness, that here in especial the science of purest and strictest thought - mathematics - should prove pre-eminently fertile." Helmholtz, "On the Physiological Causes of Harmony in Music," 27.

[23] Helmholtz, *On the Sensations of Tone*, 5. For an account of Helmholtz's role in the move to popularise science in Germany in the late nineteenth century, see David Cahan's introduction in Hermann von Helmholtz, *Science and Culture: Popular and Philosophical Essays*, ed. David Cahan (Chicago: University of Chicago Press, 1995), viii-xv. The extent of Helmholtz's influence on musical thinking in the same period is surveyed in Elfrieda & Erwin Hiebert, "Musical Thought and Practice: Links to Helmholtz's *Tonempfindungen*," in *Universalgenie Helmholtz: Rückblick Nach 100 Jahren*, ed. Lorenz Krüger (Berlin: Akademie Verlag, 1994), 295-314.

[24] ibid., 7.

[25] ibid.

[26] ibid.

[27] ibid., 8.

[28] ibid.

[29] John William Strutt (Baron Rayleigh), *The Theory of Sound*, vol. 1 (London: Macmillan, 1877; reprint, New York: Dover, 1945), 4.

[30] ibid.

[31] Gouk, *Music, Science and Natural Magic*, 165.

[32] John J. Roche, *The Mathematics of Measurement: A Critical History* (London: Athlone Press, 1998), 48.
[33] The gnomon is the vertical triangular plate in the middle of a sundial.
[34] Marie-Thérèse Debarnot, "Trigonometry," in *Encyclopedia of the History of Arabic Science*, ed. Roshdi Rashed (London: Routledge, 1996), 497, 513.
[35] Boyer, *A History of Mathematics*, 402-3.
[36]The use of the term *sine* is left for the footnotes, where Helmholtz describes 'the law of these vibrations': "Mathematically expressed, the distance of the vibrating point from its mean position at any time is equal to the sine of an arc proportional to the corresponding time, and hence the form of simple vibrations are also called the *sine vibrations* [and the above curve is also known as the *curve of sines*]", ibid., 23.
[37] Analysis here is understood as being "the study of infinite processes", Boyer, *A History of Mathematics*, 553.
[38] "The mathematically defined sine wave exists only as a theoretical concept. If there actually were one, having begun before our birth and continuing into infinity after our death, we would not be able to notice it, just as we would not notice the blue of the sky if it were never disturbed by clouds and the darkness of night." Fritz Winckel, *Music, Sound and Sensation: A Modern Exposition*, trans. Thomas Binkley (New York: Dover, 1967), 25.
[39] Morris Kline, *Mathematical Thought from Ancient to Modern Times* (New York: Oxford University Press, 1972), 53.
[40] ibid., 994. See also Charles C. Pinter, *Set Theory* (Reading: Addison Wesley, 1971).
[41] Geoffrey Hunter, *Metalogic: An Introduction to the Metatheory of Standard First Order Logic* (Berkeley and Los Angeles: University of California Press, 1971), 17.
[42] The ossicles are three small bones of the middle ear, commonly called the hammer (*malleus*), anvil (*incus*) and the stirrup (*stapes*), the last of which connects to the *cochlea* in the inner ear.
[43] Charles S. Peirce, "[from] on the Algebra of Logic: A Contribution to the Philosophy of Notation," in *The Essential Peirce* (Bloomington: Indiana University Press, 1992), 226.
[44] ibid., 227.
[45] Helmholtz, *On the Sensations of Tone*, 48.
[46] Strutt (Baron Rayleigh), *The Theory of Sound*, 1.
[47] ibid.
[48] Jonathan Crary, *Suspensions of Perception: Attention, Spectacle and Modern Culture* (Cambridge: MIT Press, 1999), 12.
[49] ibid., 44. For example, in 1880 William James employed an array of binary schemes in an attempt to pin down the slippery nature of attention: "Attention may be divided into kinds in various ways. It is either to a) Objects of sense, or to b) Ideal or represented objects. It is either c) Immediate; or d) Derived... Furthermore, attention may be either e) Passive, reflex, non-voluntary, effortless; or f) Active and voluntary." William James, *The Principles of Psychology*, vol. 1 (New York: Dover, 1950), 416.
[50] Helmholtz, *On the Sensations of Tone*, 43.
[51] Myles W. Jackson, *Harmonious Triads: Physicists, Musicians and Instrument Makers in Nineteenth-Century Germany* (Cambridge: MIT Press, 2006), 15.
[52] ibid., 16.
[53] "Both *F*# and *D* gave the same circle, but more weakly. Now the *f*# of the membrane is the prime tone of the harmonium tone *f*#, the second partial tone of *f*#, the third of *B*, the fourth of *F*# and the fifth of *D*. All these notes set the membrane in the motion of its deepest tone. A second smaller circle… was produced on the membrane by *b'* and the same more faintly by *b*, and there was a trace of it for the deeper Twelfth." Helmholtz, *On the Sensations of Tone*, 43.
[54] Scott was a typesetter who had come upon the idea for the apparatus from drawings of the anatomy of the ear while proofreading a textbook on physics. Jonathan Sterne, *The Audible Past: Cultural Origins of Sound Reproduction* (Durham: Duke University Press, 2003), 35-36.
[55] Helmholtz, *On the Sensations of Tone*, 42.
[56] ibid., 43.
[57] ibid., 372.
[58] ibid., 374.

[59] Koenig also later made tuneable resonators from two short cylinders, one sliding inside the other like a miniature trombone. However, this alteration only permitted adjustment to tuning over the range of a given note, not slide a whole octave in a glissando. ibid,. 372.
[60] ibid.
[61] ibid., 44.
[62] Sterne, *The Audible Past*, 31-32.
[63] Helmholtz, *On the Sensations of Tone*, 44.
[64] ibid., 374.
[65] ibid., 44.
[66] ibid., 56.
[67] ibid., 44.
[68] ibid.
[69] Winckel, *Music, Sound and Sensation*, 9-10.
[70] Michel Serres, *Genesis*, trans. Geneviéve James & James Nielson (Ann Arbor: University of Michigan Press, 1995), 14.
[71] Helmholtz, *On the Sensations of Tone*, 9.
[72] Tyndall, *On Sound*, 255.
[73] A. S. Eve and C. H. Creasey, *Life and Work of John Tyndall* (London: Macmillan, 1945), 43.
[74] Crary, *Suspensions of Perception*, 235.
[75] Tyndall, *On Sound*, 100-01.
[76] ibid. The monochord was a single-stringed instrument used by many natural philosophers to investigate the harmonic properties of strings, and in some schemes to chart man's relationship to the cosmos through correspondence. It has a long history in sonic investigation: "Pythagoras was reputedly the inventor of the monochord or canon, which according to Boethius was the first philosophical instrument used to demonstrate the immutable laws of nature by means of experiment." Gouk, *Music, Science and Natural Magic*, 269.
[77] Helmholtz, *On the Sensations of Tone*, 9.
[78] Douglas Kahn, *Noise Water Meat: A History of Sound in the Arts* (Cambridge: MIT Press, 1999), 76.
[79] Helmholtz, *On the Sensations of Tone*, 251.
[80] ibid.
[81] ibid.
[82] ibid.
[83] ibid., 10.
[84] The malleus and incus were named in 1543 by Belgian anatomist Andreas Vesalius (1514 - 1564) who is considered 'one of the greatest anatomists of all time' - not surprising given the intricacy of the task involved. The stapes was named in 1546 by Italian anatomist Giovanni Filipo Ingrassias (1510 - 1580), Adel K. Afifi and Ronald Arly Bergman, *Functional Neuroanatomy: Text and Atlas* (New York: McGraw-Hill, 2005), 321.
[85] Helmholtz, *On the Sensations of Tone*, 132.
[86] ibid., 134.
[87] "The impedance of water is 3750 times greater than air, so only about 1/1000 of the power in the air is transmitted to the water. What this means is that if an air molecule vibration were to hit the fluid-filled cochlea directly, only about 1/1000 of the power would be effective in creating fluid movement." Handel, *Listening*, 465.
[88] ibid., 468.
[89] The outer two chambers form the vestibular canal and the tympanic canal, which contain the fluid. Although separate at the 'base' end of cochlea, there is a small opening (the helicotrema) at the coiled end (apex) that allows fluid to flow from one canal to the other.
[90] Handel, *Listening*, 468.
[91] Helmholtz, *On the Sensations of Tone*, 137-38.
[92] ibid., 146.
[93] ibid.
[94] ibid.

[95] Georg von Békésy and Walter A. Rosenblith, "The Mechanical Properties of the Ear," in *Handbook of Experimental Psychology*, ed. S. S. Stevens (New York: John Wiley & Sons, 1951), 1089-90. For contemporaneous accounts of the research of C. H. Hurst, J. R. Ewald (1899), E. ter Kuile (1900) their various fluid dynamic frequency schemes for the operations of the cochlea, see Henry J. Watt, *The Psychology of Sound* (Cambridge: Cambridge University Press, 1917), 148-59.
[96] ibid., 1091.
[97] ibid.
[98] Dayton Clarence Miller, *Anecdotal History of the Science of Sound to the Beginning of the 20th Century* (New York: Macmillan, 1935), 80.
[99] V. Carlton Maley Jr., *The Theory of Beats and Combination Tones 1700-1863* (New York: Garland, 1990), 120.
[100] Helmholtz, *On the Sensations of Tone*, 9.

2. Sine sounds, electronic instruments, and the expansion of musical resources in the early twentieth century

The experimental music milieu that surrounded the acoustic explorations of La Monte Young and Alvin Lucier in the 1960s and 1970s finds its origins in the avant-garde and experimental music of Europe and America of the first half of the twentieth century. Throughout the nineteenth century, moves to mechanise and electrify industry, transport, communications and entertainment had brought about vast changes to urban life. In the early part of the twentieth century, musical sound and everyday noise would encounter each other as part of a developing discourse of sound, as pursued by artists engaged with the social, political and technological changes of the era.

The first half of the twentieth century was also a crucial time for the dissemination of concepts from the specialised field of acoustics into the arts, as popularised by the writings of Helmholtz, Baron Rayleigh and John Tyndall. Of equal significance was the work of American astronomer and acoustician Dayton Clarence Miller (1866-1941). Miller's book *The Science of Musical Sounds* was originally published in 1916, and became a key work for diffusing acoustical thinking throughout the avant-garde, both in Europe and America.[1] This period also saw a shift in the field of acoustics away from optical and mechanical devices for investigating sound as apparatus for analysing and recording sound became increasingly electrified.[2] These developments in theoretical and applied acoustics took place alongside the widespread industrial and household use of electricity, and were concurrent with the first attempts to electrically generate sound.

This chapter will survey examples of acoustics and electrical sound in the avant-garde and experimental music of this era, in order to establish a context for the later use of sine waves and acoustic phenomena in the work of Young and Lucier. It will also trace sine and sine-like sounds across a range of technical and musical contexts, whether these sine-like sounds are conceived of as simple sounds, constant sounds, or static, steady tones. The devices designed by inventors and scientists across several disciplines in this early era of electronic technology presented composers with the possibility of utilising steady, sine-like sounds in their compositions. Against a backdrop of the emergence of radio and telephony, the electrification of phonography, and the prevalence of the sound of electricity itself, avant-garde and experimental composers created a variety of musical schemes that sought to incorporate these new electrical sounds.[3]

Perhaps most important for this survey is the variety of discourses, opinions and interpretations of acoustics that can be read through the avant-garde. Some embraced the definitions of musical sound it offered, while others displayed a more ambivalent attitude towards this scientific incursion into the realm of the aesthetic. Acoustics can be seen to have served two different purposes; it was a means of verifying, justifying or explaining sonic phenomena, and a system for generating new sonic materials and configurations. Many of the references to acoustics in the avant-garde relate specifically to the harmonic or overtone model of musical sound produced by Fourier analysis. For some artists the overtone series became a means to explore the effects of dissonance or enharmony, or formed the basis of a discussion on the history of music itself. For others it demonstrated how a similar mapping of worldly sounds might expedite their use in a musical context. In all cases, the so-called harmonic space above the fundamental became a site of contestation, which in turn called into question the intervals and sine curves used to map it out. Redefining musical resources would in some cases lead to new theories of perception and listening, and a variety of trained and 'sensitive ears' would also be called upon to arbitrate on issues of this new musicality.

Technologies of sine-sound (and sight)

As outlined in the previous chapter, the prospect of a single frequency sound - a sine tone - was an artefact of the application of Fourier analysis to the question of the structure of musical sound. As both the simplest representation of sound and the building block of musical sound, the sine tone became useful both practically and conceptually as the acoustic standard for vibration and oscillation. The question of establishing a benchmark sound for the purposes of experimentation, measured either in terms of musical pitch or frequency, has been a long-standing concern in the study of sound. Consequently, there has been a number of efforts aimed towards developing a means of generating a stable or static tone of a known value that was harmonically simple, which could be used either as a means for examining the interaction of two related pitches, or for constructing models of the overtone structure of sounds.

The question of producing and measuring the frequency of sound was explored by French natural philosopher Joseph Sauveur (1653-1716). Sauveur's work followed on from the discoveries made by his countryman Marin Mersenne (1588-1648), who is credited with being the first acoustician to make the direct observation that musical pitch was determined by the frequency of its vibrations.[4] Sauveur's paper "Sur la Determination d'un Son Fixe", published in 1700 in the *Historie de L'Academie Royale Des Sciences*, concerns the problem of establishing a *son fixe* [fixed sound], which would serve as a reference for musical research, and also be an aid for performers and instrument builders.[5] Using two organ pipes tuned to the ratio 25:24, Sauveur counted the number of acoustical beats that were created by the pattern of destructive interference formed between the two sounds. As they produced four beats per second, Sauveur determined the higher pipe to have a frequency of one hundred vibrations per second (or 100 Hz).[6] Using this method of calculation Sauveur also speculated on the frequency range of human hearing, positing a span of approximately nine octaves: from 12.5 to 6400 Hz.[7]

Tuning forks had been a mainstay in determining musical pitch since their invention by John Shore in 1711 (a trumpeter both for the band of Queen Anne and for the composer Handel), and became useful tools for experimentation in sound and music.[8] Sir Charles Wheatstone investigated the conduction of sound by the skull in 1827, by placing a tuning fork to the temporal bone near the ear.[9] In 1834, Johann Scheibler developed the tuning fork 'tonometer', in which fifty-six tuning forks were used to divide an octave at intervals of 4 Hz, as a means of determining correct concert pitch.[10] The design of what was regarded as the laboratory tuning fork was formalised by French instrument maker Marloye in 1839, providing it with a resonance box to amplify the otherwise weak sound.[11]

Hermann von Helmholtz made extensive use of tuning forks, and considered them a practical source of simple sound (despite finding that they contained more than one frequency component).[12] Not only were they useful as a source of regular audible vibration, they could also be employed as a means of regulating vibration. Helmholtz used an apparatus in which tunings forks were sounded by positioning them within the field of a small electromagnet. An intermittent current flowing through the electromagnet would momentarily magnetise the coils and attract the tines of the fork, setting it in motion.[13] In order to sustain the sound of the fork accurately, the electromagnet had to receive an intermittent current that was the same frequency as the tuning fork to be sounded.[14] To do this, the current was transferred to the electromagnet via an interrupter - a second device that contained a matching fork driven by a second electromagnet. Small wires connected to the ends of each tine were suspended above small cups filled with mercury.[15] As the fork vibrated in the electromagnetic field, the movement of the wire in and out of the mercury would successively complete and break the electric circuit at the rate of its vibration, providing a steady stream of current to drive the sounding fork.[16] Helmholtz used arrays of up to eight of these electromagnetically driven tuning forks to perform experiments on the frequency composition of vowel sounds, an idea later developed by renowned Paris-based instrument designer Rudolf Koenig.[17]

As tuning forks were essential not only as a fixed source of sounds but as quantifiable sources of vibration, they were used to produce visual representations that affirmed the link between regular physical vibrations and musical sound. Helmholtz, using a small stylus attached to the tine of a sounding fork, inscribed a wavy line along a moving sheet of paper, a "permanent image of the kind of motion performed by the end of the fork during its musical vibrations."[18] Influenced by the work of French physicist Jules Lissajous (1822-1889), Helmholtz used another electromagnetically driven tuning fork in his vibration microscope - an apparatus that allowed him to observe vibrating objects through a microscope eyepiece.[19] He also employed this same apparatus to observe the motion of bowed strings, recording the pattern of their movement in two dimensions.

Lissajous' experimental work observing vibration patterns would also influence John Tyndall, who included a number of Lissajous' procedures for obtaining two dimensional images of sound waves in his public lectures and demonstrations. In *On Sound*, Tyndall recounted what he called Lissajous' "very beautiful method for giving optical expression to the vibrations of a tuning fork."[20] This was achieved by focussing a beam of light onto a small mirror attached to one tine of a vibrating tuning fork. A hand held mirror then caught the reflection of the beam, and in turn reflected it onto a screen. Manipulating the hand held mirror side to side caused the reflected beam of light, oscillating up and down at the same frequency as the tuning fork, to resolve into a "beautiful luminous ripple."[21] An "optical illustration of beats" was obtained by a similar method, but using two identically tuned forks with mirrors. These were arranged in a line so that the beam of light reflected from the mirror attached to one fork to the mirror on the other, before reflecting onto the screen.[22] Small amounts of wax were added to one fork to alter its rate of vibration, producing a pulsating waveform in time with the beating pattern formed between the two forks. For an "optical illustration of intervals" the two forks were placed at right angles to each other - one vertical, the other horizontal.[23] When the forks were set in vibration, the reflected light beam reproduced Lissajous' 2-dimensional images formed by the displacement of the forks in two directions - up and down, and left to right.[24]

Tyndall made extensive use of use of tuning forks in his demonstrations - not all of which were as elaborate as Lissajous' methods. A much simpler demonstration of wave motion in vibrating strings used a silk cord attached to one tine of a tuning fork, with the other end anchored to a weight. Exciting the fork with a violin bow, Tyndall used subtle changes in tension on the cord to display different vibration modes and nodal points.[25] He considered this demonstration to show wave motion "with a beauty and a delicacy far surpassing anything attainable with [the] sonometer" (Tyndall's name for the monochord).[26]

Aside from his use of the electromagnetic tuning fork, Helmholtz is renowned for his use of sirens for exploring the relationship between pitch and frequency in musical sounds. Helmholtz employed the siren designed by Heinrich Dove (1803-1879) in the 1840s, which was itself a refinement of the instruments of de la Tour and Seebeck. The operative part of the siren was a rotating disc with holes punched at regular intervals around its circumference.[27] Air was pumped into the siren and forced through the holes in the rotating disc, causing a tone to be produced. The frequency of the tone could then be determined by multiplying the number of holes in the disc by the rate of rotation in seconds (for example, a disc with twelve holes rotating at ten revolutions per second would produce a pitch with the frequency of 120 Hz).[28] Maintaining a fixed pitch would involve maintaining a regular rotation, and Helmholtz employed an electromagnetic motor to drive the siren's mechanism.[29] Helmholtz also developed a device consisting of two sirens fixed to the same drive mechanism for measuring interference phenomena and musical intervals.[30]

Although the acoustician's electromagnetic tuning fork was an electrically powered source of static, sine-like tone, an actual electrically generated tone would come from elsewhere. The spark gap oscillator developed by Heinrich Hertz (1857-1894) was the product of research into the existence of the electromagnetic waves proposed by Scottish physicist and mathematician James Clark Maxwell in his "Treatise on Electricity and Magnetism" (1873). Hertz had initially left his native Hamburg in 1877 to study engineering in Munich, but quickly moved on to the University of Berlin the following year to study physics, where Helmholtz became his mentor.[31] Hertz's paper "On Very Fast Oscillation" (1887) described his work on generating high frequency standing waves and measuring wavelengths, so becoming the first person to demonstrate experimentally the production and detection of the electromagnetic waves theorised by Maxwell. Hertz's spark gap oscillator took the form of a coupled open wire circuit, what in contemporary terms is referred to as a half-wave dipole, as the flow of current in the circuit changes direction every half cycle, causing the oscillation.[32] Hertz used a laboratory induction coil for supplying electricity to be converted into oscillating high frequency waves, which was discharged in the form of a spark between two metal balls placed either side of an open gap in the circuit (hence its name).[33]

The high frequency electromagnetic waves emitted by the spark gap oscillator became the basis of wireless radio. What Marconi and other early radio experimenters would ascertain was that devices such as Hertz's spark gap oscillator created a high frequency electromagnetic disturbance in the form of a radio wave that could be detected at a distance. Therefore a series of disturbances could be used to transmit information by replicating the dots and dashes of Morse code. Developments aimed at improving the reception of radio waves would bring significant changes to the design of oscillators. English inventor John Ambrose Fleming (1849-1945) developed his two-electrode thermionic valve while working as scientific advisor to the Marconi Wireless Telegraphy Company, which he had joined in 1899.[34] Prior to working for Marconi, Fleming had been a consultant to the Edison Electric Light Company of London in 1882, and had performed experiments to find the cause of the "Edison effect" - the darkening of incandescent light bulbs caused by the emission of electrons. During his experiments, he found that the 'hot' incandescent electrode discharged negative electricity to the cold electrode, but not vice versa (hence the name 'valve' for vacuum tubes, as current flows one way but not the other).[35] While working on devising more sensitive receivers for radio waves, Fleming recalled his earlier experience with vacuum tubes, and realised their potential as rectifiers (electronic devices that convert alternating current to direct current), which could then be used for receiving electromagnetic waves.

In 1905 Lee de Forest (1873-1961) developed a three electrode version of the vacuum tube, called the audion, by adding a grid of wires between the existing two electrodes that allowed for greater control over the current inside the tube.[36] De Forest subsequently developed an audion amplifier for boosting signal levels in radio and telephone systems. While working on amplification systems for the Federal Telegraph and Telephone Company in Palo Alto California in 1912, de Forest succeeded in electrically generating a clear audio tone through a process of feedback, or regeneration, where the output of an audion amplifier was connected to its input, causing the vacuum tube to oscillate steadily at a fixed frequency.[37] Testing showed that this system was capable of generating both audio and radio frequency oscillations.[38] Usually the howl or shriek produced by regeneration or feedback was considered an undesirable artefact of telephone systems - an indicator of malfunction or misconnection. However, in this controlled situation, feedback was a recursive means of setting the tube into continuous oscillation.

Vacuum tubes would be the basis for most forms of amplification and oscillation for the first half of the twentieth century, and were used extensively in radio, communications and broadcast equipment of all kinds. In 1938, William Hewlett and David Packard would manufacture the first Hewlett Packard product - the 200A Audio Oscillator. The oscillator used an incandescent bulb as part of its wiring scheme to provide variable resistance in the feedback loop, producing a stable oscillation with low distortion, and was the first low-cost method for testing sound equipment. The Walt Disney Company would effectively bankroll the fledgling company when it ordered eight Model 200B oscillators, which were used for testing the multi-speaker systems installed in the twelve theatres specially designed for screening Disney's *Fantasia* in 1940.[39] However, aside from being components in test equipment, oscillating vacuum tubes would also become the source of sound for some of the first electronic musical instruments.

Simple sounds, electronics, and musical instruments

There were several significant electronic musical instruments that caught the ear, and the imagination, of composers in the early twentieth century. These instruments were regarded as potential means for introducing the electrified soundscape of modernity into music. In fact, many of these instruments had their origins as offshoots of technical developments in telephony, electric lighting, electricity generation, and radio. These instruments made available to composers a range of electrically generated synthetic sine-like sounds, which had, or were perceived to have, simple harmonic structures. They were attractive to composers seeking new approaches to music as the instruments often featured novel control systems that transcended the restrictions of conventional, fixed tonality, allowing the production of pitches not just between the notes, but to make sounds that extended below and above the range of orchestral instruments.[40]

The late nineteenth century had seen an array of proposals and schemes for making musical sound with electricity. Elisha Gray (1835-1901), an American inventor and early competitor with Alexander Graham Bell, devised the 'singing telegraph' in 1874 as a result of his work on telephony. The idea came from Gray's nephew, who had contrived an electric circuit involving batteries and a vibrating metal strip, producing an audible hum.[41] Gray refined the idea, using an electromagnetic circuit that vibrated a metal reed. This was the effectively a simple electrical oscillator, sound of which could then be transmitted along telephone lines. The singing telegraph used a small keyboard to control a number of these oscillators, and had a range of an octave. Similarly, English electrical engineer William Duddell (1872-1917) devised the 'singing arc' in 1899 while working on reducing the noise produced by carbon arc lamps used to light the streets of London. Duddell discovered that he could control the frequency of the hum by varying the voltage to the lamps. A keyboard controlled circuits that allowed him to tune the rate of pulsation of the arc to produce distinct musical pitches. The sound was generated by the spark rate of the carbon arc lights, making it one of the first electronic instruments that did not use the telephone system to produce sound.[42]

However, the most significant of these early schemes, and one of the first fully operational electronic musical instruments, was the telharmonium (or dynamophone) of Thaddeus Cahill (1867-1934). In his patent application in 1897, Cahill cited the influence of Helmholtz in his approach to generating musical sound electrically. He proposed a machine to "generate music electrically with tones of good quality and great power and with perfect musical expression, and to distribute music electrically generated by what we may term 'original electrical generation' from a central station to translating instruments located at different points."[43] Cahill's invention utilised technology for the generation of electricity, employing a bank of one hundred and forty five modified dynamos (mechanisms that convert mechanical energy into electrical energy) specially geared to produce alternating currents of different audio frequencies; these were controlled by two touch-sensitive keyboards, with a range of five octaves.[44] Cahill also devised systems for controlling dynamics and for shaping the harmonic content of individual tones.[45] As the telharmonium had been designed long before the invention of electrical amplification, the sound produced by dynamos was initially amplified acoustically using modified piano soundboards. Later versions were connected directly to the telephone network, which not only allowed the sound to be heard locally over modified telephone receivers, but to be transmitted across the network to theatres, private homes, restaurants, businesses and factories, providing the earliest form of piped music - a proto-Muzak.[46]

Despite its ingenious design and ambitious deployment, the telharmonium had some distinct problems, the first being its size. The first complete model unveiled in 1906 in Holyoke, Massachusetts was an enormous structure about two hundred tons in weight and twenty metres in length. Secondly, in order to overcome the lack of electrical amplification, Cahill's dynamos had to produce over ten thousand watts in order to transmit the sound of the telharmonium over the telephone wires.[47] As a result, music from the telharmonium had a tendency to cause interference with other signals on the telephone network.[48]

The sound of the telharmonium was very much an artefact of its era. Cahill effectively recast the buzz of electricity generation as musical sound with his use of tuned dynamos. However, the telharmonium still relied on mechanical means for providing the regular oscillations needed to create continuous electrical tones. De Forest's later success in developing regenerative amplification with three-electrode vacuum tubes provided a completely electrical source of oscillation, which in turn became the sound source of several fully electrical instruments. The etherphone - developed in 1920 by Leon Theremin (1896-1993) while working on an electronic motion detector - used an oscillating audion vacuum tube to generate high frequency radio waves, which produced a small electromagnetic field around an aerial. Theremin found that the natural capacitance of the human body interfered with the electromagnetic field emanating from the aerial, and induced a change of capacity within the circuit, altering its oscillating frequency and producing an audible sine-like tone.[49] The instrument - later renamed the theremin - was adapted to use two oscillating tubes, where the heterodyning effect of the high frequency signals produced a lower audible beat frequency tone that could be more easily and accurately controlled by movements of the hand through the electromagnetic field. A similar process was then applied to a second aerial in order to control volume.[50]

The theremin was controlled not by a mechanism such as a keyboard but by the movement of the hands in relation to the two aerials, and was therefore capable of producing a continuous, sine-like glissando with a range broader than that of an orchestra. This form of control did, however, complicate the process of accurately sounding discrete pitches, as it required performers to slide from note to note in a search for precise intonation. Still, there was a great deal of interest in this new instrument when Theremin toured his invention throughout Europe in the 1920s. He relocated to New York in 1927, where he gave a number of demonstrations and sought commercial applications for his invention.[51] The following year saw the appearance of the *ondes Martenot* (literally "Martenot waves," also known as the ondes musicales) invented by French cellist and telegraphist Maurice Martenot (1898-1980). It also used oscillating thermionic valves, and was very similar in sound to the theremin. However, the *ondes Martenot* proved to be more popular with composers, as it featured both a conventional keyboard and a strip control for glissando and vibrato, making it a more flexible instrument.[52]

The future of electronic musical instruments would turn away from simple sine-like sound of the theremin and *ondes Martenot* towards increasingly sophisticated schemes for the synthesis of complex tones and the control of electronically generated sound. Many of these would seek to replicate the sound and tonality of existing instruments. Others, such as the modular synthesis systems invented by Harald Bode and Robert Moog, and the instruments developed by Donald Buchla would take electronic music in a very different direction.[53] However, the 'simple' sonic possibilities presented by instruments such as the telharmonium, theremin and *ondes Martenot* would figure as important elements in the renegotiation of musical resources by the avant-garde.

Acoustics, electronic sound and the extra-musical

The electronic musical instruments that appeared in the first half of the twentieth century became one part of a tactical reappraisal of music making. A number of new methods of composition, aided by the new representations of musical sound provided through the influence of acoustics, aimed to break the stranglehold that conventional musical practice had on sound and tonality within western art music. The redefinition of musical language undertaken by avant-garde and experimental composers was characterised by appeals for the expansion of musical resources. This included a call for the category of sounds made available to music to be extended to include those previously excluded from the practice of music making, such as the worldly sounds of urban life and nature. The incorporation of these *extra-musical* sounds was paralleled by attempts to take advantage of the possibilities arising from the emergence of electronic means of generating, recording and controlling sound. Amongst these related but divergent imperatives the development of a discourse of sound can be traced, one in which relative notions of musical sound and noise blend, fold, interleave or separate according to definition.

Douglas Kahn has written extensively on the use of extra-musical sounds in the first half of the twentieth century, and has documented the various rhetorical and compositional processes for their incorporation into the music of the avant-garde, particularly through the tropes of noise, glissandi, and silence.[54] Kahn argues that while on one hand the incorporation of what was traditionally regarded as non-musical sound into music rejuvenated musical practice, it simultaneously diminished or removed the worldly character of those same sounds.[55] This removal of the signifying power of these sounds Kahn in part attributes to prohibitions against imitation inherent in Western art music.[56] Either by separating sounds from their sources through recording, or by rhetorically arguing for a contemplation of sounds abstract from both their modes of production and any meanings they might carry, this *musicalisation* of noises revitalised Western art music, while at the same time inuring it against the questioning of these practices along non-musical lines.

Compared to *extra*-musical sounds such as steam trains, car engines or factory whistles, the sine wave could instead be considered to be *intra*-musical: whether it was regarded either as a component of musical sound or as a sound in itself, the sine wave was an artefact produced from within the scientific study of music. Sine tones would be represented in avant-garde discourses on musical sound through a sustained interest in the overtone series, but the inclusion of sine-like sounds into compositions would occur indirectly. Acoustics, however, provided a description of the material aspects of sound, and composers made extensive use of the framework provided by Fourier analysis as a means to both understand and substantiate their attempts to move beyond traditional tonality and timbre.

Italian composer and pianist Ferrucio Busoni (1866-1924) described the basis for his exploration of tonality in his *Sketch of a New Aesthetic of Music*, published in 1911, in part a response to the music of Richard Wagner and the Romantic aesthetic of his adopted homeland, Germany.[57] Busoni attacked the predominance of the equal tempered scale, seeing it as a synthetic structure that only served to deprive musicians of the full scope of their medium. He considered the artificial division of the octave into twelve notes by equal temperament to have "so thoroughly schooled our ears that we are no longer capable of hearing anything else - incapable of hearing except through this impure medium."[58] Instead, Busoni proposed a return to a boundless, unmediated and natural sonic continuum: "Nature created an *infinite gradation - infinite*! Who still knows it nowadays?"[59] Accordingly artists would then work in an unfettered sonic field, allowing an idealised union between artist and nature to take place: "Instinct leads the creative musician to employ the tones that press the same key within the human breast, and awaken the same response, as the processes in Nature."[60]

Clearly Busoni's conception of the "natural" extends beyond the physical or material aspects of musical sound, and suggests a cosmological view of creation and eternity. His appeal to an infinite gradation of tone was part of a process by which music would be restored to its "primitive, natural essence."[61] In freeing music from what he termed "architectonic, acoustic and esthetic dogmas" music could slip beyond the material into a realm of "pure invention and sentiment, in harmonies, in forms, in tone-colors... *let Music be nought else than Nature mirrored by and reflected from the human breast*; for it is sounding air and floats above and beyond the air."[62]

The question of how to generate tones outside the equal tempered scale could be answered through emerging technologies of electronic sound generation. Busoni proposed the use of Cahill's telharmonium, which, he recounted, was capable of transforming an electric current into a "fixed and mathematically exact number of vibrations. As pitch depends on the number of vibrations, and the apparatus may be 'set' on any number desired, the infinite gradation of the octave may be accomplished by merely moving a lever corresponding to the pointer of a quadrant."[63] Of course, any unfretted string instrument, such as a violin or viola, is able to produce tones 'between' the notes of the piano, but it cannot empirically indicate the fundamental frequency of any note. Therefore, Busoni's appeal to an infinitude of pitches within the octave is moderated by a desire to not just produce these illusive notes, but to be able to identify and control the frequency of each of the pitches involved.

However, technology would solve only part of the problem. Even though Busoni's new aesthetic was to bring musicians and listeners into line with the natural origins of musical sound, they would need to learn (or perhaps re-learn) to identify and discriminate between these novel sounds: "Only a long and careful series of experiments, and a continued training of the ear, can render this unfamiliar material approachable and plastic for the coming generation, and for Art."[64] This new music required habits of perception to be overhauled in order to interpret these new sensations.

Where Busoni's call to nature was a rhetorical petition for more notes, in *The Art of Noises: Futurist Manifesto* (1913), the Italian Futurist painter Luigi Russolo (1885-1947) proposed re-invigorating music through the incorporation of quotidian sound. Russolo considered a musical art comprised of a "soft and limpid purity of sound" inadequate for portraying the sensibilities of the mechanised age.[65] Instead, the manifesto - which took the form of a letter to his Futurist compatriot composer Balilla Pratella - proposed an attempt to "break at all cost from this restrictive circle of pure sounds and conquer the infinite variety of *noise-sounds*."[66] Rather than the sweeping scale of Busoni, the sounds of trains, factories and street life would fill the gaps between the notes.

Despite Russolo's radical approach to the use of noises as new musical materials, his definition of noises does not differ greatly from those provided by Helmholtz or Strutt: "thunder, wind, cascades, rivers, streams, leaves, a horse trotting away, the starts and jumps of a carriage on the pavement, the white solemn breathing of a city at night, all the noises made by feline and domestic animals and all those man's mouth can make without talking or singing."[67] However, Russolo denies that noise is inherently problematic, finding that noise, in its "surprising variety," is instead capable of providing what he (perhaps ironically) refers to as "pleasant sensations," making it fit for aesthetic contemplation.[68] In an echo of Strutt's example of how the simultaneous striking of a number of consecutive keys on a piano produced an approximation of noise, Russolo claimed an aesthetic precedent to his art of noises in the extended use of dissonance by early twentieth century composers, which he considered had already pushed musical sound towards the condition of 'noise-sound.'[69] An art of noises would therefore form the next logical step in this progression.

Acoustic investigations into the composite nature of sound informed Russolo's understanding of the physical principles of noise. However, he considered that the work of Helmholtz and other acousticians had concentrated too much effort on providing a rarefied image of musical sensation that was perfectly stable, uniform and regular, and consequently had done little to further their physical theories of noise.[70] In developing his own definition of noise, Russolo made reference to the visual representations of waveforms in the work of Dayton Clarence Miller's *Sound Waves: Their Shape and Speed* (1937), attributing the difference between the simple sine-like waveform produced by a tuning fork and the more complex waveform produced by a violin as indicating the presence of a greater number of harmonics in the violin sound.[71] He then extended this analogy to his own experiments with a sheet of steel, which had yielded comparable results. Stimulating the sheet with a violin bow produced a regular vibration, whereas beating produced "more vibrating parts and a larger number of harmonic sounds."[72] Russolo concluded that noise was therefore richer in harmonics than musical sound, and was produced when the "secondary vibrations are more numerous than those that usually produce a sound."[73]

In his manifesto, Russolo struggles to present a notion of harmony removed from consonance. He considered each noise contained a dominant pitch - not unlike the fundamental frequency of a musical tone - which was to provide a means for the organisation of sounds within a composition. However Russolo is at pains to maintain that what he calls the harmonic scoring of noises would not temper the perceived 'noisiness' of a given sound - what he called their "irregular vibrations (of tempo and intensity)".[74] He would later borrow the term *enharmonic* from Pratella's *Technical Manifesto of Futurist Music* to describe the relationship between two sounds not based on traditional notions of musical harmony.[75]

Acoustics would also come into play when designing instruments to make this new music. Russolo proposed a range of new instruments (the *intonarumori* - 'noise intoners') in order to perform his compositions such as *Awakening of a City* (1913) and *Meeting of Automobiles and Airplanes* (1913). The intonarumori would provide an "infinite variety of timbres of noises obtained through special mechanisms," and were to be constructed in accordance with the laws of acoustics.[76] These instruments had descriptive titles such as howlers (*ululatori*), roarers (*rombatori*), and cracklers (*creptitatori*), highlighting their imitative qualities.[77] All of the sounds they produced were generated by mechanical means - and many of the instruments were entirely mechanical and operated by means of handles and levers (although some had been designed to be partially driven by electric motors).[78] While most of the intonarumori recreated the sounds of steam-powered, mechanised, industrial Europe, one particular instrument, the hummer or *ronzatore*, hinted at the new sound of electricity. Russolo described the *ronzatore* as having a "sweetly harmonious noise-sound, full of fascination and recalling the humming of dynamos and electrical motors, whose curious sound fills the great electrical centres and is always associated in our minds with the vision of great, gleaming, very modern and marvellous factories."[79] Russolo even described the timbre of the *ronzatore* in musical terms, noting that it produced "very charming harmonics, the fifth above, the octave, and its third, over the fundamental."[80]

Edgard Varèse (1885-1965) would make particular use of electronic sound in his work, both as an indicator of worldly sounds, and of the glissandic sweep of tones ala Busoni. Varèse's work can in some senses be seen as a practical synthesis of the concerns that emerged in the work of Busoni, Helmholtz, and Russolo. His early interest in percussion made him initially sympathetic towards the musical pronouncements of the Futurists, and he shared their enthusiasm for sounds of the mechanical modern world. However, he eventually drew a hard distinction between their approach and his own, which was grounded in modernist prohibitions on imitation, proclaiming: "The Futurists imitate, an artist transmutes."[81] While living in pre-World War I Berlin, Varèse befriended Busoni, having already been strongly influenced by his *Sketch of a New Esthetic in Music.* Varèse considered this relationship formative of his mature aesthetic, as Busoni's influence helped confirm his belief that new means must be found to "liberate sound, to free it from the limitations of the tempered system."[82] His early experiments with sirens were a direct result of his reading of Helmholtz's experiments in *On the Sensations of Tone*. This allowed him to form what he called "parabolic and hyperbolic trajectories of sound" in works such as *Amériques* (1926), enacting Busoni's infinite gradation of sound unfixed from tonality.[83]

Varèse became involved with electronically generated sound after he moved to America in 1915. He had learnt of the telharmonium from Busoni's book, but was disappointed after hearing it in operation. He collaborated with Leon Theremin to develop two specially designed instruments for *Ecuatorial* (1932-34), but later opted to use two *ondes Martenot*.[84] While the electronic instruments may have produced a novel sweeping sine-like sound over a range of frequencies beyond the reach of conventional instruments, works such as *Ionisation* (1929-31), with its textural use of non-pitched percussion and siren glissandi, display a greater permeation of the sounds of industrialised modern life into Varèse's music. His later interest in electronics would be in the area of tape-based composition, firstly in the percussion and factory sounds used in *Déserts* (1950-54), and the montage of machine noises, bells, percussion, voices, and electronic sounds that comprised *Poème Electronique* (1957-58).[85] Much like Varèse himself, many of his concerns with acoustics and electronic sound would find resonance in the USA.

American composer Henry Cowell (1897-1965) completed the first draft of his book *New Musical Resources* in 1919, only two years after completing his studies at Berkeley, although it was not completed for publication until 1930.[86] Its aim was to provide an historical overview of the influence of the overtone series on musical sound, and how it could be used to generate a range of new materials, and to provide what he called a system for "coordinating the various materials of modern music".[87] Cowell had been lead to this study in order to find "genuine scientific and logical foundations" for the idiosyncratic techniques he had introduced into his compositions.[88] His findings convinced him that even though he was unaware of the acoustical theories that explained his compositions at the time that they were composed, there had nevertheless been "enough unconscious perception so that the means used were not only in accordance with acoustical law, but are perhaps the best way of amalgamating sounds formerly considered discords."[89]

In describing the physical structure of musical sound, Cowell defers to Fourier analysis, (although he baulks at naming it explicitly):

> Music is based upon, and conditioned by, the physical laws of sound-waves. These laws disclose that musical tones have a relation to each other which is measurable by mathematics. They further show that each tone produced generates a series of overtones which are related to that tone, and to each other, by definite mathematical ratios.[90]

Although Cowell's description of Fourier analysis is synonymous with harmony, throughout the text Cowell strategically makes reference only to the *overtone* series, rather than a *harmonic* series. The difference between these two terms is partly semantic, as they both describe a range of component parts arrayed above a fundamental frequency. The crucial distinction lies in the kind of relationships they each represent. Strictly speaking, a harmonic series implies frequency relationships based on whole number ratios only and presents an idealised image of musical sound - insofar as it implies that a musical sound contains only those frequency relationships and no others. Cowell's use of the term overtone series, on the other hand, incorporates any and all components of an actual sound, of which a harmonic series would comprise only one possible set. Borne of Cowell's empirical observation of musical sound, even the most basic musical intervals contained dissonances between the highest combinations of overtones, which would be pivotal to Cowell's interpretation of tonality.

In contrast to the grand cosmic sweep of Busoni, Cowell's music is instead drawn along more functional lines. One of his most significant contributions to musical materials was the t*one-cluster* - dense chords often constructed from major and minor seconds - that could be played on a conventional piano. Explaining the tone-cluster would not mean an appeal to infinite nature, only to the physical nature of the overtone series: "One reason a large cluster is a natural reinforcement when played at the same time as a simple chord is that whenever a simple triad is played, the higher overtones of all three tones, which are plainly audible to a sensitive ear, form such a cluster."[91] Tone-clusters, therefore, were merely a transposition from the overtones of notes in a chord to the level of the fundamental. If Cowell's explanation of tone-clusters showed how harmony also embraced dissonance in the interactions of the overtones of different notes, it also implied the reverse - that dissonant tone-clusters also embraced harmony in the overtones.

Tone-clusters blurred the line between consonance and dissonance, instead proposing a music that could be described as having its basis solely in the mutual sounding of pitches. However, particular attention would need to be paid to the inner workings of sound to understand why Cowell considered his tone-clusters to be musical. Listeners needed to apply their 'sensitive ears' to the overtones produced by all combinations of musical sounds, familiar or otherwise. Only those listeners with "very crude hearing" would be upset by the sounds of tone-clusters or natural dissonances, attributable to the fact that they had already failed to attend to the overtones present in familiar chords.[92]

This concept of listening to overtones as a product of chord formation marks a key stage in the practice of listening in the twentieth century avant-garde. It presents the centrality of the experience of listening, and importantly a particular *kind* of listening. Listening specifically to the overtone series served an important epistemological function for Cowell, as it provided an understanding on the physical nature of musical sound, which in turn influenced the production of new music. Cowell's notion of an 'unconscious perception' on his part also seems to owe something to Helmholtz's theory, where the physical act of sensing the material aspects of musical sound lead directly to its aesthetic contemplation.

Cowell mentions the 'electrical instruments' of Leon Theremin, and not unlike Busoni, reflects on the ability of these devices to transcend conventional tonality. That Theremin's instrument could produce discernable change in pitch of a "one hundredth step" lead Cowell to posit a music built on the parameters of perception: "the probabilities are that any intervals which are perceivable as distinct to the human ear can find musical use in some form and under certain circumstances."[93] This would necessitate even closer listening.

The importance of listening in schemes for the musical deployment of extra-musical resources would find its ultimate realisation in the music and theorising of Cowell associate and student John Cage (1912-1992).[94] In his clarion call, *The Future of Music: Credo* (1937), the use of extra-musical sounds and technology coalesces in this succinct opening statement: "I believe that the use of noise to make music will continue and increase until we reach a music produced through the aid of electrical instruments which will make available for musical purposes any and all sounds that can be heard."[95] With this assertion Cage declared his intention to move away from a concept of music based on the dichotomy between consonance and dissonance, to one predicated on the contrast between musical sound and noise. This would be an encompassing aesthetic of *all-sound*, where any sound could be used for musical purposes. Listening would play a critical role, as it had in Cowell's work, serving to transmute annoyance into interest: "Wherever we are, mostly what we hear is noise. When we ignore it, it disturbs us. When we listen to it, we find it fascinating."[96] In a combination of attention and technology, any sound could be a musical sound.

Although Cage argued for the inclusion of worldly noises into music, this is not to say that he had abandoned any distinction between types of musical sound and noises. In sketching out his programme, Cage defined three types of electrical instruments; each of these was to have its own role to play in creating this new music: recordings, to be used "not as effects but as musical instruments"; "electrical musical instruments" such as the theremin; and he also envisaged a new class of 'electrical instrument' - a kind of synthesiser which was to provide "complete control of the overtone structure of tones (as opposed to noises) and to make these tones available in any frequency, amplitude and duration."[97] Delimiting the role of this new 'electrical instrument' to generating tones and not *noises* is significant. Noises were not to be synthesised for their use in Cage's new music, but were instead to be found in the physical world, and obtained for use in music via recording. Noises were therefore conceptually grounded in the natural and physical world, albeit abstracted from their original context through the process of recording. Tonal material would be the domain of synthetic instruments. So a distinction between tone and noise in line with that defined by nineteenth century acoustics was still well and truly at play in Cage's thinking of this era.

Cage also makes several references to creating new sound using descriptions drawn from acoustics. He discusses the role of frequency in generating pitched sounds directly using optical film, and also the use of devices for manipulating the overtone structure of sounds. This would not, however, extend to Cage employing the overtone series as the structural basis of composition, as Cowell had proposed. Cage considered any compositional process that was restricted to relationships based on harmony incapable of addressing the "entire field of sound", and therefore an inadequate system of composing the kind of new music he proposed.[98]

Although Cage cited the theremin as an electrical instrument capable of producing a "wide variety of sound qualities," he was disparaging of performers who applied traditional instrument techniques, such as vibrato.[99] Cage also saw attempts to design electric instruments that mimicked existing keyboard instruments as anachronistic. To counteract this he proposed centres for experimental music, which would house equipment to both synthetically generate and reproduce new sounds, using oscillators, turntables and film phonographs, along with "the means for amplifying small sounds."[100]

Cage put these ideas into practice with *Imaginary Landscape No.1* (1939), a work written while he was working at the Cornish School in Seattle.[101] The school had a radio studio, equipped with variable speed turntables, and Cage used two of these for *Imaginary Landscape No.1*, along with a muted piano and cymbal. The source materials for the turntables were test-tone records - recordings of sine tones used for the calibration of studio equipment.[102] During performance, alterations in the playback speed formed the static sine tones into sweeping glissandi. Cage had intended the work to be performed as a live radio broadcast, and so for its debut performance the sounds were broadcast the short distance from the studio to the theatre nearby.[103]

In terms of the incorporation of sine-like sounds into Cage's work, it is significant that he employed test tone records as opposed to the electronic instruments of the era. For Cage, the sine-like sound produced by the theremin or *ondes Martenot* had already been co-opted by conventional performance techniques. By contrast, sine tone records developed for the technical needs of the radio and communications industry constituted extra-musical resources. That these tones were obtained in the form of recordings also served to distance these test records from other sources of electronically-generated pitches, in that recordings were already given a special status as sources of extra-musical sound.[104] Although it would be prohibited in Cage's later directive to listen to sound in and of itself, the sweeping glissandi of *Imaginary Landscape No.1* would also have extra-musical associations for listeners with the sounds of radio - specifically, the swoops and squeals heard between stations when tuning.

Of course, Cage's most significant encounter with acoustics would occur at Harvard University in the 1950s - inside an anechoic chamber, one of the key apparatus to come from acoustics.[105] In this oft-repeated story, rather than experiencing silence, Cage heard the sounds of his nervous and circulatory systems in operation, proving to him that there was in fact no such thing as silence. This experience of a continuum of sound, audible or inaudible, formed an important stage in his musical programme, and filled the gaps in 'music' with extra-musical sound:

> In this new music nothing takes place but sounds: those that are notated and those that are not. Those that are not notated appear in the music as silences, opening the doors of the music to the sounds that happen to be in the environment.[106]

Ironically, Cage's experience in an acoustically controlled, "unnatural" listening environment proved to be pivotal for accepting uncontrolled sounds into the realm of music.

The publication in 1937 of *Toward a New Music: Music and Electricity* by Mexican composer Carlos Chavez (1899-1978) outlined a much broader scheme for the possibilities presented by the emerging fields of radio, cinema, sound reproduction, and electronic instruments for the creation, performance and distribution of new music. For Chavez, electricity promised emancipation from the musical and institutional hangovers of the previous century:

> The present age, with its fertile agitation, its incredible social injustices, its portentous scientific development, is perfecting, in electricity, its own organ of expression, its own voice. This, clarified and matured, will become the legitimate art of our era, the art of today.[107]

Chavez depicted electricity as an unlimited source of novelty and variety, with the alternating current of electricity itself as the new 'sound-agent', to be added to the existing methods of producing the vibrations of musical sound.[108] Advancing on Busoni's infinite graduation of the octave, Chavez saw that the manipulation of the overtone series by electronic instruments would have the capacity to provide a continuum of timbre, not only filling the timbral gaps between the instruments of the orchestra, but creating new combinations, giving the composer an "infinite number of musical instruments."[109] Chavez also considered that electricity would allow for the generation of musical sounds of infinite duration, as there was "no lungs to tire or strings to snap."[110]

Although electricity was to be emblematic of the environment of the 1930s, for Chavez it would not be the sounds of electricity that would be significant so much as its use. The electric apparatus of sound production and reproduction was to "augment extraordinarily the range and capacity of our expression."[111] However, the character of this expression would still be a subject of contestation when it came to electrical musical instruments, as Chavez was torn between a desire for "new music for a new instrument" and establishing instrumental techniques that paralleled existing modes of expression and performativity.[112] Chavez had not necessarily found the instruments of his era to his liking: he considered the theremin imitative of traditional instruments, and found its idiosyncratic controls a hindrance to intonation and inflection.[113] Even though he believed new instruments would produce an "unforseen music" derived from their physical attributes and capabilities, this prospect was tempered by an expectation of its expressive character.[114]

Chavez's proposals for the use of electricity for the production, performance, transmission and recording of music were aimed not only as a means to create art with the hallmarks of its era, but also as having a democratising effect. Alongside radio, Chavez posited the cinema as providing another contemporary avenue for new compositions to reach the public.[115] Electrical amplification also had a democratising effect, not just in allowing for the staging of concerts outdoors, but for the possibilities of addressing imbalances in the relationship between instruments of the orchestra.[116] In his somewhat utopian vision, democratisation had a didactic function, as outdoor concerts would serve as forums to educate the public about these "new forms of expression". Artistic advances would therefore not be a "purely subjective process", but instead be able to participate in the "complex of circumstances forming the great sociological picture of the present."[117]

Of all the composers in the first half of the twentieth century that were progenitors of the experimental music milieu of the 1960s, the work of Harry Partch (1901-1974) exhibits perhaps the most extensive incorporation of acoustics in his exploration of harmony, timbre, and intonation. Partch drew inspiration not only from recent acoustic developments, but from the entire history of inquiry into the nature of musical sound. He cites as pivotal his discovery of Helmholtz's *On the Sensations of Tone* in the Sacramento Public Library in 1923. At the time he was engaged in a search to find out whether there was "any logical reason for 12 tones in an octave... I was always dissatisfied with the explanation of musical phenomena given in school and by music teachers."[118] Partch considered conventional equal temperament to be a limitation to both the intonational and timbral possibilities of music.

In his tome *Genesis of a Music*, originally published in 1949, Partch outlined his system of monophony: “An organisation of musical materials based upon the faculty of the human ear to perceive all intervals and to deduce all principles of musical relationship as an expansion from unity, as 1 is to 1.”[119] Partch’s pan-historical theory tied together: the division of the monochord string into ratios by Pythagoras; the relationship between sound and frequency first defined by Mersenne; and the perceptual analysis of tone outlined by Helmholtz. As all pitches in the system of monophony were defined through a relationship of proportion, Partch adopted a scheme of nomenclature where individual pitches were expressed as frequency ratios rather than note names. As conventional instruments were linked to prevailing notions of tonality, Partch also created an extensive instrumentarium, inventing string, wind and percussion instruments capable of performing his music.

Despite his own adoption of the implications to musical sound that his study of the history of acoustics and harmony had imparted, Partch was disdainful of acoustics’ deference to musical aesthetics:

> In general, science has also refused to focus its illumination on the deficiencies of current musical theory, treading with feet of absorbent cotton when it skirts the sacred dogma of the art of music, if not actually discouraging reformatory or tangential endeavours. Almost any book by an acoustician that one happens to pick up contains the implication, if not the positive assertion, that it is futile and irreverent to look for anything better than the present Equal Temperament.[120]

However, although Partch was keen to expand the sonic palate of music through tuning and timbre, he was not necessarily appreciative of other attempts to escape from conventional notions of musical sound - especially if they were not based on tonality or did not employ instruments. Partch particularly expressed contempt for the "clipping and joining" process of tape-based musics such as *musique concrète*, dismissing what he called "the tape idea" as a kind of musical labour-saving device.[121] Although some compositions such as *"U.S. Highball" - A Musical Account of Slim's Transcontinental Hobo Trip* (1943) contained quotidian sound sources or imitations of everyday sounds (in this case sounds such as train whistles), they were as much in the tradition of programmatic music than a Futurist-style appeal to the noisiness of the modern age. Partch's idiosyncratic percussion instruments were often constructed from found materials, but their novel timbres were subjected to his rigourous tuning regimen. In Partch's sound world - unlike that of Cage or Russolo - any incursion of the physical world into his compositions was mediated by the overtone structure of sound itself.[122]

New tools for new music

From this account of the interplay between acoustics theory, electronic instrumentation and extra-musical sounds in the work of avant-garde and experimental composers in the first half of the twentieth century, some conclusions can be drawn about the importance of these factors in influencing the later American experimental music milieu. The consideration of the physical aspects of sound by these artists was important for creating a context from which an artistic practice founded on the exploration of acoustic phenomena could emerge. In developing a discourse of sound that had extended beyond the traditional reference points of music, there is a strong focus not only on the inclusion of extra-musical or noise-sounds into compositions, but on the physical shape of sound, and on a continuum of pitch as designated by frequency, as opposed to note values. Apart from supplying a technology and a terminology, the study of acoustics provided the means by which a discussion of sound could take place that was in part divorced from the immediate concerns of music. Of course, as the discussion in this chapter has shown, composers freely adopted, adapted and disposed of aspects of acoustics as they saw fit, depending upon its perceived relevance to their specific agendas.

Several techniques later employed in experimental music, such as the use of feedback to produce continuous sounds, can be traced directly back to developments in electronics during this era. However, the use of the sine wave as a sound source within experimental music had a more circuitous path. The sustained oscillation of de Forest's audion amplifier effectively had provided a usable sine tone sound by 1912. However, as the exemplary model of simple sonic regularity, sine waves would not readily find a place within aesthetic approaches that called for the incorporation of the harmonically complex and irregular sounds of the modern world. After all, Russolo's art of noises was in part aimed at reducing the "boredom stemming from familiarity" - what could be more boring to a Futurist sensibility than the static, regular tone of a sine wave?[123] Although the more harmonically complex sound of buzzing associated with electrification would be a feature of the urban landscape, the rarified sound of sine tones would only gradually escape the confines of acoustics laboratories and radio workshops. Due in part to their problematic status as the building block of musical sound as defined by acoustics, sine waves *qua* sine waves would not initially be used for music making by these avant-garde composers. Instead, the sound of oscillating vacuum tubes became the voice of electronic musical instruments such as the theremin and *ondes Martenot*.[124] The inclusion of sine waves into the musical resources of the American experimental scene would conversely be reliant upon its association with the extra-musical world of radio and electrical communications as a test tone, before it could be embraced within this emerging expansive aesthetic of sound.

[1] Dayton Clarence Miller, *The Science of Musical Sounds* (New York: Macmillan, 1916). Miller's other major works in acoustics include Dayton Clarence Miller, *Anecdotal History of the Science of Sound to the Beginning of the 20th Century* (New York: Macmillan, 1935). and *Sound Waves: Their Shape and Speed* (New York: Macmillan, 1937).
[2] According to Harry B. Miller, the era of mechanical investigation in acoustics effectively came to an end in 1926, when Maxfield and Harrison used electrical circuit theory to describe mechanical systems such as phonographs. Harry B. Miller, "Acoustical Measurement and Instrumentation," *Journal of the Acoustical Society of America* 61, no. 2 (1977): 277. For an historical account of the development of electrical instruments used for the investigation into hearing, see Hallowell Davis, "Psychological and Physiological Acoustics: 1920-1942," *Journal of the Acoustical Society of America* 61, no. 2 (1977): 264.
[3] This chapter is aimed at examining the influence of acoustics and electrical sound on the music of the avant-garde and early experimental period in Europe and America, rather than a discussion of the music *per se*. There is already a large body of work that comprehensively surveys this era solely from a musicological perspective, of which a small sample would be Alan Rich, *American Pioneers: Ives to Cage and Beyond* (London: Phaidon Press, 1995), David Nicholls, *American Experimental Music, 1890-1940* (Cambridge: Cambridge University Press, 1990), Otto Karolyi, *Modern American Music: from Charles Ives to the Minimalists* (London: Cygnus Arts, 1996), and *American Composers on American Music: a Symposium*, edited by Henry Cowell (New York: Frederick Ungar, 1962).
[4] Peter Dear, *Mersenne and the Learning of the Schools* (Ithaca: Cornell University Press, 1988), 148-49. For a comprehensive overview of Mersenne's work see the chapter "Mechanics, Music and Harmony" in same, 117-170, and also Penelope Gouk, *Music, Science and Natural Magic in Seventeenth-Century England* (New Haven: Yale University Press, 1999).
[5] Rudolf Rasch, Introduction, *Collected Writings on Musical Acoustics (Paris 1700-1713)*, by Joseph Sauveur, ed. Rudolf Rasch (Utrecht: The Diapason Press, 1984), 25. See also "Sur la Determination d'un Son Fixe" (1700) in same, 68-77.
[6] ibid.
[7] ibid., 27. Organ pipes would remain useful as fixed sources of sound. In 1895, Wallace Sabine used an organ pipe with a pitch of 512 Hz driven by compressed air as his sound source for measuring the reverberation times of the Fogg Lecture Room and Sanders Theatre at Harvard University. See Emily Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America 1900-1933* (Cambridge: MIT Press, 2002), 34-36.
[8] Miller, *Anecdotal History of the Science of Sound*, 29.
[9] ibid., 51.
[10] Hermann von Helmholtz, *On the Sensations of Tone as a Physiological Basis for the Theory of Music*, trans. Alexander J. Ellis, Second ed. (New York: Dover, 1954), 199, 443.
[11] Miller, *Anecdotal History of the Science of Sound*, 60.
[12] Helmholtz, *On the Sensations of Tone*, 54-55.
[13] ibid., 120.
[14] ibid., 121.
[15] ibid., 122.
[16] One could easily imagine a recursive series of interrupters driven by interrupters, achieving greater and greater regulation of current, assuming enough tuning forks could be made to match.
[17] Helmholtz, *On the Sensations of Tone*, 398.
[18] ibid., 20.
[19] ibid., 81.
[20] John Tyndall, *On Sound* (London: Longmans, Green, and Co., 1867), 60.
[21] ibid., 61.
[22] ibid., 267.
[23] ibid., 311.

[24] ibid., 318-9. This experiment was made famous by Lissajous in 1855, but Hugh Blackburn, Nathaniel Bowditch, and Charles Wheatstone had performed similar experiments in the preceding forty years, amongst others. Robert T. Beyer, *Sounds of Our Times: Two Hundred Years of Acoustics* (New York: AIP Press, 1999), 37.
[25] Tyndall, *On Sound*, 106.
[26] ibid., 105. In the early part 20th century tuning forks would be put to use in a vastly different programme for inducing regularity. Tuning forks were one of the acoustic means of stimulus (along with metronomes and electric buzzers and bells) used by Ivan Pavlov for his experiments on conditioned reflexes in dogs. See Ivan Pavlov, *Conditioned Reflexes: An Investigation of the Physiological Activity of the Cerebral Cortex*, trans. G. V. Anrep (Oxford: Oxford University Press, 1927), 39-41.
[27] Helmholtz, *On the Sensations of Tone*, 11.
[28] ibid., 12.
[29] ibid., 372.
[30] ibid., 162.
[31] Philip Lenard, Introduction, *Miscellaneous Papers,* by Heinrich Hertz, trans. D. E. Jones & G. A. Schott (London: Macmillan, 1896), ix - xi.
[32] John H. Bryant, "Heinrich Hertz's Experiments and Experimental Apparatus: His Discovery of Radio Waves and His Delineation of Their Properties," in *Heinrich Hertz: Classical Physicist, Modern Philosopher*, ed. Davis Baird, R. I. G. Hughes, and Alfred Nordmann (Dordrecht: Kluwer Academic Publishers, 1998), 52.
[33] ibid. For an exhaustive catalogue of Hertz's laboratory apparatus see Bryant, 55-8.
[34] Hugh G. J. Aitken, *The Continuous Wave: Technology and American Radio, 1900-1932* (Princeton: Princeton University Press, 1985), 209.
[35] ibid., 210.
[36] ibid., 217, Vaclav Smil, *Creating the Twentieth Century: Technical Innovations of 1867-1914 and Their Lasting Impact* (Oxford: Oxford University Press, 2005), 255.
[37] ibid., 239.
[38] ibid. For the legal, industrial and historical aspects of Lee de Forest's invention, see "De Forest and the Audion," in Aitken, *The Continuous Wave*, 162-249.
[39] HP History-HP Timeline-1930s, Hewlett Packard web site [cited 23rd June 2004], http://www.hp.com/hpinfo/abouthp/histnfacts/timeline/hist_30s.html.
[40] An extensive (and growing) list of electrical devices for producing sound can be found at *120 Years of Electronic Music - Electronic Musical Instrument 1870 - 1990*, ed. Simon Crab, http://www.obsolete.com/120_years/, [cited 1.04.07]. For other advances in the early history of the synthetic production of sound using optical technologies (amongst others) see Thomas Y Levin, "Tones from out of Nowhere: Rudolph Pfenninger and the Archaeology of Synthetic Sound," in *New Media Old Media: A History and Theory Reader*, ed. Wendy Hui Kyong Chun & Thomas Keenan (New York: Routledge, 2006), 45-81.
[41] Thom Holmes, *Electronic and Experimental Music: Pioneers in Technology and Composition*, Second ed. (New York: Routledge, 2002), 43-44.
[42] Institute of Electrical and Electronics Engineers, Inc. Virtual Museum, http://www.ieee-virtual-museum.org/collection/people.php?taid=&id=1234785&lid=1 [cited 17 July 2006]. See also
[43] Reproduced in Holmes, *Electronic and Experimental Music*, 45.
[44] David Dunn, "A History of Electronic Music Pioneers," in *Classic Essays on Twentieth-Century Music*, ed. Richard Kostelanetz and Joseph Darby (New York: Schirmer, 1996), 23.
[45] ibid.
[46] Peter Manning, *Electronic and Computer Music* (Oxford: Oxford University Press, 1985), 5.
[47] Dunn, "A History of Electronic Music Pioneers," 23.
[48] Elliott Schwartz, *Electronic Music: A Listener's Guide* (London: Secker & Warburg, 1973), 38-39.
[49] Albert Glinsky, *Theremin: Ether Music and Espionage* (Urbana: University of Illinois Press, 2000), 23.
[50] ibid., 25-6.

[51] ibid., 73-5. Glinsky's biography provides an account of Theremin's turbulent life in the USA and Soviet-era Russia, alongside his technological achievements.
[52] Schwartz, *Electronic Music*, 39.The *ondes Martenot* has been used by a number of composers whose work does not necessarily fall within the ambit of this survey, such as Milhaud and Honegger, and is perhaps mostly notably associated with Olivier Messiaen, who first used it in his "Fête des Belles Eaux" (1937), ibid.
[53] See Dunn, "A History of Electronic Music Pioneers," 38; Thom Holmes, ed., *The Routledge Guide to Music Technology.* (New York: Routledge, 2006); Trevor Pinch and Frank Trocco, *Analog Days: The Invention and Impact of the Moog Synthesizer* (Cambridge: Harvard University Press, 2002).
[54] The ambit of Kahn's study extends beyond the parameters of music to include activities in literature, visual art, and film, forming a wider investigation of sound in the arts. See "Concerning the Line" and "The Sound of Music" in Douglas Kahn, *Noise Water Meat: A History of Sound in the Arts* (Cambridge: MIT Press, 1999). Also Douglas Kahn, "Introduction: Histories of Sound Once Removed," in *Wireless Imagination: Sound, Radio and the Avant-Garde*, ed. Douglas Kahn and Gregory Whitehead (Cambridge: MIT Press, 1992); Douglas Kahn, "Track Organology," *October* 55 (1990): 67-78.
[55] Kahn, "Track Organology," 68.
[56] Kahn, *Noise Water Meat*, 102-04.
[57] Ferrucio Busoni, "Sketch of a New Esthetic of Music," in *Three Classics in the Aesthetic of Music* (New York: Dover, 1962), 80.
[58] ibid., 89.
[59] ibid., emphasis in original.
[60] ibid., 78.
[61] ibid., 95.
[62] ibid., emphasis in original. The reference to "architectonic, acoustic and esthetic dogmas" might suggest ambivalence towards acoustics, although there are no specific targets suggested in the text. There is, however, a rather strange reference to Helmholtz. Pursuing an argument against musical orthodoxy, Busoni muses on the cultural meaning of the term 'musical' in German (and therefore, as the translator notes, in English), identifying a connection between aesthetics and technique lacking in his native Italian. Busoni notes: "Only in Germany is it a point of honour to be 'musical,' that is to say, not merely to love music, but more especially to understand it as regards to its technical means of expression, and to obey the rules". In relation to this he makes the comparison: "When I say 'Schubert was one of the most musical amongst men,' it is the same as if I should say, 'Helmholtz was one of the most physical amongst men.' ibid., 87-88.
[63] ibid., 94.
[64] ibid., 95.
[65] Luigi Russolo, *The Art of Noises: Futurist Manifesto*, trans. Robert Filliou (New York: Something Else Press, 1967), 5.
[66] ibid., 6.
[67] ibid., 7.
[68] ibid.
[69] ibid., 5.
[70] Luigi Russolo, *The Art of Noises*, trans. Barclay Brown (New York: Pendragon Press, 1986), 38.
[71] ibid.
[72] ibid., 39.
[73] ibid.
[74] Russolo, *The Art of Noises: Futurist Manifesto*, 9.
[75] Russolo, *The Art of Noises*, 64.
[76] Russolo, *The Art of Noises: Futurist Manifesto*, 11.
[77] Russolo, *The Art of Noises*, 75.
[78] ibid., 76.
[79] ibid., 79.
[80] ibid.
[81] Louise Varèse, *Varèse, a Looking-Glass Diary* (New York: W. W. Norton & Co., 1972), 106.

[82] Edgard Varèse, "The Liberation of Sound," in *Contemporary Composers on Contemporary Music: Expanded Edition*, ed. Elliott Schwartz and Barney Childs (New York: Da Capo Press, 1998), 205.
[83] ibid.
[84] Ernst Lichtenhahn, "A New Primitiveness: Varèse's *Ecuatorial* in Its Parisian Surroundings," in *Edgard Varèse: Composer, Sound Sculptor, Visionary*, ed. Felix Meyer and Heidy Zimmerman (Woodbridge: The Boydell Press, 2006), 268.
[85] For the enduring influence of Varèse in the American post-war scene, see Austin Clarkson "The Varèse effect: New York City in the 1950s and 60s", in *Edgard Varèse: Composer, Sound Sculptor, Visionary.*
[86] David Nicholls, "Henry Cowell's *New Musical Resources*," in *New Musical Resources*, ed. David Nicholls (Cambridge: Cambridge University Press, 1996), 153. Nicholls notes that a specific reference was made to Helmholtz in the original 1919 version of the manuscript in the beginning of Section 2 'Rhythm,' but later removed.
[87] Henry Cowell, *New Musical Resources*, ed. David Nicholls, Expanded ed. (Cambridge: Cambridge University Press, 1996), x-xi.
[88] ibid., xv.
[89] ibid.
[90] ibid., 3-4. Nicholls notes that direct references are a rarity in *New Musical Resources*. Nicholls, "Henry Cowell's *New Musical Resources*," 153.
[91] Cowell, *New Musical Resources*, 119.
[92] ibid.
[93] ibid., 18.
[94] James Pritchett, *The Music of John Cage* (Cambridge: Cambridge University Press, 1993), 8-9.
[95] John Cage, "The Future of Music: Credo," in *Silence* (Hanover: Wesleyan University Press, 1961), 3-4.
[96] ibid.
[97] ibid. This instrument would be capable of producing the all-sound music Cage mentions in his opening statement. As he expressly delimited the role of this new 'electrical instrument' to generating tones, not noises, this would effectively mean the absorption of noises, and therefore recordings, into his scheme of all-sound.
[98] ibid., 4. Cage would later include a description of Fourier analysis as one of the "questions and quotations" that comprised the third part of *Composition as Process* (1958), "Communication." There is, however, an ambivalence towards an exclusively scientific reading of sound, or any natural phenomena, expressed in a following question: "Do you really think that the discovery that a measurable entity exists, namely, the energy which can measure mechanical, thermal, or any other kind of physical activity, greatly simplifies thinking about physical phenomena?" John Cage, "Composition as Process," in *Silence* (Hanover: Wesleyan University Press, 1961), 47-48.
[99] ibid.
[100] ibid., 6.
[101] David Revill, *The Roaring Silence: John Cage, a Life* (London: Bloomsbury, 1992), 65.
[102] One turntable played a Victor frequency record, 84522B and a constant-note record, No.24; the other Victor frequency record 84522A. ibid.
[103] Cage recounts the process of performing with electronic equipment in John Cage, "For More New Sounds (1942)," in *John Cage: An Anthology*, ed. Richard Kostelanetz (New York: Da Capo, 1970), 64-66.
[104] *Imaginary Landscape No.3* (1942) used a wider array of electronic devices. Along side three variable speed turntables (two of them playing test tone records, and the third a recording of generator whine), the work is scored for a battery-powered buzzer, a phonograph cartridge, an audio-frequency oscillator, and a marimbula with a contact microphone. ibid., 76.
[105] John Cage, "Experimental Music," in *Silence* (Hanover: Wesleyan University Press, 1961), 8.
[106] ibid., 7-8.
[107] Carlos Chavez, *Toward a New Music: Music and Electricity*, trans. Herbert Weinstock (New York: Da Capo Press, 1975), 16.
[108] ibid., 140.

[109] ibid., 162.
[110] ibid., 141.
[111] ibid., 24.
[112] ibid., 164.
[113] ibid., 165.
[114] ibid.
[115] ibid., 90.
[116] ibid., 176.
[117] ibid., 174.
[118] Bob Gilmore, *Harry Partch* (New Haven: Yale University Press, 1998), 48.
[119] Partch continues: "In this sense of growth from unity Monophony is a development of the theories deduced by Pythagoras of Samos on his monochord in the sixth century BC; beginning with the whole string of the monochord, or 1, Pythagoras divided the string into two parts and produced the interval 2/1, then into three parts and four parts, producing the intervals 3/2 and 4/3. In another sense monophony may be regarded as an organisation deducible from the sounding of one tone, or the sounding of 1, or 1/1; in this sense it is an evolved expression of the phenomenon of the overtone series, first perceived by Marin Mersenne, French monk of the 17th c.; this interpretation, however, involves a certain equivocation with the analysed phenomenon of sound, that is, with the *klang*, with the components of a tone." Harry Partch, *Genesis of a Music*, 2nd ed. (New York: Da Capo Press, 1974), 71.
[120] ibid., 96.
[121] ibid. 318. Partch would also be critical of La Monte Young's electronic drone work, even though it aimed to realise intervals related to the overtone series in a similar manner. See chapter 4, fn. 18.
[122] Partch also would employ another kind of found or worldly sound: Both *US Highball* and *Barstow* would make use of the idioms of the hoboes and train hoppers Partch encountered in the 1930s and '40s.
[123] Russolo, *The Art of Noises: Futurist Manifesto*, 6.
[124] The use of sine tones to create synthetic musical materials would later be exploited intensively in the form of *electronische Musik* practiced by Werner Meyer-Eppler, Karlheinz Stockhausen and Herbert Eimheit in the 1950s in Cologne. However, this work was undertaken as the electronic realisation of serial technique, and as such is tangential to the aesthetic context this chapter has endeavoured to survey. As later chapters indicate, Lucier and Young's encounters with Stockhausen at Darmstadt in the 1960s would be more influential in terms of introducing them to the work of American experimental composers such as John Cage, rather than igniting their interest in the European electronic scene. The first issue of German periodical *die Reihe* (1955) was dedicated to electronische Musik and provides a comprehensive overview of the history and concerns of the genre up to and including the 1950s. Herbert Eimert posits electronische Musik as the logical extension of serial technique in his "What is Electronic Music?" (p. 1-10). The materials and techniques of electronic music are discussed in Karel Goeyvaerts "The Sound Material of Electronic music" (p. 35-38). Herbert Eimert and Karlheinz Stockhausen, eds., *Die Reihe*, English ed., vol. 1 'Electronic Music' (Bryn Mawr: Theodore Presser Co., 1957).

3. Tracing the steady tone: La Monte Young, 1958-1965

This chapter traces the development of the long tone in the works of La Monte Young in the period 1958 to 1965. In doing so it will survey: the influence of his childhood experiences of sound on his musical development; his early compositions *Trio for Strings* (1958) and *2 sounds* (1960); the prose and performance pieces written in association with the nascent Fluxus movement, specifically *Compositions 1960* (1960) and *Compositions 1961* (1961); and his later rule-based improvisations, ending with the formation of the performance group the Theatre of Eternal Music and the commencement of their work *The Tortoise, His Dreams and Journeys* (1964). It aims to investigate several key characteristics of Young's oeuvre, such as his use of extended duration and sustained sounds, conceptual sounds, and his deployment of whole number ratios as a compositional tool. This is accompanied by an examination of a number of factors that Young has cited as key influences for his mature aesthetic, including natural and environmental sounds, experimental composition, and the music of India and Japan. Most importantly, this chapter will track the development of Young's concept of listening 'inside a sound', and the alterations to this kind of listening brought about by each successive composition.

Young has been a subject in numerous surveys on experimental music and sound arts of the 1960s, and is widely considered to be one of the founding figures of Minimal music.[1] However, while many of those works have produced an historical examination of Young's work, their discussion of the sonic and auditory aspects of his compositions and installations is often limited, perhaps due to the disciplinary restraints of musicology or art history. Through its attention to the use of sine waves and simple acoustic phenomena, this reading aims to provide a more focussed account of sound and listening in Young's work.

The period under investigation largely presages the use of actual sine tones in Young's work. It does, however, see Young begin to align himself with the philosophical tradition in music - in the west dating back to Pythagoras - that employs a descriptive practice centred on number, finding its most succinct expression in Fourier analysis. As previous chapters have indicated, sine waves are ever present within this numerical discourse due to their privileged position at the heart of Fourier analysis. However, theories of number not withstanding, this section will illustrate a series of parallels between the sounds Young would use in his compositions during this period and two particular aspects of sine waves: infinite duration and harmonic stasis. It will also chart Young's initial encounters with the types of simple acoustic phenomena that he would later exploit more fully in his work with sine waves, such as acoustical beats, standing waves and combination tones. This is also a period of reduction and refinement in terms of the sonic resources Young would employ. After the brush with the work of John Cage that directly influenced more broad-spectrum work such as *2 sounds*, this chapter will chart the progressive delimiting of both Young's instrumentation and of the sonic content of his work.

Constant beginnings and listenings

The tale of the rustic early life of La Monte Young has been so often repeated as to have accumulated a somewhat mythic aura. Born in a log cabin in Bern, Idaho in 1935, the story of him listening to the sound made by wind blowing across the crisscrossed logs as a small child is cited (by him and others) as the origin of his appreciation of long tones and their subsequent incorporation into in his music.[2] However, in accounts of his youth Young actually identifies four additional examples from his childhood where he had what he considered "sound experiences of constant frequency": the sounds of insects; sounds produced by steam escaping, from tea-kettle to train whistles; resonances from geographic areas such as valleys, lakes, and plains; and sounds produced by telephone poles and motors.[3] In light of the work he would go on to produce, this last example was later considered by Young to be particularly significant: "Actually, the first sustained single note at a constant pitch, without a beginning or end, that I heard as a child that did not have a beginning or ending was the sound of telephone poles - the hum of the wires."[4]

Rather than the naturally produced whistle of wind through the logs, which came and went with the weather, the electrical infrastructure was a source of *constant* sound, unchanging and ever available (aside from malfunction or maintenance). Whereas acoustic ecologists such as R. Murray Schafer and Barry Truax characterise electrical hum as a 'flat line' sound - an invariable and technologised addition to the underlying strata of the 'soundscape' to which attention can only be paid problematically at best - to Young the hum was irreducibly environmental as it formed a pre-existing part of his milieu.[5] This alternation in the position of natural sounds and technological sounds, played out amid the landscape of rural Idaho, results in both the whistle of the wind and the hum of electricity to be able to be conceived of as sonic markers capable of conveying a notion of the physical environment. Young would often listen to the sound of the transformers at the local power plant, just as he would listen to the sounds of owls in the local canyons, and even had a favourite telephone pole.[6]

Relocating to Los Angeles in the early 1940s, the more conventional aspects of Young's musical life included learning the saxophone, and participating in the musical activities of the Mormon Church in which he and his family were heavily involved. After another brief interval of rural life in Utah, Young returned to Los Angeles and continued his musical development formally. He established an interest in jazz during his high school years, especially the work of Charlie Parker, Miles Davis and Lee Konitz, and became a proficient saxophonist, performing with jazz bands in formal and improvised settings.[7] First at Los Angeles City College, then at UCLA, he studied the music of Schoenberg and Webern, and was instructed in twelve-tone or serial composition, at that time the prevailing style within the academy.

Importantly, the music department at UCLA was a centre for ethnomusicology and was renowned for its vast library of recorded music from around the world. Young became an ethnomusicology minor, and availed himself of the opportunity to listen to a wide range of music.[8] UCLA was also home to a number of Japanese music specialists and had its own student *gagaku* orchestra, whose rehearsals Young often listened in on. Gagaku, traditionally an austere ritual music, represents the oldest form of harmonic music still in existence, dating from the seventh century.[9] It is a stately music of drones, silences and harmonic stasis. Many of these aspects are exemplified by the *sho* - a multi-reeded mouth organ on which a number of pitches are sustained for long periods. Many members of the post-war artistic community on the west coast of America had incorporated aspects of east Asian or 'oriental' culture, adopting a range of literary and musical influences and philosophical positions (a move soon to be popularised by the rise of the so-called 'beat' movement in the wake of the publication of Jack Kerouac's *On the Road* in 1957). Young was no exception; alongside his ethnomusicology studies, he read haiku while at high school, and the Tao while a college student.[10] Young has acknowledged that this period formed a break with the rather authoritarian notions of religion that had characterised his Mormon upbringing.[11]

Around this time Young also encountered the recording of Indian *sarod* player Ali Akbar Khan, performing *Raga Sindh Bhairavi* on Angel Records - the first popularly available recording of Indian music in the USA. It was the first time he heard the *tamboura*, the long-stringed instrument that provides the backing drone of Indian 'classical' music, and Young was clearly taken by his discovery: "You know the tamboura is the continuous drone, and I was just crazy about the sound of the tamboura. I used to spend hours in my room at my grandmother's house listening to this recording."[12] Young's later compatriots Henry Flynt and Tony Conrad would also cite this record as being influential in their musical development.[13]

Although there were other compositions from this era, the most significant is Young's *Trio for Strings* (1958) for violin, viola, and cello.[14] This work, executed within the twelve-tone system, calls for each instrument to sustain a series of long notes - some of them over four minutes in duration - separated by lengthy silences. These notes combine to form static dyads and chords, and as Kyle Gann has noted, this work marks the beginning of Young's concern with sustained intervals.[15] Young cites the influence of serialist composer Anton Webern on *Trio for Strings*, noting that sound and silence in Webern's compositions were treated as being of equal importance. He also notes Webern's tendency to repeat pitches at the same octave position within a section of a movement.[16] Young interpreted this repetition of pitches as a form of stasis in terms of the harmonic content of the music, as each iteration presented "the same information repeated over and over and over again."[17] This element of harmonic stasis exists in abundance in *Trio for Strings*. As a work comprised only of individual tones, intervals and silences, it has a harmonic or vertical construction, rather than a melodic, 'horizontal' one. The long tones, lack of modulation between keys and extended duration (approximately fifty eight minutes) are all components that will resurface in Young's mature work, but not before an important intervention.

Young first encountered the music of John Cage whist attending the composition seminars during the Darmstadt Festival for New Music held by German electronic music composer Karlheinz Stockhausen. At the time he regarded Stockhausen as "the greatest living composer" and had also encountered electronic composer Richard Maxfield while making his way to Germany (although Young has not expressed that he had any particular interest in making electronic music at this time). However, it was not electronic music but the presentations of the works and theories of Cage - mainly as performed by pianist David Tudor, Cage's key musical collaborator - that proved to be influential.[18] His absorption of these ideas would not only lead Young away from traditional compositional techniques and the serial music he had studied at university through the use of prose scores and indeterminacy, but towards conceptualism and a new understanding of sound and listening.

Immediately on his return to California, Young composed *Vision* (1959), a thirteen-minute work to be performed in darkness, with the performers placed around the room. Continuing from *Trio for Strings*, it contained long sounds played on traditional classical instruments (piano, 2 brass, recorder, 4 bassoons, violin, viola, cello, contrabass), some to be held as long as four minutes. However, these were to be what Young described as "really wild sounds", with names such as "Howl", "Growl" and "Herd of Elephants", suggestive of a kind of primal, naturalistic and perhaps even fundamental model of sonic communication. The timing and arrangement of each sound was determined aleatorically by finding logarithmic relationships between randomly chosen numbers from the telephone directory, which, as Edward Strickland indicates, reveals Young's debt to both the chance procedures of Cage and to Stockhausen's pre-determined compositional structures.[19]

Listening inside sounds

At this time Young and his classmate at Berkeley Terry Riley (b. 1935) began providing sound for choreographer Anna Halprin. This accompaniment, later developed into a recording for Halprin called *2 sounds*, involved friction sounds created by scraping metal objects across glass, tin, wood and metal surfaces for extended periods. One realisation involved Young dragging a gong across a concrete floor while Riley scraped a wastebasket against a wall, much to the displeasure of the audience.[20] The experience of performing this type of work had a profound effect on Young, which he outlined in his "Lecture 1960" (itself heavily influenced by Cage's *Indeterminacy* [1959], in that it was comprised of anecdotal passages to be read in any order), delivered to a class in contemporary music at Anna Halprin Dancer's Workshop in the summer of 1960:

> When the sounds are very long... it can be easier to get inside of them. Sometimes when I was making a long sound, I began to notice I was looking at the dancers and the room from the sound instead of hearing the sound from some position in the room. I began to feel the parts and motions of the sound more, and I began to see how each sound was its own world and that this world was only similar to our world in that we experienced it through our own bodies, that is, in our own terms. I could see that sounds and all the other things in the world were just as important as human beings and that if we could to some degree give ourselves up to them, the sounds and other things that is, we enjoyed the possibility of learning something new. By giving ourselves up to them, I mean getting inside of them to some extent so that we can experience another world. This is not so easily explained but more easily experienced.[21]

Much has been made of this facet of Young's subsequent practice, and his description of the experience of being 'inside a sound' is pivotal. It describes an encounter with a particular kind of sound as much as it does a kind of listening. Listening 'inside a sound' becomes for Young shorthand for an inextricable integration of the sonic and the auditory - the conflation of what is heard and how it is heard into a single, and for him singular, experience. However, in order to investigate what Young meant by being 'inside a sound', it is important to tease out the parameters of the listening experience he described.

Given the account that Young has provided, it would seem that listening 'inside a sound' was not something that could be experienced with just any sound, or in any context. Instead, it required plenty of sound to be heard and also an equal willingness to listen to that amount of sound, and could occur only within a specific context that featured this kind of sonic abundance and auditory specificity in equal amounts. As such, one of the most apparent factors of this context is *sustain*. This is exercised sonically both in terms of maintaining the duration of the sounds, and through maintaining the harmonic or frequency structure of the sound to be heard 'inside' of. Individual sounds were required to be lengthened in duration to the point of appearing continuous, and combinations of different sounds have to be sustained almost to the point of stasis, so that the harmonic content of the sound could be perceived. In Young's scheme, it was not just sound, but audition that had to be maintained for extended periods, with listeners needing to persevere in the face of what, in the case of *2 sounds*, might otherwise be regarded as harsh or unpleasant sounds in order to have the experience Young found so profound. Listening 'inside' this sustained sound would involve an equally sustained listening - one prepared to hang in there for the duration.

The second significant factor is that of *profusion*, whereby various physical aspects of sound, particularly frequency range and amplitude, needed to be present in large quantities. In *2 sounds* this was accounted for in the broad-spectrum sounds produced by the scraping metal and concrete, but also evident in the tendency towards producing sounds at high volume. Of course, an individual listener could not somehow be 'profuse', although identification with the sound by experiencing it through the body, as Young described, might grant feelings of expansion. Instead, for listening 'inside a sound' to occur, it required listeners to exercise a kind of profusion of reception in allowing all the sounds and noises present to form their experience of listening, not just a select group of pitches, frequencies, or rhythms.

According to Young, this particular combination of sounds and listening induced a unique situation, where sound comes to both define a physical space and to be realised within it. The combined effects of sustain and profusion can be seen as playing important roles in creating the sense of immersion in sound that Young's account describes. The long durations involved diminished the ability of the sounds to indicate the passing of time, eschewing a melodic line in favour of a harmonic or vertical construction, highlighting the aspect of timbre. The profusion of frequencies would also have induced a sense of spatiality, situating the listener inside an overall mass of sound, accompanied by the overwhelming sensation of immersion created by volume, which would have contributed to Young's experience of inhabiting a physical sound environment.

However, as Young's account shows, listening 'inside a sound' cannot simply be a product of a sound with these attributes, requiring as it did the considered and sustained attention of the listener. There is an element of passivity or perhaps even submission in his call for listeners to 'give over' to the sounds in order to have an experience of its component nature, which for Young was emblematic of sound containing a "different kind of existence."[22] However, the harmonic and temporal stasis would have contributed to this focusing on the "parts and motions" within the sound mass, and were therefore an important factors in effecting in Young's work a shift in the relationship between sound and aurality as it was traditionally approached in a musical situation.[23] His experience of listening 'inside a sound' moved away from one of 'following along' a sequence of notes or events in a song or symphony, becoming instead one of 'listening around' to the range of sounds present, much as one might in a forest, city street or other environmental situation. This emphasis upon the alteration of the listener's relationship to sound, and an attention to the physical relationship between sound and its environment, both of which being activated through extended durations, would remain central to Young's concerns and be subject to continuous re-voicing throughout subsequent compositions.[24]

Following the scraping metal and glass of *2 sounds* was *Poem for Chairs, Tables, Benches, etc.* (1960), which involved the production of friction sounds by moving pieces of furniture across the floor. The objects and floor surface were unspecified, as were the duration of the work and the type of sounds to be produced, using randomly generated numbers in the same manner as *Vision* for determining the timing and ordering of events.[25] With its open-ended duration, and the incorporation of any occurrence - sonic or otherwise - into its ambit (an obvious debt to the inclusive rhetoric of Cage), *Poem for Chairs, Tables, Benches, etc.* exhibited the beginnings of what Michael Nyman would describe as Young's tendency towards "compulsive universality."[26] This is not to say that Young would continue to exercise these tendencies in such a manner. In fact, Young has found it necessary in hindsight to highlight what he considered the more influential aspects of duration and listening experience, rather than the sonic content of these works, stressing that he and Riley were working with "very irrational timbres," as opposed to the music of ratios Young would go on to develop.[27]

Another important work also had its genesis during this period. Initially performed as an improvisation for Anna Halprin in April 1960, *X to Henry Flynt* (1960), as it came to be known as, reined in the free-form aspects of *2 sounds* through the use of repetition.[28] Primarily realised as a percussive work, the 'X' of the title represented the number of repetitions to be made of a single sound at regular intervals. Typically the numbers chosen were large, such as the debut performance of the scored version of the work given by Toshi Ichiyanagi in 1961, which involved five hundred and sixty six repetitions.[29] While the work did receive realisations as clusters of piano notes played with the forearm, it was renowned for being performed on beaten metal, be it a gong, frypan or pot.[30] While these kinds of metallic sounds could be easily identified with the sense of sonic profusion found in the abrasive sounds of *2 sounds*, the use of repetition in producing sustained sound redefined the overall listening experience. As Douglas Kahn has noted, this repetition acts to suspend the temporal flow, allowing the listener to hold the sounds "still within time, so that the acoustical intricacies might be perceived," making explicit an act of examination and investigation within the experience of listening inside a sound, and giving *X to Henry Flynt* further significance in the face of Young's later work with sine waves.[31] The relentless repetition also showed how a single sound source could produce enough harmonic content in order to induce an experience of listening 'inside a sound', a concept would be reflected in Young's use of harmonic theory for delineating pitch material in his later compositions.[32]

Later in 1960 Young moved to New York, ostensibly to study electronic composition with Richard Maxfield at the New School for Social Research.[33] Through Maxfield he became acquainted with artists later involved with the Fluxus movement, such as George Brecht, Jackson Mac Low, Yoko Ono and Nam June Paik, several of whom had studied with John Cage in his composition and experimental composition classes at the New School. By the end of the year Young and Ono gave a series of loft concerts featuring conceptual and proto-Fluxus compositions by artists including Henry Flynt, Simone Forti, Toshi Ichiyanagi, Robert Morris, and Young himself.

Young's pieces of this time moved even further away from his serialist education, relying more on prose instructions for performative actions, of often unspecified or extended durations, which formed part of what he later called the Theatre of the Single Event (a term that could easily describe the earlier *X to Henry Flynt*). Like other artists in this early Fluxus era, Young's compositions often extended mundane or pedestrian non-musical situations to their (il)logical conclusion as a mechanism to extract poetic or aesthetic meanings from everyday existence. Many practitioners were inspired by the influence of Zen and other 'eastern' philosophies, often following the lead of Cage, in its elevation of the quotidian and the effacement of the self, as well as the championing of 'enlightened understanding' over rational meaning. Fluxus also borrowed strongly from Dada in its disruption of ordinary, everyday behaviour, often incorporating boredom, violence and repetition.

Young's series *Compositions 1960* (1960) shows a range of conceptual approaches for questioning and destabilising the prevailing notions of composition and performance of the era. Performer-audience relationships are challenged in *Composition 1960 #4*, in which the lights of the performance space would be turned off, and later back on again; the period of darkness in between constituting the work. In *Composition 1960 #6*, the performers on stage mimic the usual activities of an audience: sitting in rows, conversing, leaning on a bar, and so on.

Some pieces incorporated what might be classed as 'natural' sounds. *Composition 1960 #2* involved the building and lighting of a fire in front of an audience. *Composition 1960 #5* also uses natural sounds, but in this case it is the inaudible sound of butterfly wings. The score called for any number of butterflies to be released into a space, the performance ending when they had finally flown from the room. C*omposition 1960 #15* consists simply of the statement: "This piece is little whirlpools in the middle of the ocean." These last two works presented a situation where the sonic content of the work, while notionally extant, was either absent or inaccessible to the unaided ear, rendering them inaudible. The sonic aspects these inaudible sounds were instead realised through a kind of poetics of nature, allowing that these sounds could form the work, if only we had ears with which to hear them. As such they explore a liminal zone of operation where audibility could be supplanted by possibility - a theme that Young continued throughout his work in his later use of technology and acoustic theories.

Other compositions treated sound on a more strictly conceptual level. These conceptual sounds are in evidence in the graphic score of *Composition 1960 #9*, which consisted of a single straight line on a piece of card. As if partially responsible for its predecessor, *Composition 1960 #10* held the simple instruction "Draw a straight line and follow it." Young would adopt this not only as his compositional strategy, but as his total compositional output for the following year. In January of 1961, Young divided the year into twenty-nine equal divisions to indicate what he considered to be the average number of works he produced in a year. All of these works contained the same instruction: "Draw a straight line and follow it." Young performed *Compositions 1961 #1-#29* (1961) in March at 'A Concert of Avant-Garde Music' at Harvard University organised by composer Henry Flynt, and again later as his contribution to the loft series in May. To realise this work Young used a plumb line to draw twenty-nine chalk lines on the floor, with each new line drawn over the last.[34]

The most important work from this series in terms of the further development of long tones in Young's compositions is *Composition 1960 #7*. Written in July of that year, it was the only one of the series to employ standard musical notation. The score consisted of a staff with a treble clef displaying a B below and $F^{\#}$ above middle C - an interval referred to as a 'perfect fifth'- accompanied by the instruction "to be held for a long time."[35] As such it draws together a number of significant threads. Most obvious is the return of the long tones of *Trio for Strings*, but here extended to a continuum of fixed pitch, recalling both the tamboura drone of Indian music and the sustained harmonic intervals of gagaku. However, more significant is how *Composition 1960 #7* relates to the earlier *2 sounds*. There is again a strict delimitation of tonal resources, in line with *2 sounds*, from which a range of effects are drawn. Edward Strickland has commented that in performance *Composition 1960 #7* moves from "the conceptual realm to the realm of Minimal music - very minimal indeed in terms of technical complexity but not necessarily in terms of content."[36] As with *2 sounds*, *Composition 1960 #7* was capable of providing elements of sustain and profusion that were sufficient to allow listening 'inside a sound' to take place. Extending duration indefinitely would cause the two tones to delaminate, enabling their harmonics to become more apparent as individual components within the overall sound. However, unlike *2 sounds*, *Composition 1960 #7* indicated an important shift in Young's music, in so far as this new conceptualisation of sound and listening could now be enacted within a more 'traditional' musical framework (albeit an extremely reductive one) in its utilisation of a conventional score, instrumentation, and tonal resources.

Composition 1960 #7 also marks the beginnings of Young's attempts to control various forms of noise within his aesthetic, often exercised through suppression or exclusion of particular sounds or methods of producing sound, or through the incorporation of previously errant factors into his musical programme. From *Composition 1960 #7* onward, Young would move away from the broad spectrum friction sounds found in *2 sounds* (scrapings, screeching, gratings), *Vision*, and other broad spectrum sounds such as fire and conversation, in favour of instruments, voices and devices that delivered tones and pitches. With this return to conventional instrumental tonality with *Composition 1960 #7,* elements that had previously marked Young's initial description of 'being inside a sound' were now left outside. In moving away from indeterminate compositions utilising everyday sounds to a musical score, the sense of inhabitation that had previously been located between two *noises* could now be enacted in the space between two *notes*, effectively placing the listener 'inside the interval' defined by B and $F^{\#}$. With listeners now located inside a space of audition bordered by two lines of tone, Young allowed that this engulfing aspect of sound could be activated not only through broad-spectrum sounds but the relationship between two musical notes in harmonic combination. As such it denotes a process of delineation, both in terms of sketching out the future of Young's compositional strategies, and also of forming sound into lines, much as he had already done visually - here into single notes, later into the single frequencies of sine tones.

Pre-*Tortoise* music

In the spring of 1962 Young formed a performance group with poet and hand drummer Angus MacLise (1938-1979). Influenced by John Coltrane and North Indian *shenai* player Bismillah Khan, Young had developed a distinctive rapid style of modal improvisation on both the soprano and sopranino saxophones, which involved blowing a flurry of modally related notes at a furious rate, in order to give the impression of one continuous chord. Inspired by his interest in the role of the tamboura in Indian music (or perhaps Composition *1960 #9* which he had performed on occasion as one continuous pitch[37]), he added dancer Simone Forti to the group to sing drone, who was soon replaced by visual artist Marian Zazeela (b. 1940) on vocal drone and later harmonium.[38] Zazeela and Young married the following year and have remained close artistic collaborators since this period. Billy Linich also joined for a period on guitar and additional vocal drone. By July of 1962 this group was regularly performing their open-ended, meandering improvisations at 10-4 Gallery in Manhattan.[39]

These performances attracted the attention of violinist Tony Conrad (b. 1940), an acquaintance of Young's who had moved to New York after completing a degree in Mathematics at Harvard University. They had met when Conrad had visited Berkeley in 1959 and subsequently maintained a correspondence. Conrad joined the group early in 1963, his initial contribution being a one-note violin drone, which after a month's performances he extended to two notes with the interval of a 'perfect fifth.'[40] This pleased Young no end, who saw it as contiguous with his *Composition 1960 #7*.[41]

Conrad had found his own way to drone-based music. Finding that his teenaged charge was uninterested in the nineteenth century repertoire, Conrad's violin teacher had introduced him to exercises in intonation and tunings, where he was encouraged to play slowly as an aid to hearing accuracy of pitch.[42] He became interested in the contemporary music scene while a student at Harvard. Christian Wolff, one of John Cage's close associates, was a graduate student at the time (as was David Behrman and Frederic Rzewski), and a conduit for information on new music.[43] Touring in Europe after completing his degree, Conrad discovered the *Mystery Sonatas* of 17th century composer Heinrich Ignaz Biber. He was intrigued by the sound of these works for *scordatura* (retuned) violin, with their long pedal tones, open fingerings and double-stop playing (the bowing of two strings simultaneously), along with the basis for their composition: "I perceived Biber's music as having been constructed according to timbre, not melody."[44] Conrad employed the same slow and careful approach he had used in his earlier exercises in intonation, which had the effect of emphasising the *Mystery Sonatas'* idiosyncratic timbre: "My body merged with the body of the violin; our resonances melted together in the rich dark colors, harsh bright headlights. Slower, slower."[45] Like Young, Conrad had been struck by the recording of Ali Akbar Khan, and through Indian classical music found a further vindication of his emergent drone-based performance style.[46]

One of Conrad's earliest performances with the group was the premiere of Young's work for bowed string instruments *The Second Dream of The High-Tension Line Stepdown Transformer from The Four Dreams of China* (1963). This was a version of a larger composition, *The Four Dreams of China* (1962), which Young had written during a cross-country car trip the previous year. The debut performance took place outdoors during the YAM festival staged by George Brecht and Robert Watts at artist George Segal's farm in North Brunswick, New Jersey in May 1963. Young and Conrad were part of an expanded ensemble that included Zazeela, MacLise, artist Larry Poons, and photographer and filmmaker Jack Smith.[47] Although composed two years after *Composition 1960 #7*, this new work harked back to the earlier *Trio for Strings*. Both pieces feature long tones interspersed with long silences but differ in their choice of musical materials. *Trio for Strings* followed the serialist twelve-tone system for its harmonic and pitch construction, whereas *The Second Dream* contained just four pitches (actually drawn from the opening of *Trio for Strings*). Structurally it is a rule-governed improvisation, with instructions determining which pitches can be played together and in what order, with the result being a series of held harmonies, each rising out of and returning to silence, but retaining a drone-like continuity.[48]

Young credits *The Second Dream* with expanding the time structure in his work - in this case, from the indefinite to the infinite:

> Each performance is woven out of an eternal fabric of silence and sound where the first sound emerges from a long silence, and after the last sound the performance does not end but merely evanesces back into silence until a new group of musicians "picks up" the same set of pitches again, or from time to time, emphasising the audible aspects of the performance.[49]

While the duration of individual long tones are to some degree defined by the rules governing which tones may be sounded together, the silences in between performances could be of any length. It becomes a work containing both performed and unperformed parts, with the vast bulk of the duration comprised of the latter. Unlike later works which rely on constant tones to enact Young's notion of the eternal, in *The Second Dream* 'eternity' is realised through silence, or more specifically, through not playing - through the cessation of the 'audible' content of the work (not to mention those epochs of unplayed time that preceded the first performance). In relation to this work Young has cited both his early experiences with wind sounds and the constant hum of electricity.[50] However, as it is punctuated with vast silences or cessations of playing, *The Second Dream* really only draws on the vicissitudes associated with the first. The influence of the continuous power station drone on his music would become more evident later.

Numbers, intervals and ratios

Apart from already having developed a drone-based performance style, Conrad was to bring another important factor to the group. Young credits Conrad, a trained mathematician, with introducing him to the mathematical description of relationships between notes as simple numerical frequency ratios.[51] It provided them with both a method for choosing new notes to add to the drone, and a means by which to categorise the relationship between notes. By February of 1964 Young would begin to notate the majority of his works as whole number ratios.[52]

As has been described in the earlier chapter on nineteenth century acoustics and Fourier analysis, the component or harmonic structure of a so-called 'musical' sound can be represented as a series of simple tones - sine tones - the frequencies of which are all whole numbers; therefore, the interval between any two of these individual frequencies can be expressed as a ratio between two whole numbers. The use of this scheme for the construction of musical scales is referred to as *just intonation*. Notes for a scale are derived from the harmonic series of a given fundamental, and therefore all intervals between the notes in the scale are expressible as whole number ratios. As such, it differs from the conventional western musical system of *equal temperament* that divides the octave into twelve evenly spaced notes with the relationships between them initially defined by frequency ratios of 2, 3 and 5. The notes are then slightly retuned to allow greater modulation between keys, the octave being the only remaining interval comprised of whole numbers.

Just intonation is often characterised as a method of deriving notes and scales from the physical properties of sound, and as such is often regarded as a product of nature, not analysis.[53] As earlier chapters may have indicated, these notions are problematised by the abstractions implicit in Fourier analysis and sine tones, and perhaps even by the compound nature of the actual harmonics produced by musical instruments. However, within this stage of the work of Young, Conrad, Zazeela and MacLise, the aim was to define relationships between notes arithmetically as determined by their fundamental frequencies, providing them with a process by which one tone - designated the fundamental - determined all the other pitches to be played. The resources for listening 'inside a sound' could therefore be found within *one note*. Through paying close attention to pitch and to the inner structure of sound, the use of ratios provided the group with what Conrad would later describe as both "an incipient technology and a systematic elaboration of our whole idiom."[54]

This investigation of whole number ratios not only provided a system for determining a scale, it also proved to have a generative function. Performing the intervals that these ratios introduced another characteristic of tone formation that could be manipulated through an examination of frequency ratios. Conrad began to play two sustained notes at all times, which produced the acoustic phenomena known as *combination tones* through the interaction of the combined frequencies. *Sum* tones are often so high as to be inaudible, but *difference* tones contribute significantly to the construction of a sound, supplementing or reinforcing the deeper tones.[55] Combination tones are perceived as separate independent tones, and can combine with the original tones to produce second order combination tones, and so on. Simply put, playing two tones together produced more tones, and Young would go on to exploit this phenomenon in many of his future compositions.

There is an implicit relationship between this system of whole number ratios and a music that was already structured around a drone. The drone acted as the fundamental, becoming the baseline for the formulation of ratios. The sustained tones in their music were already allowing the individual harmonics in their sound to become more apparent which not only exposed the inner operations of sound, but had the effect of disassembling the individual pitches into a series of sounds that, according to Fourier analysis, already had frequencies that matched whole number ratios. Now ratios could be employed not only to determine the relationships between notes to be played, but provide a terminology for the describing and codifying sounds that were already present in their material.

Where the elongation of sound allowed performers and listeners to experience small alterations and components within the static harmonic construction, ratios became the method by which these interactions were described. Having establishing the drone as the context for their music, listening increasingly became a question of one's ability to listen in - in to the micro-pitch variations and harmonic interactions which would now be catalogued by a series of ratios on the one hand, and inside or within the overarching, unitary macro-structure of the sound on the other.

As the first of his truly drone-form works, it is frequently noted in discussions on Young's tuning theories that his *Composition 1960 #7,* which describes a 'perfect fifth' B-F$^{\#}$, could be easily reinterpreted as an interval with the whole number ratio 3:2.[56] The 'perfect fifth' holds a special importance in the equal temperament system. Aside from the octave, the 'perfect fifth' is the only interval without minor or major iterations, and as such is considered an exemplary example of 'musical' consonance. It is one of the basic forms of harmony across the spectrum of western musical traditions and genres, from classical, to rock, blues and jazz.

Although it is clearly an anachronism, there is some attraction in claiming *Composition 1960 #7* can be represented as the ratio 3:2, seeming as it does to feed into Young's later preoccupation with whole number ratios. Indeed there is a relationship there, although at this stage it is still founded in Young's experience of listening rather than the use of number. However, this conflating of the original score and its later interpretation as a numerical ratio elides something more interesting, something that Young himself would later cite as a problem with conventional tonality. He observed a tendency in musicians who play instruments that are of unfixed intonation (especially singers and string players) to instinctively alter the intervals they performed to be those that matched whole number ratios in order to make them sound 'in tune', counter to the 'out of tune' sounds of equal temperament.[57]

There is an obvious difference between an interval expressed as the ratio 3:2, and the interval B-F$^{\#}$, irrespective of any notion of intonation. The fundamental frequencies of the notes B and F$^{\#}$ from *Composition 1960 #7* are 246.94 Hz and 369.99 Hz.[58] Expressed as a ratio of 1, the interval 3:2 becomes 1:1.5 while the ratio for frequencies of the interval B-F$^{\#}$ is approximately 1:1.4982, where the right hand number is a non-repeating decimal. The microscopic difference between these two intervals may seem insignificant, yet they do yield distinctly different sonic outcomes. Each would exhibit different aspects of the productive nature of intervals: a performance that replicates the score would produce a slow *beating pattern*, an acoustic phenomena which appears as an oscillation of amplitude caused by the relationship of the frequencies; a just intonation performance would sound a static chord with lower difference tones. Just as the closeness of the frequencies in the 'out of tune' interval B-F# would produce a beating pattern, there is also both a literal and a conceptual beating pattern that occurs due to the difference between the ratios B-F$^{\#}$ and 3:2.

With this in mind, *Composition 1960 #7*, possesses a tension between the work as scored and the work as performed, conveyed by the difference between the intervals 3:2 and B-F$^{\#}$. Given that it represents an interval with a whole number ratio, Young would find 3:2 to sound 'in tune'. If musicians did display a propensity for performing intervals that sounded more in tune by Young's definition, then they would have deviated from the work as scored. It is, as with any work, a question of intonation. Any actual performance of *Composition 1960 #7* by human musicians would more than likely produce any number of minute variations in intonation, where B-F$^{\#}$ and 3:2 would be just two out of an infinite number of possibilities. These tiny fluctuations in pitch and accuracy would create subtle shifts in the overall sound, changing emphasis from one harmonic to another and setting off chains and ripples of acoustic beats, not unlike the interaction between either conception of *Composition 1960 #7* and its realisations. This tension between concept and realisation would resurface again (also in the form of acoustical beats) in Young's later sine wave installation works.

This shift in the use of number as a tool for composition is crucial to the later work of Young, as it indicates both the beginning of his transition from the traditional equal tempered scale to employing a system based on whole number frequency ratios, and a highlighting of not just the interval but particular kinds of intervals as the basis for his compositions. However, as this example aims to show, the vicissitudes of performance could disrupt abstract idealisations of *any* system of intonation. Close listening had already been recognised by Young, Conrad and Zazeela as a primary factor in the determination of intonation, through perceiving and identifying the products of the various intervals of their drone-based music. In order to increase their ability to hear and exploit what are often ephemeral acoustic phenomena, the group, now with the addition of John Cale, would be drawn towards the electrification of their sound.

A Theatre of Eternal Music

By September 1963 John Cale (b. 1942) had joined the group on viola. Cale had abandoned the music scholarship that had brought him to America from London, moving from the rather more sedate confines of a Massachusetts college to New York City. His introduction to the city's new music scene was his involvement in John Cage's eighteen hour staging of *Vexations* (1893) by French composer Erik Satie. The work for piano calls for 840 repetitions of a short 180-note passage. Alongside Cale and Cage, other performers included David Tudor, and composers James Tenney, Philip Corner and Christian Wolff.[59] This performance also exposed Cale to repetition and extended duration - two factors he would find in abundance in the group.

Aside from the addition of the viola, Cale was to introduce the group to the *Tableau Comparatif des Intervalles Musicaux*, written by French ethnomusicologist Alain Daniélou and published by the Institut Français d'Indologie, in 1958.[60] The book is a vast catalogue of intervals, and aims to define all of the possible pitch ratios which use prime numbers smaller than 512. Kyle Gann has described the work as "La Monte Young's bible", stating that as such it holds a crucial position in the history of minimalism.[61] Daniélou had previously published a number of books on the physical and metaphysical aspects of Indian music, and was one of the key disseminators of information on Indian music and philosophy in the West in the post-war era.[62] His numerous works proposed a universalised understanding of musical sound based on numerical symbolism, drawing from a range of general correspondences across Greek, Indian, Chinese and western culture.

MacLise left the group to travel early in 1964, which removed the percussive element he provided and tightened the focus on sustained sounds. The group rehearsed for three to four hours at a time on a regular basis, developing greater acuity of intonation, and a much needed stamina. In order to compete with the volume of the saxophone, Conrad and Cale began to amplify their instruments with contact microphones. Cale also modified his viola, flattening the bridge so as to be able to sustain three notes simultaneously. Young and Zazeela also began using amplification, with Young eventually forgoing the saxophone in favour of singing sustained pitches. Completing the electrification of their sound would be the addition of the 'turtle motor' - the small filter motor from the aquarium in which Young and Zazeela kept small turtles, amplified via a contact microphone - and eventually an audio frequency oscillator, or sine tone generator.[63]

Along with a new sound, turtles would also provide inspiration for *The Tortoise, His Dreams and Journeys* (1964-present) - a new work, but one for which each realisation would form only a section, and be given its own title. Although the first public performance in the new electrified configuration occurred earlier in the month, the first performance of *The Tortoise, His Dreams and Journeys* was in October at the Pocket Theatre, NYC, under the title *The Tortoise Droning Selected Pitches from The Holy Numbers for The Two Black Tigers, The Green Tiger and The Hermit.*[64] By February of 1965, the group began performing as the Theatre of Eternal Music, with *The Tortoise, His Dreams and Journeys* comprising its entire repertoire.

Like *The Four Dreams of China*, this new work was also deemed to be of theoretically infinite duration, although this time it was to be enacted by theatrical means. The group would begin playing before the audience were allowed to enter, and after a performance lasting several hours continue to play until the audience had left.[65] Each performance would therefore function as one portion of the overall work, but unlike *The Four Dreams of China* that maintained its existence between successive performances through its inaudible or silent movements, the performances of *The Tortoise, His Dreams and Journeys* implied an unbroken continuum of sound. The electrical drone of the turtle motor harked back to the constant sound of the transformer hum from Young's childhood. The incorporation of the sine wave, predicated in its abstract form as being of infinite duration, completed the picture.

Amplification played a pivotal role in both realising and defining the group sound. It also aligned this 'dream music' (as it was increasingly known) with the world of popular music. This would later turn to influence when John Cale began performing with Lou Reed (and also MacLise and Conrad at different times) in an outfit that would become The Velvet Underground. As Conrad wrote at the time, the technologies of sound reproduction and amplification provided the group with a new context in which to operate:

> Ours is the first generation with tape, with proper amplification to break down the dictatorial sonority barriers erected by the master instruments of the cultures. It is no longer necessary to press upon groaning mechanical instrumentation to produce the terrific power and sonority necessary for dealing with partial complexity and without shattering the all-important sound - the throbbing reverberance that has fixed musical attention on consonance and formal design.[66]

Not only did the use of sound reproduction technology allow for the production of loud sounds, but for amplification of small sounds, and acted as an aid for listening into the interaction between otherwise inaudible or subaudible acoustic phenomena such as harmonics and difference tones.

The electrification of the group not only reproduced the sounds of the instruments and voices - it became a source of other sounds. As an artefact of the technology, noise in the form of electrical hum had to either be excluded, or incorporated into the group sound. The steady sound of the turtle motor, as Young points out, represented a solution to the issue of unwanted sound:

> In c.1965, I selected the 120-cycle hum of the aquarium motor for a drone in order to keep our drone in tune with the frequency of the 60 Hz AC power supplied by Con Edison. 60 Hz is the drone of the city and, in those days, all too frequently showed up as hum in our sound systems.[67]

Of course, the120-hertz hum would have already 'showed up' in Young and Zazeela's apartment due to the use of the motor in their pet turtles' aquarium. As the group frequently rehearsed at the apartment, it suggests that the decision to incorporate the hum of electricity may also have been influenced by its presence as a persistent sound at the site of rehearsals.

Now that it had been safely re-categorised as the fundamental frequency of their drone, amplifier hum could be put to use in effacing itself:

> We were tuning to a 60-cycle hum. The third harmonic was 60 cycles tuned to the hum of the refrigerator, or to the hum of the amplifier system. In order to tune you

had to hold one of the cables, then Tony would tune first and everybody else would tune.[68]

This technique of incorporation not only yielded practical results; it also important conceptual ramifications. Designating the system hum as the fundamental drone frequency had the combined effect of removing noise from their music and of 'musicalising' the sound of electrical hum, and therefore by extension the continual hum of the modern electrified environment. Returning to Young's claim, which situates the ever-present 'hum of the wires' within an environmental context, this musicalising of electrical hum equates a technological artefact - one with its own particular and finite history (that being the history of urban electrification) - with a natural condition. As Young had now incorporated this hum into his work as a musical sound (through its new found conceptualisation as the fundamental drone) he would now also be able to apply the same naturalistic conceptualisations he had inscribed in electrical sound to his music. The ever-present hum of the wires from Young's youth now resurfaced in the ever-present hum of the 60 Hz electronic drone. Its ubiquitous presence in the urban environment meant that the fundamental tone of their composition was heard everywhere. This transcended the theatrical devices the group had employed in order to give their work a sense of the infinite, and provided an actual sonic continuity between performances, and therefore enacted another facet of Young's sought after sense of eternity.

Sustaining sounds

Charting the work of La Monte Young up to the introduction of sine waves has in part been a study of his progressive extension or prolongation of duration, and the significant role it has played in Young's developing aesthetic. Young progressed from long instrumental tones, to broad-spectrum sounds of unspecified duration (*2 sounds*), to musical intervals held 'for a long time', and finally to compositions of which the durations are theoretically infinite. This effect has been aided by the addition of electrical sound, such as the 'turtle motor', and through performance gestures. This tracing exposes the elements of his work that lean most closely towards the condition of the sine wave, in terms of their extended duration and their frequency composition, on both an acoustic and conceptual level.

This mapping also shows that alongside Young's prolongation of duration, there was a corresponding series of reductions, the implications of which would become even more apparent in Young's future compositions. The first of these is a reduction of musical resources, shifting away from the random, noisy sounds of tin cans, metal and glass, the scrapes of moving furniture, conceptual sounds, and natural sounds, towards a more traditional instrumentarium, with string instruments and voices holding notes and intervals of extended duration. Accordingly, the sonic space in which Young's notion of listening 'inside a sound' could occur had also been subjected to a similar reduction. Having identified sustain and profusion as the significant factors in the experience of this inhabited form of audition, this mapping has followed the progressive shift from listening inside the noisy space of *2 sounds* to the rather more consonant interval between two notes. Composition and performance has also been similarly reduced to the production and sustaining of these particular types of intervals. However, the focusing on accuracy of execution by the Theatre of Eternal Music also produced sum and difference tones, along with other associated acoustic phenomena - highlighting how the reductive aspects of this style of performance in turn developed into a variety of generative procedures.

Listening had also come to the fore as an important performance practice, but one enacted within a context of the electrical amplification of sound. While the 'close listening' of the Theatre of Eternal Music allowed them to attend to the minutiae of sound production, the use of amplification facilitated this greater focus on progressively finer sonic components, and made subtle changes in the overall mass of droning sound more audible. Amplification and focussed listening would continue to be important hallmarks of Young's future work. However, as he moved closer to the introduction of sine tones in order to achieve greater accuracy of pitch, notions of noise and disturbance would need to be more clearly delineated from musical content. The electrification and amplification used by the Theatre of Eternal Music had already provided its own problems in the form of system hum and noise, although these problematic elements were eventually incorporated into the overall musical structure. The Theatre of Eternal Music effected the removal of noise from their overall sound via the rhetorical and literal interpolation of system hum as their fundamental tone. As Young turned to sine waves in order to enact greater control over the sound of his future projects, new definitions and delimitations of sound, listening and the role of technology would begin to play an even larger role in his oeuvre.

[1] For example, Wim Mertens, *American Minimal Music: La Monte Young, Terry Riley, Steve Reich, Philip Glass*, trans. J. Hautekiet (London: Kahn & Averill, 1983); Keith Potter, *Four Musical Minimalists* (Cambridge: Cambridge University Press, 2000); K. Robert Schwartz, *Minimalists* (London: Phaidon, 1996). Edward Strickland's survey of minimalism across the arts in general includes a comprehensive review of Young, alongside other notable Minimal composers Terry Riley, Steve Reich and Philip Glass. Strickland defines the minimalist aesthetic as one that "makes its statement with limited, if not the fewest possible, resources, an art that eschews abundance of compositional detail, opulence of texture, and complexity of structure. Minimalist art is prone to stasis (as expressed in musical drones and silence)... and resistant to development (repeated modules and held harmonies in music)... It tends towards non-allusiveness and decontextualisation from tradition, impersonality in tone and flattening of perspective through emphasis on surfaces (the restriction of dynamic and harmonic movement in the music)" [the quote here restricts the examples to the musical] Edward Strickland, *Minimalism:Origins* (Bloomington: Indiana University Press, 1993), 7.
[2] John Schaefer, "Who Is La Monte Young?" in *Sound and Light: La Monte Young and Marian Zazeela*, ed. William Duckworth & Richard Fleming (Lewisburg: Bucknell University Press, 1996), 28. For a similar recounting of Young's rustic origins see all the titles above.
[3] Richard Kostelanetz, "Conversation with La Monte Young," in *Selected Writings* (Munich: Heiner Freidrich, 1969), 33.
[4] ibid.
[5] Barry Truax, *Acoustic Communication*, Second ed. (Westport: Ablex Publishing, 2001), 137-39. The acoustic ecology movement emerged largely in response to the work of Canadian composer and writer R. Murray Schafer's book *The Tuning of the World* when it emerged in 1977. Influenced equally by Cage and Rousseau, acoustic ecology seeks to redress the "trampling" of the natural *soundscape* (a term coined by Schaefer) by modernity.
[6] William Duckworth, *Talking Music: Conversations with John Cage, Philip Glass, Laurie Anderson, and Five Generations of American Experimental Composers* (New York: Schirmer, 1995), 222.
[7] Ian Nagoski, "Interview with La Monte Young & Marian Zazeela," *Halana*, winter 1996, 26-27.
[8] Duckworth, *Talking Music*, 223.
[9] William P. Malm, *Music Cultures of the Pacific, the near East, and Asia* (Englewood Cliffs: Prentice-Hall, 1967), 139.
[10] Duckworth, *Talking Music*, 233.
[11] Edward Strickland, *American Composers: Dialogues on Contemporary Music* (Bloomington: Indiana University Press, 1987), 55.
[12] Nagoski, "Interview with La Monte Young & Marian Zazeela," 26. For an extensive account of the influence of this recording on western composers and musicians, see Peter Lavezzoli, *The Dawn of Indian Music in the West: Bhairavi* (New York: Continuum, 2006).
[13] Kenneth Goldsmith, *Henry Flynt Interviewed by Kenneth Goldsmith on WFMU* [radio interview] (2004 [cited 26 February 2004]); available from http://mediamogul.seas.upenn.edu/pennsound/authors/Flynt/Henry_Flynt_Interviewed_by_Kenneth_Goldsmith_WFMU_2.25.04.mp3. See also liner notes, Tony Conrad, *Four Violins (1964)* (Table of the Elements, 1996), LP record. np.
[14] Schwartz, *Minimalists*, 23.
[15] Kyle Gann, "The Outer Edge of Consonance: Snapshots from the Evolution of La Monte Young's Tuning Installations," in *Sound and Light: La Monte Young and Marian Zazeela*, ed. William Duckworth and Richard Fleming (Lewisberg: Bucknell University Press, 1996), 154-55.
[16] Schwartz, *Minimalists*, 22.
[17] Kostelanetz, "Conversation with La Monte Young," 24.
[18] Strickland, *American Composers*, 61.
[19] Strickland, *Minimalism:Origins*, 135.
[20] ibid.,136.
[21] La Monte Young, "Lecture 1960", *Tulane Drama Review* 10, no. 2 (Winter 1965) reprinted in Mariellen R Sandford, ed., *Happenings and Other Acts* (New York: Routledge, 1995), 79.

[22] ibid.
[23] Douglas Kahn, *Noise Water Meat: A History of Sound in the Arts* (Cambridge: MIT Press, 1999), 229.
[24] Perhaps it was this physical, spatial dimension to the sounds that formed a point of attraction for experimental dancers. The recorded version of *2 sounds*, with its density of texture and extreme frequencies, became popular amongst other choreographers, with Anna Halprin's dancer Simone Forti later utilising in conjunction with her rope piece, and later by Merce Cunningham as accompaniment for his work *Winterbranch* (1964). Strickland, *Minimalism:Origins*, 136.
[25] Michael Nyman, *Experimental Music: Cage and Beyond* (New York: Schirmer, 1974), 82.
[26] ibid., 83.
[27] Kostelanetz, "Conversation with La Monte Young," 30.
[28] Henry Flynt, "La Monte Young in New York," in *Sound and Light: La Monte Young and Marian Zazeela*, ed. William Duckworth and Richard Fleming (Lewisberg: Bucknell University Press, 1996), 51-52. This work was later revised under the title *arabic number (any integer) to Henry Flynt.*
[29] ibid. Other notable versions include "1698" performed by Young on piano, and 923 beatings of a kitchen pot. ibid., 72, Strickland, *Minimalism:Origins*, 144.
[30] ibid.
[31] Kahn, *Noise Water Meat*, 232.
[32] The 'relentless' aspect of *X for Henry Flynt* was often a provocation for audiences in the early sixties, and even remains problematic for some contemporary commentators. See Strickland, *Minimalism:Origins*, p. 144-5.
[33] Young includes no electronic work from this period in his list of compositions. There is elsewhere a reference to this work by Maxfield: "Maxfield created another piece especially for me called *Perspectives for La Monte Young* (1961-2). In this work, I created all of the original sounds for the music on bowed stringed instruments. Maxfield recorded these sounds and ran them through electronic processing to produce a set of tape permutations on the original sounds, which were then played as a background over which I improvised live in concert." La Monte Young, *Notes on the Theatre of Eternal Music and the Tortoise, His Dreams and Journeys* [pdf document] (2000 [cited 2nd March 2004]); available from http://www.melafoundation.org/lmy.htm., 8.
[34] Flynt, "La Monte Young in New York," 63.
[35] Reproduced in Nyman, *Experimental Music*, 84.
[36] Strickland, *Minimalism:Origins*, 139.
[37] Kostelanetz, "Conversation with La Monte Young," 32.
[38] Nagoski, "Interview with La Monte Young & Marian Zazeela," 29.
[39] Flynt, "La Monte Young in New York," 77.
[40] Liner notes, Conrad, *Four Violins (1964)*. np.
[41] ibid.
[42] ibid.
[43] Howard Pollack, *Harvard Composers: Walter Piston and His Students, from Elliot Carter to Fredrick Rzewski* (Metuchen: The Scarecrow Press, 1992), 371-72. Flynt, "La Monte Young in New York," 50-51.
[44] Liner notes, Conrad, *Four Violins (1964)*. np.
[45] ibid.
[46] ibid.
[47] Liner notes, La Monte Young, *The Second Dream of the High Tension Line Stepdown Transformer from the Four Dreams of China* (Grammavision, 1991), compact disc. np.
[48] ibid.
[49] ibid.
[50] ibid.
[51] Strickland, *Minimalism:Origins*, 155.
[52] Gann, "The Outer Edge of Consonance," 157.
[53] Young has described Just Intonation as "that system of tuning based on the idealised principles of harmonics and resonances as our ears hear them and our voices produce them, that is, as they are found in nature." Young, *The Second Dream*. np.

4. Listening to sine waves in the *Dream House* and the ear: La Monte Young, 1966-1974

The second part of the case study of sine waves and simple acoustic phenomena in the work of La Monte Young will deal briefly with the last stages of the inaugural Theatre of Eternal Music in 1966, before examining in detail his use of sine waves in the period from late 1966 until 1974. During this time, Young would primarily concern himself with two works: the 'sine-tone installation' *Dream House* and his composition *Map of 49's Dream The Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery* (1966-present). Although they have separate theoretical and conceptual origins, the two works would later become intertwined, with one providing a context for the other. Both also would rely on the formal and conceptual properties attributed to sine waves. Additionally, there would also be an important third work in the form of Marian Zazeela's projection piece *Ornamental Lightyears Tracery*.

Surprisingly, little writing on Young has concentrated on this era, due in part to the dearth of compositions.[1] However, this eight-year period represents an important stage in Young's career, consolidating his compositional and aesthetic position, working methods and philosophy. Fortunately, several of Young's own writings began to appear in print in the latter part of the 1960s, producing some clear statements on his thought processes at the time. Unlike the earlier Theatre of Eternal Music performances, the work from this period is indisputably Young's own, and as such it is a vehicle for his theories on music, psychology and perception.[2]

This chapter shall examine in closer detail the interaction between these works by focussing on the role that sine waves have to play in both their conception and execution. In doing so it will canvass Young's compositional strategy and philosophy, charting the expansion of his use of number as a determining factor of composition, which will in turn influence his theory not only of music, but of hearing, spatiality, and perception. In doing so it will examine Young's methods for controlling potentially problematic sounds and effects (in this instance the sounds of technology and nature), his notion of a composed sonic environment, and his conception of acoustical concepts such as the propagation of sound in space and the nature of sound itself.

Tail of the *Tortoise*

The sonic and conceptual effects of 'dream music' continued to compound: with the addition of electronic sounds to *The Tortoise, His Dreams and Journeys* the Theatre of Eternal Music was able to realise a greater density of sonic texture. The modified viola of John Cale allowed him to hold three pitches. Tony Conrad, employing double-stop technique on the violin, provided another two. The voices of Zazeela and Young held one each, as did the turtle motor and the sine tone generator, allowing the group to produce up to nine sustained pitches at a time.[3] The intervallic relationships between these pitches also lead to the formation of sum and difference tones, adding to the overall mass of sound. As mentioned earlier, these secondary tones would in turn interact with the original tones, forming further pitches, and so on. The sustaining of pitches for long durations would also allow for the individual harmonics of the instrumental and vocal sounds to become more apparent, creating even greater harmonic complexity.

An important factor in the production of the 'dream music' sound was instrumental and vocal timbre. Timbre, the characteristic sound attributable to an instrument or voice, has traditionally been defined through the relationship between the amplitudes of the harmonics of a given sound. However, as Jean-Claude Risset discovered in his attempts to synthesise trumpet sounds at Bell Laboratories on the 1960s, variations of the harmonic spectrum over time were crucial for the development of timbre.[4] The attack and decay stages of a tone, known as *transients*, are one of the key factors in forming the identity of instrumental sounds. With the tones of the Theatre of Eternal Music, where the attack and decay of individual notes had been subsumed by an overwhelming sustain, identification of specific instruments was partially confounded. Not only were the strings and voices assimilated into the overall sound, the reduction in individuation along with the interplay between the elongated pitches generated a phantom instrumentarium. The combined effect of these acoustic phenomena added the sound of "tubas, trombones, double basses, and cellos that, you notice, we don't have in the group but whose sounds are apparent on the speakers."[5]

The experience of participating in the formation of this particular type of group sound was vastly different from other performance situations, as Tony Conrad indicates:

> The quality of listening inside the sound, once our playing began to approach rational frequency ratios very closely, became different from other listening experiences. Our unfamiliar intervals, built on tones and timbres which are alien to the vocabulary of 20th century common practice, were surprisingly sonorous - dissonant but not discordant. Ripples of beats, in various ranges of the frequency spectrum,

> emphasised various aspects of the performance - its focus on timbre, its demands for technical accuracy, and its engagement with rhythm as an aspect of pitch.[6]

This focussing on the minute interactions of sound production illustrates how, at the same time as their performance strategies were signalling a drive towards conceptually infinite duration, the act of listening for the performers was being conversely directed towards a moment-by-moment assessment of pitches, intervals and their effects. This intersection of extended tones and continuous scrutiny allowed for finer and finer degrees of discrimination: "We lived inside the sound, for years. As our precision increased, almost infinitesimal pitch changes would become glaring smears across the surface of the sound."[7] As Douglas Kahn has noted, through focussing on both the internal interrelationships of the interval and the opportunities for those interrelationships to generate further sounds, the Theatre of Eternal Music "worked within a very specific *telos* of western art music where hearing harmonies would become hearing liminal harmonic phenomena."[8]

Even if the music could be conceived of as being "eternal", no group could last forever. John Cale left late in 1965 to concentrate his efforts on the Velvet Underground, replaced by Terry Riley, who joined Zazeela and Young in the vocal drone. Riley remained with the group for several concerts in 1966, but was absent for the final concert in August 1966 at the Sundance Festival in Upper Black Eddy, Pennsylvania.[9] Shortly afterwards, Conrad and Young became involved in a disagreement over the rigidity of the rules governing pitch selection. This led to Young abandoning rehearsals, which effectively ended the group.[10] However, even before the end of this first version of the Theatre of Eternal Music, Young had already telegraphed the future direction of his music - one that would lead away from traditional instruments towards the rendering of his project in sine tones:

> Now I've become more interested in controlling which harmonics are present at any given time. This is not easy to do with conventional instruments and voices, but I have developed a technique that allows me to emphasize, for instance, the seventh harmonic or the third harmonic, or, quite possibly, some other harmonics. With the use of electronic equipment, I should be able to set up situations in which I can have precisely, and only, the seventh harmonic or the ninth harmonic, as they are required. In other words I'm really interested in a very precisely articulated situation - I always have been. I'm interested in the most clear and sparse sounds - in control and in knowing what I'm doing.[11]

Sine waves, 'drift' and assembling the *Dream House*

With the end of this first version of the Theatre of Eternal Music, Young began a new era of work by combining an older idea - that of an environment containing continuously sounding compositions - with his newest sound source: the sine tone generator. Doing so would create a moveable space of controlled articulation for Young, providing both sonic content and a performance context, and resulted in both the *Dream House* installation and his composition *Map of 49's Dream The Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery*.

Young is uncharacteristically vague as to the exact beginning of the *Dream House* project, going only so far as to say it had been formulated by 1962, situating it chronologically between his conceptual proto-Fluxus pieces and his full-scale adoption of the drone in *The Tortoise, His Dreams and Journeys*.[12] Initially the dream house was conceived of as an architectural structure, influenced by his *Four Dreams of China*: "I thought if you could have a *piece* that could be continuous, it would be nice to have a *place* where the piece could be performed at a greater frequency."[13] The first mention of

'Dream Houses' in print comes from a 'stream-of-consciousness' essay Young provided as programme notes for a concert at the East End Theatre in March 1965.[14]

> In the life of the Tortoise the drone is the first sound. It lasts forever and cannot have begun but is taken up again from time to time until it lasts forever as continuous sound in Dream Houses where many musicians and students will live and execute a musical work. Dream Houses will allow music which, after a year, ten years, a hundred years of constant sound, would not only be a real living organism with a life and tradition of its own, but one with a capacity to propel itself by its own momentum.[15]

Instead of taking the form of an actual building, realisations of the *Dream House* up until 1979 took the form of sound installations that Young described as 'continuous sound environments', the prototype of which was established in Young and Zazeela's loft in September 1966. Influenced by the sound they had been producing with the Theatre of Eternal Music, Zazeela and Young began using sine wave generators to sound intervals for extended periods of time, a practice they maintained more or less continuously until 1970. Again, Young is vague as to when he acquired his first Heathkit Sine Wave generator, guessing at sometime in 1966 (even though, as already mentioned, a sine wave generator had been used in group performances the previous year).[16] This would be the first in a range of electronic tools used for creating this new type of 'precisely articulated situation.'

Apart from producing a circumstance in which a musical work could develop over long periods of time, one of the stated aims of this project situated their aesthetic plan within the realm of experimental psychology: "To our knowledge there had been no studies on the long-term effects of continuous periodic and almost-periodic composite sound waveforms on people."[17] In order to remedy this, sets of frequencies were often played twenty four hours a day for weeks at a time, sometimes at high volume, as Young and Zazeela "studied its effects on ourselves and the varied groups of people who were invited to spend time amongst the frequencies".[18] With this additional aspect of 'research', this prototype *Dream House* environment - alongside providing a residence, a studio and a concert venue - incorporated a 'laboratory'. The 'results' of their research would constitute their artistic output for the following decade.

This formulation of constant sound as representative of environmental conditions harks back to Young's youthful whistling wind and transformer experiences, as well as the inhabited sense of listening 'inside a sound' he described in "Lecture 1960"; but it also has another more quotidian predecessor. The much quieter, unacknowledged beginnings of this particular *Dream House* would actually have been two years prior, in 1964, when they first began keeping turtles as pets, the 'turtle motor' already maintaining a constant sound, albeit at a much lower volume. In this sense the *Dream House* continued Young's programme of 'musicalising' the sound of ambient electrical hum that he had pursued in *The Tortoise, His Dreams and Journeys*.

Outside of his domestic situation, Young's first three public sound installations date from 1967 and are important precursors to the *Dream House*. The first of these, the *Robert C. Scull Commission* (1967), utilised a dense array of fourteen closely related sine tone pitches.[19] With the ratio between the lowest tone and the highest tone being 7:9, Young packed twelve pitches into an interval that approximates in musical terms a slightly sharpened major third. The *Claes and Patty Oldenburg Commission* (1967) used only four sine tones in a ratio of 12:13:14:18.[20] The interval from lowest to highest tone would be larger at 3:2 (mimicking *Composition 1960 #7*), containing a close order pair of frequencies inside it. The ratio of the highest two numbers is also reducible to 7:9, recalling the Scull Commission work. The third work in this series was the *Betty Freeman*

Commission (1967), a collaboration with Marian Zazeela. This work took the form of a plexiglass light box fitted with small speakers, which emitted two sine tones with frequencies tuned to the tiny ratio 64:63 to produce a pulsing chain of acoustical beats.[21]

As forerunners to the public versions of the *Dream House* installations, these three works chart a progressive reduction in Young's conception of a sound environment. As such, it parallels the shift in listening 'inside a sound' that occurred as it developed from the experience of performing the friction pieces that lead to *2 sounds*, to the sound created through the restriction of tonal resources in *The Tortoise, His Dreams and Journeys*. The densely packed minor third interval comprised of fourteen tones of the *Robert C. Scull Commission* would have created a complex, shifting drone field, with plenty of close order beating and pulsing produced by the convoluted interaction of so many frequency components. In decreasing the number of single frequency sounds from fourteen to four, and then to two, Young induced a situation where the least number of sonic components could be used, but where their interactions would still be sufficient to provide a sonic environment in which immersive listening could occur. This accompanied a decrease in the size of the interval, moving from larger intervals with conventional musical approximations (major third, fifth) to an extremely close interval only capable of being expressed mathematically (64:63). As he had earlier moved from *2 sounds* to the two notes of *Composition 1960 #7*, now he would shift the space in which listening 'inside a sound' occurred to the space in between two sine tones. For Young, a listening environment could be expressed as a single, tiny ratio.

Using a pair of sine tones in a close ratio such as 64:63 to create a sonic environment emphasises one particular facet of listening inside a sound. While sustain would continue to be enacted through duration and harmonic stasis, profusion of sound is provided not by the number of components used to generate the sound or by the number of frequencies present, but by the acoustical and psychoacoustical phenomena produced by the two frequencies in the form of beats and standing waves. This shift has potentially significant implications for both the experience of listening inside a sound, and for defining what might constitute a sonic environment. Tuning in to a single ratio of sine tones seems a severely restricted act of listening when contrasted against the everyday lived experience of a broad-spectrum sonic environment, with all its attendant sounds and noises - traffic, rain, voices, and so on. Instead, listening becomes condensed into a highly regulated procedure with two primary foci, both of which contain a spatial component, expressible by number. One is listening to the distance between the frequencies of the two *generative* tones (as Young would later name them) - described as an interval with a ratio of whole numbers. The second is listening to the product of the interaction between the sine tones, which would not only produce combination tones (and therefore introducing another interval), but another *countable* phenomenon in the form of auditory beats.

In its abstract conception as whole number ratios realised in time through the use of sine tones, these installations would have fulfilled Young's desire for greater control over his sonic resources and his ability to control the inner workings of tonality - to produce a 'precisely articulated situation'. However, in realising these projects 'real world' factors would come into play. The very means by which the sine waves used to produce these works were generated would prove to be problematic. Analogue electronic oscillators, such as those used by Young, are prone to very slight fluctuations in output, especially over long durations. These fluctuations would cause gradual changes in the phase relationship between the two sine tones (or in fact any number of sine tones), creating audible shifts in the standing wave patterns.[22] Young acknowledged that these alterations in the sound played a significant role in the reception of the work, and therefore the effects of these changes had to be accounted for. In the same manner in which Young recast electrical hum as the fundamental tone for *The Tortoise, His*

Dreams and Journeys, his next works with sine tones, the *Drift Studies (1967-Present)*, would integrate this 'drifting' of the oscillator output into its programme. With the aid of amplification, listening, or rather listeners, would drift also:

> Not only did sound become louder or softer with this changing algebraic sum or difference, but also at very loud volumes one began to feel that parts of the body were somehow locked into sync with the sine waves and were slowly drifting with them in space and time.[23]

Young ascribed what he termed 'psychological effects' to accompany different phase relationships, characterising some as "relaxed, lazy summer afternoon" or "progress, industry and achieving", turning this unintended aspect of the works into a desirable effect.[24] This fluctuating, uncontrolled aspect of the sine wave generators could be accommodated through the reconceptualisation of error as 'drift', with the resulting products of this inexactness reconfigured in positive terms. Drift was also incorporated rhetorically, as the term sat easily alongside other descriptors in Young's work such as 'dream music' and 'drone', describing as it did a similar feeling of transportation or transcendence.

Young recognised that 'drift' was a feature of all his sound environments until he began using phase-locked oscillators in 1975.[25] As a precursor to the *Dream House* environments, this discovery of drift in the sine tone installations was to have important implications when it came to Young's later sonic constructions. If the dream houses were to provide a controlled space of audition, then drift represented the settlement cracks, a slip in the foundations. Drift would exist within the later *Dream House* installations, but it would be shored up by the addition of voice and through procedures of comparison and visualisation.

The aspect of drift in Young's work is also emblematic of the mobility the *Dream House* concept had in the period between its debut in July 1969 and the commissioning of a permanent location by the Dia Art Foundation in 1975 (coinciding with the introduction of phase-lock technology).[26] During this time, as temporary dream houses were installed in galleries, museums and theatres around the US and Europe, the *Dream House* acted as the context within which the presentation of both the sine tone installations and performances occurred. By the time a site had been developed for use as a permanent *Dream House* in 1979, the concept had been literalised as referring to a specific location, its conceptual malleability reduced to that of the evergreen advertising adage of the 'dream home'. Phase-locked indeed.

An example of 'drifting' would become the subject of the first publicly issued recordings made by Young. Released on a five-inch reel of quarter-inch tape in an edition of forty, "Excerpt from *Drift Study 4:37:40 - 5:09:50 PM 5 VIII 68*" accompanied issue No. 4 of *SMS*, a New York-based art magazine, published in 1968.[27] It contained a recording of five sine tones forming a tight chord. Comparatively more available was a second recording released the following year as one side of a flexidisc included in *Aspen* magazine issue no. 8. Guest curated by artist Dan Graham and having the subtitle "Art Information and Science Information share the same World and Languages..." it contained contributions by artists Robert Morris, Yvonne Rainer, Edward Ruscha, Richard Serra and Robert Smithson and scores by composers Philip Glass and Steve Reich, amongst others, with Fluxus stalwart George Maciunas as guest designer.[28] Much like the sonic component of the *Betty Freeman Commission*, the "Excerpt from *Drift Study 31 I 69 12:17:33 - 12:49:58 PM*" consisted of only two tones in a close ratio of 31:32, again exhibiting a beating pattern of stark, phantasmal pulsations.

The accompanying article by Young outlined the other major component of his musical programme during this period, the composition *Map of 49's Dream The Two*

Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery.[29] As such it would be an attempt by Young to elucidate the scope of his musical progress since the end of the Theatre of Eternal Music.

A (conceptual) Map of 49's Dream

The end of the Theatre of Eternal Music coincided with Young's first attempts to formalise the theories that underpinned his music. In November 1966 he began work on *2-3 PM 12 XI 66-3:43 AM 28 XII 66 For John Cage From 'Vertical Hearing Or Hearing In The Present Tense'* which was revised the following year under the title *The Two Systems Of Eleven Categories 1:07:40 AM 3 X 67 –*. [30] The new composition, which Young produced to explicate his theory would in fact be a section of *The Tortoise, His Dreams and Journeys*, but one with its own subsections and titles. Begun in late 1966, *Map of 49's Dream The Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery* would occupy Young for the following eight years. This period would also highlight the implications for Young's concepts of sound and listening and the performance context brought about by the shift from acoustic instrumentation to the total electrification of his sound.

Much in the same manner as *The Tortoise, His Dreams and Journeys*, this new work would be constructed from sustained tones, except that now the string instruments would be replaced by sine tones. This recast the nature of continuous sound as it appeared in Young's work, removing both the human and the instrumental elements in maintaining the drone pitches. Whereas previously intonation had been subject to the vagaries of performance, accuracy of pitch became a question of technological, or perhaps even financial, capacity (although, as mentioned above, still prone to 'drift'). While this may have ensured that pitch was not subject to fluctuation, it removed a layer of random or unspecified sounds found within *The Tortoise*: the result of changes in pressure of the bow on the violin and viola, subtle alterations of fingering, exhaustion, and other factors. Although construed as being outside the programme of the work, these sounds provided points of contrast and, as previously noted, were important performance indicators used by the participants for judging the accuracy of intonation. Shifting from strings to sine waves for *Map of 49's Dream* also meant a corresponding reduction in the frequency spectrum of the overall sound, due to the loss of the timbral qualities of the stringed instruments. Effectively, intervals made up of instrumental pitches, each containing a range of interacting frequency components, were replaced with intervals constructed from individual sine tone frequencies.

Not only was there a massive change in the sonic or profusion aspects of the overall sound, the replacement of instruments with sine tones had a profound effect on sustain: sine tones provided a single source of continuity, removing the need for a distinction between sustained duration and sustained pitch. Technical malfunctions aside, to have a sine tone was to have a fixed sound for as long as required. Shorn of the fluctuations and variations provided by the strings, the chord formed by the droning sine waves achieved a monolithic stasis, the only variable in the sound coming with the introduction of Young's singing voice. This static quality of *Map of 49's Dream* mirrors the environmental conditions found in the sound installations and *Drift Studies*; it also exceeded the harmonic stasis of his earlier compositions and group performances. In fact, drawing hard and fast distinctions between composition and installation in Young's work had become increasingly difficult to make. For example, prior to its premiere in 1968, *Map of 49's Dream* had already undergone one realisation as a sound environment under the tile *Intervals and Triads from Map of 49's Dream The Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery* (1967). In realising his new aesthetic agenda Young would continually blur the boundary between composition and installation.

Although still using the Theatre of Eternal Music moniker at this stage, Young performed solo in the initial realisations of *Map of 49's Dream*, accompanied only by sine waves. However, performing alone had not restricted his ability to create a sound of sufficient magnitude to listen inside of, with the sine tones and voice amplified to extreme volume in order to accentuate the sense of envelopment.[31] One legendary review of the February 1968 performance at New York's Barbizon Plaza theatre by John Perreault described the abundance of sound Young was producing: "The sound was painfully loud even with the doors closed. Entering was like being hit in the face with a blast of hot wind or like walking into a room full of brine and discovering you could still breathe."[32] Through the use of an electronic instrumentarium and amplification, Young could now induce this overpowering sense of immersion on his own if desired.

Concurrent with the decrease in the number of performers was a greater emphasis on the visual accompaniments to Young's music. In addition to her singing, Marian Zazeela's artworks had become an essential component of the performance environment during the Theatre of Eternal Music. Her light boxes, displaying calligraphic imagery, had accompanied the group since 1964, and she later utilised slides of these same patterns, projecting them onto the performers.[33] By 1968 Zazeela had developed the *Ornamental Lightyears Tracery*, a work for four slide projectors, which would accompany all subsequent performances of *Map of 49's Dream*.[34] It is comprised of a series of black and white slides of calligraphic forms in both positive and negative, forming what Zazeela described as "interlocking modular sections of one overall design".[35] The work conveyed a sense of depth and dimensionality through a kind of optical misalignment, created by the overlaying of negative and positive versions of the one image fragment, with each coloured by either a green or magenta gel. Other aspects of presentation, such as focus, image size and positioning were improvised during performance, introducing duration as one of the key parameters of the work. Zazeela considered the use of this particular set of performance strategies of *Ornamental Lightyears Tracery* a parallel to the rule-based improvisations found in Young's compositions.[36]

By July of 1968 Zazeela would again join Young on vocal drone, and together they would combine their sound and light works in the context of a new collaboration. By the time of the first public *Dream House*, established for a two week period at Galerie Heiner Friedrich in Munich in July 1969, the composition, the projections and the 'continuous sound environment' were inseparable. Young described the sound contained within the *Dream House* as a performance of the *Map of 49's Dream*, and the whole work as constituting "a total environmental set of frequency structures of sound and light – a collaboration of my work with light projections and designs created by Marian Zazeela" in the form of *Ornamental Lightyears Tracery*.[37]

Sine tones ran continuously during the gallery's opening hours for the fourteen days, with Zazeela and Young singing what they described as "additional frequencies" for hours at a time.[38] Young had abandoned his sine wave generators in favour of a Moog synthesiser, equipped with what he described as "ultrastable" sine wave oscillators in a bid to restrict the 'drift' effect.[39] A more important technological addition was the use of oscilloscopes not only as an aid to tuning the intervals of the sound environment, but for incorporation into the work itself: "The frequency ratios being played will be displayed continuously as lissajous and intensity-modulated ring patterns on oscilloscopes so that visitors to the gallery can study them and their relation to what they hear."[40] Procedures for the visualisation of sound had not previously been a part of Young's work. Now, with the electrification of Young's audio, oscilloscopes could be employed not only as a means of cross-sensory comparison, but for contributing to what art critic Frank Popper has described (in the terminology of the era) as "polysensorial expression in the environment," where sound and visual information both compliment and construct one another.[41]

Their first full-length album was recorded in Munich after the closing of this first *Dream House* installation. Colloquially referred to as the 'black record' due to Zazeela's black-on-black calligraphic cover design, the album contained *31 VII 69 10:26 - 10:49 PM Munich from Map of 49's Dream The Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery*, a twenty-three minute segment featuring Young and Zazeela accompanied by a sine tone.[42] It is a prime example of both how stasis and harmony interlock in Young's work. The sustained pitches of the voices combine with the unremitting stability of the electronic sound, and with each other, to produce a series of intervals, chords, and distinct combination tones. There is a stark contrast between the components that go into this composition, between the paucity of timbre of the sine tone and the complex of frequencies that make up the human voice; the interaction between them produces a remarkable synthesis. As Young and Zazeela sing, the overall sound expands upward in pitch from the drone, stratifying into distinct layers as the frequencies within their voices delaminate and recombine, both with the sine tone and with each other. It is this process of sonic stratification - through contrasting specific pitches of a complex sound (voice) against a simple one (sine tone) - that furnishes the sense of spatiality, the tones shifting up and outwards the longer they are held, before evanescing as breath runs out and the drone reasserts itself. The longer certain tones are sung, the greater the number of harmonics contained within the voices become isolated as individual sounds, all more distant from the drone frequency. Listening 'inside the sound' therefore expands alongside this proliferation of frequencies as they create further intervals and further spaces.

One prominent aspect of the work is the highlighting of the human voice's ability to create a range of tonal colours and effects while only using a small number of notes. For the greater part of the recording, Zazeela holds the same drone pitch as the sine tone, while Young improvises over a handful of pitches. Young's vocal style had become increasingly influenced by Indian music, particularly the vocal music of Pandit Pran Nath (1918-1996) that he had first encountered in 1967.[43] Young and Zazeela would later study with Pran Nath, relocating him to New York and becoming his disciples.[44] However, at this stage, Young was yet to fully employ vocal mannerisms such as vibrato, so indicative of Indian vocal music, instead exploring the acoustic possibilities of nose and throat tones as a means to expand the timbral qualities of his otherwise unmodulated singing voice.

The B-side of the album contained an older acoustic work: *23 VIII 64 2:50:45-3:11 AM the volga delta from Studies in The Bowed Disc* - a section of the work *Studies in The Bowed Disc* (1963). This recording from 1964 featured Zazeela and Young bowing a large gong, which had been given to them by artist Robert Morris the previous year. The gong had frequently served as a backdrop for performances by the Theatre of Eternal Music, and Young and Zazeela had occasionally contributed a duet of *Gong Contests* (as they were sometimes called), where the gong was amplified with contact microphones and bowed from each side.[45] The deep, churning drones, rumbling textures and enharmonic overtones of *Studies in The Bowed Disc* hark back to the harsher, metallic sound world of the earlier *2 sounds* (realisations of which had Young playing a gong with drum sticks or dragging it across a concrete floor) and produce an altogether more subterranean and compacted listening experience compared to the harmonically spacious sound Young was aiming for with *Map of 49's Dream.*

The contrast between *Map of 49's Dream* and *Studies in the Bowed Disc* illustrates another shift in the importance of sound sources in Young's work that accompanies his move to electronically generated sine waves. As has been noted in the previous section, there had been a progressive reduction in first the number and then the density or texture of the sounds used in Young's work from *2 sounds* onwards, particularly with regard to the aspect of profusion so crucial to listening inside a sound. *Studies in the Bowed Disc* provides a profusion of sound in a similar manner to *2 sounds* - through a broad spectrum of frequencies. Apart from the voices of Young and Zazeela, the section of *Map of 49's Dream* presented on this recording contains only sine tones - theoretically sounds of a single frequency. Therefore the source of profusion in *Map of 49's Dream* is found within the complex timbre of the human voice. This places the voice in a privileged position at the centre of Young's sound production universe. Within a sonic environment defined by sine tones, voice would provide the important components for listening 'inside a sound'. This does not relegate sine tones solely to the role of the drone - the various *Dream House* environments would contain sets of tones at high volumes, forming intervals of whole number ratios inside of which immersive listening could be experienced without the presence of voice. Further, the spaciousness induced by the delamination of tones within the overall sound was the product of maintaining a precise relationship between voice and sine tone. However, the richness of harmonics in the human voice, along with its flexibility in terms of quality and pitch (along with other attendant variables such as wavering, slurring and truncation), would provide a greater activation of profusion in the overall sound: where sine tones might be profuse in terms of volume, they were scarce in frequency next to the complex timbre of the human voice.

Sine tones still trumped the voice in terms of sustain, which Young and Zazeela considered a crucial factor of the *Dream House* installations: "Much of our work has focused on the relationship of the media to time, or on time directly. Time is so important to the experiencing and understanding of our work"[46]. With sine tones capable of continuing for as long as there was power to drive the equipment, a fully electrified *Dream House* and therefore *Map of 49's Dream* could be maintained for weeks, months or years. Having identified duration as an essential aspect both for the reception and comprehension of his music, Young would give it centre stage in his theoretical efforts to define the musical experience. As previously noted, when it came to the aspect of sustain, Young's use of sine tones had already removed the need for a distinction between duration and pitch, achieving both through massive repetition (as indicated by frequency). It would be this aspect of the exact repeatability of sine tones that would be crucial In Young's developing theory of music and listening.

Sound inside a listener

The development of Young's theoretical work *The Two Systems Of Eleven Categories* took place during the period that he was occupied with *Map of 49's Dream* and the *Dream House* installations.[47] This work has remained unpublished, and the nature of its contents shall not be speculated upon here. However, Young's statement on his work - which was published shortly after the first *Dream House* installation in 1969, both in *Aspen* and in the volume *Selected Writings* - provides significant insight into his aesthetic programme of the period.[48] In *Notes on the Continuous Periodic Composite Sound Waveform Environment Realizations of "Map of 49's Dream the Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery"* Young would set out the basis for realising his 'precisely articulated' musical situations.

Prior to commencing his theoretical writings, Young cited the influence of the musical theories of Alain Daniélou (author of *Tableau Comparatif des Intervalles Musicaux* [1958]), who sought to establish a correlation between the structure of sound and auditory function.[49] As noted in earlier chapters, this motivation also guided Helmholtz in his acoustical research, although Daniélou would extend his own theories along the lines of the spiritual concerns of Hinduism, of which he was a devotee. However, it was more in the spirit of cross-cultural comparison that he proposed a psychophysiological basis for the reception and appreciation of music. Daniélou posited that it was a dictate of the "mental mechanism" itself that only harmonically related intervals could be analysed as musical. This would encourage Young to explore how music functioned on physiological and perceptual levels. This conflation of physical and psychological properties served Young as the basis for his study of musical cognition:

> This is an area in which I plan to do more work - what happens after the information carried by the sound passes the reception stage at the ear. It is highly likely, as I hear it, that what makes me like this sound is more than just the way the ear receives information; the brain finds this kind of information congenial.[50]

In the sketch of his musical system given in *Notes*, Young described a model in which the basis of musical pleasure is derived from identifying and interpreting frequency information via the direct and repetitive stimulation of the auditory centres in the brain. In this ontology, listening to his music is defined by psychological experience, which in turn is reducible to a physiological substrate:

> In the tradition of modal music a fixed tonic is continued as a drone or frequently repeated, and a limited set of frequencies with intervallic relationships established in reference to the tonic is repeated in various melodic permutations throughout a performance in a particular mode. Generally, a specific mood or psychological state is attributed to each of the modes.[51]

Describing the method of generating these 'psychological states' would require a model for hearing and cognition, and a model for what kind of sound was to be heard. Young outlined a model of hearing based on repetition that would allow for the direct and accurate transmission of sound. He states that when a sound is heard, its frequency components would each register in individual places along the basilar membrane inside the cochlea, causing the nerve cells at each of those points to deliver an impulse to a specific part of the auditory cortex. Young posits that with each successive repetition of a sound, the component frequencies should register on exactly the same part of the basilar membrane each time, causing the same number of nerve cells to fire at exactly the same rate as had previously, and therefore deliver an identical impulse to the same spot on the auditory cortex. It would be this repetitive stimulation of a single spot of the auditory cortex that Young would cite as being capable of triggering a psychological state.

In the process outlined, this recognition of the exactness of a given interval over a period of time would be concurrent with the onset of an associated psychological state, and vice versa. For Young, experiencing the psychological state would be both a sign and a product of analysis, and also provide the potential for further scrutiny: "When these states are sustained over longer periods of time they may provide greater opportunity to define the psychological characteristics of the ratios of the frequencies to each other." Young does not define the effects or parameters of these states, going only so far as to equate them with traditions of musical affect, offering a comparison with the classical music of India, which he considered "has nearly always included a sustained drone and has evolved and actually practices the most highly developed system of modal scales and moods related to modes in the history of music."[52]

Apart from being a description of Young's music making, one of the most interesting aspects of *Notes* is the discourse it contains on sound and listening. Aside from the discussion of parameters such as intervals and ratios, the term 'sound' is eschewed in favour of frequency, or subjected to the cryptic reductionism of "information of a periodic nature." These two descriptions are then conflated in

Young's choice of sine waves as sound sources for his frequency environments. The overall sound is portrayed as a "complex" consisting of first order "concurrent generating frequencies" (sine tones) and further orders of "associated combination frequencies" (sum and difference tones).[53]

If Young's music were to be governed by the ability of a given sound to stimulate the exact same spot on the brain, then the sound itself would also need to exhibit this identical repetition. In order to "best analyse information of a periodic nature", Young posits that the brain performs a kind of comparative analysis, where the relationship between two frequencies is assessed through the repeatability of the resulting complex waveform.[54] Non-rational frequency ratios, such as those produced by intervals based on equal temperament, produce "composite sound waveforms that are infinitely non-repeating, only an infinite number of lifetimes of listening could possibly yield the precise analysis of the intervallic relationship."[55] Intervals of whole number ratios, however, produce "periodic composite sound waveforms" which would repeat exactly in a minute period of time, allowing the interval to be 'recognised' (although the exact form that this recognition would take is itself unclear). Young therefore identified sine waves as the best sound sources for his "frequency environments, since they have only one frequency component" and, as earlier chapters have illustrated, were generally considered to be exemplary models of modular repetition.

More significant are the shifts to listening implied by Young's formulation of the processes of hearing. There is a conceptual relocation of auditory experience, from outside the body to inside. Young had previously surmised that profound experiences of sound occurred while listeners inhabited a sound, which therefore invited the shared experience of sound in a social situation. However, contrary to his previous position, one implication of this emphasis on the behaviour of sound inside the listener is that it would ostensibly serve to isolate listeners within their own psychological realm. In fact, a definition of listening as the act of attending to the perception of sound would seem to be in some ways superfluous to Young's theory. If hearing music is synonymous with experiencing a psychological state, as it was in Young's scheme, then the need to actively attend to sound in order to appreciate 'dream music' could be bypassed. Rather than defining a process of active and attentive listening, Young instead makes reference to what he termed the "human auditory mechanism" which would automatically (if not autonomically) perform an analysis of incoming frequency information.[56] A successful assessment of the sound as periodic would be confirmed by the onset of the appropriate psychological state. Attention to sound only comes into play in relation to duration - 'staying the course' long enough for analysis to be completed. According to Young's theory, audience members would not only have to measure sound, but they would also have to 'measure up' in terms of the discipline required in order to have a musical experience.

Without overstating Young's claims or submitting them to scientific verification, this attempt to codify the musical experience represents an important transition point for his epistemology of listening. The progression from *The Tortoise, His Dreams and Journeys* to the various realisations of *Dream House* and *Map of 49's Dream* parallel the shift of the site of listening from 'inside the sound' to 'inside the brain' or 'inside the mind'. The sense of exploration and attendant understandings attributed to auditory experience described by Young in "Lecture 1960", and encapsulated in the phrase 'listening inside a sound', would eventually be interpolated into his later term 'drone state of mind' - a catch-all description of the psychological experience.[57] Rather than delivering the chance to "see how each sound was its own world" as he stated in "Lecture 1960", listening would now be a gateway into an internal, personal world.

In proposing this model Young laid down a prescriptive situation encompassing both sound and listener. Sound is to be represented as intervals of whole number ratios, and listening a process of analysis and recognition of those same intervals, the accuracy of which was determined by sustained attention. In doing so, Young merges acoustic event (the sound outside the ear), physiological process (the mechanism by which sound travels from ear to brain) and psychoacoustical function (how the brain interprets sound) through the figure of repetition, realised in intervals of sine waves. Young is careful not to use the term sine tones - which denotes only a sound - and instead uses the ambiguous sine waves, which allows his notion of 'frequency' to be interchangeable for a sound, a nerve impulse or a brain wave. Any perceived contradiction between the listening experience as a psychological state, and the inhabited, externalised sense of listening one might find in the spacious sound of *Map of 49's Dream* could apparently be resolved through Young's exact transmission model of hearing, as one set of sine waves was deemed capable of generating both situations.

Having selected sine waves as the tools with which he would construct his frequency environments, Young would be subject to the difficulties of converting abstract models into concrete phenomena. In fact, the shift in the site of listening from 'inside a sound' to 'inside the mind' indicated in *Notes* is dependent on sine waves being able to maintain their formal abstract properties in the physical world. Young's earlier attempts to employ sine waves in his installations had already revealed a difficulty of alignment due to the limitations of available technology, but this had been assimilated rhetorically simply through the metaphor of 'drift'. As the sine wave was now the key to Young ambitious efforts to induce psychological states, this practice would also be contingent upon the ability of sine waves to register all their abstract characteristics in the physical domain.

Hearing sines/waves/tones

Throughout his work, Young has been content to use the accepted description of sine waves as designating sounds of a single frequency. As indicated in previous chapters, a 'true' sine tone - one that represents all of and only the characteristics of a sine curve - cannot be said to exist, if only due to the impossibility of producing anything of an actually infinite duration. However, even allowing that a sine-like sound consisting of a single frequency could be produced, at the acoustic, physiological and psychoacoustical stages in Young's model, there would be significant factors that would limit the possibility of these abstract properties of sine waves being realised. Corresponding with his endorsement of sine tones as single frequency sounds, Young's model of music is predicated on notions of linearity. Given that a single frequency sound can in fact be produced, a sine wave has to maintain this single frequency state at every stage: from being produced by a loudspeaker, to travelling through the air in a room, through the cochlea and along nerve fibres to the auditory cortex in the brain.

Regardless, Young makes a number of claims for the scientific validity of his aesthetic programme. Terms such as 'research' and 'analysis' frequently surface in his writings, and he makes reference to both place theory and volley theory in his discussion on aural function and pitch identification.[58] The *Dream House* itself was in part modelled on the self-experimentation he and Zazeela undertook while examining the effects of long-term exposure to periodic intervals of sine tones. This chapter is not proposing a scientific analysis of what are largely aesthetic claims; Young's use of sine tones does however warrant a comparison between related acoustical and psychological research and his claims for the kind of listening experiences his artwork creates. What is most significant is the product of the encounter at those points where these areas intersect. Like the discussion in the previous section of the inherent tension between systems of intonation and performance possibilities in Young's *Composition 1960 #7*, the interplay between Young's sine waves and contemporary research into acoustical and psychological situations would in turn induce their own type of conceptual 'beating patterns' - subtle, but pulsing.

Physical aspects of sound propagation play a large part in *Map of 49's Dream*, once again highlighting the relationship between Young's compositions and the environments in which they were performed. His use of constant sine or sine-like tones to realise the *Dream House* meant that standing waves - stationary vibrationary patterns formed by the superposition of reflected sound waves - became a structural feature of the work. The standing waves organised the sound into areas of high and low amplitude, meaning the balance between the relative volumes of the intervals became dependent on the physical location of listeners. Young would consider that this had the effect of making the listener's position and movement in the space an integral part of the sound composition, marking at least a slight recouping of the physical, embodied aspects of the listening experience that had been eschewed in favour of the internalised listening prescribed by Young's formulation of hearing.[59]

It is perhaps ironic, given that his work relies on the exact articulation of specific frequency structures within a space, that Young makes no mention of tuning his sine tones to match the resonant frequencies of the venues in which his music was to be performed. As the frequencies for *Map of 49's Dream* were defined by sets of ratios, new frequency values could have been easily calculated in relation to a new fundamental frequency - although it is of course extremely unlikely that any predetermined set of frequency relationships could apply equally to the resonant characteristics of all spaces. Further, apart from resonance, the spaces themselves presented other problematic aspects in respect of the absorbent and reflective characteristics of materials and surfaces - environmental factors that might reinforce, attenuate or even remove frequencies from his work. Young's comment that standing waves created an opportunity for audience involvement seems more an accommodation of the acoustical effects of his composition rather than a specific desired outcome (surely moving about could only hinder the exact reception of the sine tones), and shows that despite the other spatial concerns in his music, Young had made little allowance for any theory of resonance in the conceptual structure of the *Dream House*.

This is indicative of Young's reluctance to substitute the constraints of any physical environment for the prescriptions of his synthetic one. An episode where Young and Zazeela sang by the seaside in tune with the Atlantic Ocean in 1968 is often cited as exemplar of Young's interest in performing with natural resonances. However, his account retains an air of ambivalence:

> I would listen to the waves break and hear which frequencies were set into resonation and then determine the fundamental frequency of the area. Marian would sing the drone pitch from "Map of 49's Dream the Two Systems of Galactic Intervals Ornamental Lightyears Tracery" from *The Tortoise, His Dreams and Journeys*, and I would sing the intervallic relationships improvised within a set of given rules over her drone tuned to the resonance of the area.[60]

Rather than submit to nature, the relationship between Young and environment was mediated through his established compositional procedures. *Map of 49's Dream* became a screen or framework, through which the sounds of nature were to pass in order to participate in the work. However, the idea that the pre-determined ratios of *Map of 49's Dream* might retain their aesthetic cohesion within earshot of the broad spectrum of surf sound does seem hopeful at best.

Singing with waves in the ocean was one thing, but the mere fact of sound as a vibration in air presented its own problems for sine waves. Irrespective of the manner in which they might be arrayed in a physical space, for *Map of 49's Dream* to be 'correctly' realised in terms of Young's expressed aims, the sounds that produced the standing waves that formed the work needed to be of a specific order. As mentioned earlier, Young's direct transmission model of hearing assumes linearity of both the physical acoustic situation and of the processes of hearing: that sounds in the physical situation outside the ear were identical to those received by the auditory cortex. However, once the abstract concept of a sine wave is rendered as a soundwave traversing a physical space, any possibility of actually delivering an unmodified, purely sinusoidal sound to the ear is destabilised.

Given that it could be generated, the movement of any sine tone through a medium - in this case, air - immediately problematises the very possibility of it remaining a single frequency. Beginning with the theoretical work of German mathematician Bernhard Reimann in 1860, research into the nonlinear aspects of wave propagation has shown that any vibrational wave is liable to become distorted over time due to contact with the medium in which it takes place.[61] Richard D. Fay, working at the Massachusetts Institute of Technology in the early 1930s, found that the nonlinear relationship between air pressure and the specific volume of free air induced a transfer of energy within a sound wave, enriching its harmonic content.[62] As the viscosity of the air itself tended to attenuate the higher frequency components that were created through this process (rather than the lower frequencies), the distorting effects of the air would modify a sinusoidal wave into one approximating a saw-tooth waveform. Fay concluded that there was in fact no permanent wave form, only a continual changing one, positing that any wave would tend toward this comparatively "stable" saw-tooth form. He also found that there was a marked departure from the sinusoidal even for waves of very moderate amplitude.

With the expansion of the harmonic content of sound due to nonlinear relationships, playing even a single sine tones into a space would in itself be a procedure of the generation of additional frequencies. Were Young still interested in the profusion aspects of 'listening inside a sound' he outlined in "Lecture 1960" then this attribute of the interaction between sine tones and the viscosity of the air might well have been desirable. It would mean that even a simple sound such as a sine tone would be considered capable of creating its "own world", removed from human agency.[63] However, in line with the shift to an internalised listening experience brought about by the sine-tone construction of *Map of 49's Dream*, the acoustic attributes of the performance space or the influence of the air contained within it received little conceptualisation (apart from the spatial distribution of relative volumes). It would seem rather than working within the realities of the physical space, Young attempted to transcend restrictions in realising his compositions with an increase in amplitude.

Amplification was the only alteration Young applied to his sine waves between generation and audition in the *Dream House* and *Map of 49's Dream*. Even without taking the maintenance of sine waves into consideration, his use of amplification would also prove to be problematic. Electrical amplification had been emblematic of Young's music since the initial Theatre of Eternal Music, and by the time of *Map of 49's Dream*, it had come to represent both an expansion of resources for composition and for enhancing the listening experience for the audience:

> The louder a sound is, the more likely you are to hear the harmonics that sound makes, which is to say that they increase as the amplitude goes higher. At ordinary volumes they are so soft that you don't even hear most of the higher partials. In fact, if you listen closely to my singing voice without amplification, you will hear perhaps up to three. With amplification, the seventh harmonic in my voice and often the

> ninth harmonic in Marian's voice become clear and audible for everyone. That's only one reason we play the *Tortoise* piece so loud.[64]

Given that Young's music incorporated within it the product of every frequency interaction, the unaided ear would seem to be incapable of hearing all aspects of his music. Amplification would therefore overcome what Young perceived to be physical limitations of hearing, just as it already served as an aid to the ears of performers, providing a kind of enlargement of the individual frequencies for the purposes of 'analysis': "It's like putting something under a microscope. You can hear the discrepancies in tuning even more. You have a much finer, more precise degree of intonation because of the fact that you have amplified the frequencies."[65]

Young found the restriction in being able to hear higher frequencies mirrored in research that tracked listeners' subjective experience of the loudness of low sounds. Young cited psychoacoustical studies such as those by Fletcher and Munson in the 1930s that showed how listeners' impressions of loudness were attenuated at the lower end of the audible spectrum.[66] As with the problems of audibility of higher harmonics, amplification became a strategy seemingly capable of undermining these subjective aspects of listening:

> If we take a given sound situation that has basses and highs and middle-range tones and it's not too loud, the ear really doesn't perceive all the bass that is there. It can't pick it up as easily. We find, however, that at louder amplitudes the ear hears bass more in proportion to the way it is actually being produced. This gives you a fuller chord.[67]

Despite the emphasis on acoustic spatiality in his work, often realised through the interrelations of high frequencies, there was in fact a tendency of Young to favour low sounds in his compositions. Since his earliest sound environments, the volumes of the individual sine tones had been set in inverse proportion to the ratio of the interval, ensuring that the lowest tone will be loudest, and establishing a fundamental tone (although in a ratio such as 32:31 this distinction might be all but impossible to draw).[68] While turning up the bass also had the effect of reinforcing the fundamental drone as the foundation (s)tone of his sound, the issue of the audibility of low sounds cannot be overcome simply through the application of sheer force. Physiological parameters of the ear would again come into play where loud sounds are involved, as highly amplified sound would in turn trigger the *acoustic reflex* of the middle ear (also known as the middle ear muscle reflex).[69] High sound intensity causes the stapedius muscle to contract, stiffening the chain of bones in the middle ear and attenuating the transmission of frequencies below 1000 Hz to the cochlea. Ironically, the high volume of the overall sound would itself be a factor in reducing the subjective sensation of low sounds. As low sounds have a tendency to mask higher sounds, the attenuation of low frequencies by the acoustic reflex is thought to act as an aid to the perception of higher frequencies required for understanding speech.[70] So while Young sought to emphasise low sounds through amplification, this had the concurrent effect of enhancing the audibility of vocal harmonics. Just as the simple timbre of sine tones had focused *Map of 49's Dream* onto the tonal breadth of the human voice, boosting the bass not only increased the presence of low frequency sound, it also aided in the perception of vocal sounds.

The amplification of sine waves would, in regards to Young's direct reception model of hearing, have its most significant effect in the area of pitch identification. The quantitative psychoacoustical research into the effects of loudness on audition by S. S. Stevens at Harvard University in the 1930s identified the role that volume played in altering the perception of pitch. Up until that time, physicists had regarded pitch and frequency to be the same. Counter to this, Stevens's experiments showed that the pitch of a given tone could be altered without changing its frequency:

> By increasing the intensity of tones of high frequency we raise their pitch; whereas in the case of low frequencies, an increase in intensity lowers the pitch. This change of pitch can amount to as much as half an octave at certain low frequencies. Clearly, then, pitch is not frequency, nor is it correlated one-to-one with frequency.[71]

This spreading of pitches due to amplification presents another hurdle in the 'correct' reception of Young's work, and emphasises the ambiguous role attention plays in his listening scheme. His model requires the sine tone intervals of *Map of 49's Dream* to remain unaltered from their calculation and production, through to their reception and analysis by the ear and transmission to the brain, before inducing a psychological state. However, this notion of the correct analysis of intervals would be problematised by the relative shift in pitch brought about by amplification, widening the magnitude of some intervals while shrinking others. Young's model of hearing does tend to function more on a notion of force, or perhaps intention, rather than attention: effects are produced in the listener through an act of submission, not through a conscious or deliberate act of reception or attentiveness such as listening. This does assume that listening, especially in a concert or performance situation, can somehow be suspended, and that its attributes and vicissitudes have no effect on the transmission of frequency information. Should audition of this kind occur - where the pitches of tones are altered due to amplification - it could only serve as an impediment to the kind of analysis Young's writing implied.

When considered simultaneously, however, the superimposition of these two models of perception - one for the direct transmission of Young's abstract intervals, the other with these same intervals expanded or contracted through amplification - induces in the brain an array of beating patterns between abstract and empirical frequencies marginally out of alignment. Each of Young's carefully calculated intervals would have two iterations: one a whole number ratio repeating exactly, one an irrational fraction changing indefinitely. Perhaps the 'infinite' Young proposes exists in the playing out of this interaction, and any accompanying psychological state is stimulated by the continuous agitation of the imagined by the heard.

The examination of each of the aforementioned problems highlights a certain oscillation between the ideal and the empirical, which, when considered outside the strictures of Young's direct transmission model of hearing, present generative possibilities for the interpretation of his work in this period. However, this situating of his approach within a broader acoustical context also throws into question the validity of some of his claims from an empirical standpoint, and in doing so it has sought to examine how the idealised aspects of *Map of 49's Dream* and the *Dream House* attempted to construct sound and listening on both a physical and psychological level.

Sine wave and piano coda

Map of 49's Dream proved to be a highly successful and transportable realisation of Young's work, and he and Zazeela staged a number of *Dream House* installations across Europe and the US between 1969 and 1974.[72] Having already expanded from solo to duo performances, by the summer of 1970 they had begun to add additional members and once again used the Theatre of Eternal Music name.[73]

By 1974, Young had turned his attention to *The Well-Tuned Piano* (1964), a work for piano tuned in just intonation that he had composed ten years earlier.[74] By the time a permanent *Dream House* was established by the Dia Art Foundation in 1979 in the former Mercantile building at Harrison Street, Young had shifted his compositional focus onto *The Well-Tuned Piano* to the point where his installations would be representations of its various idiosyncratic chords, realised in sine waves.[75] Just as the nomadic *Dream House* was now firmly locked to a location, literalised in and as a physical structure, the "sets of concurrent generating frequencies" that once comprised *Map of 49's Dream*, with all their problematic implications and contradictions, were now fixed as chords made up of notes from a piano (albeit a justly tuned one). However, the formulations of sound, listening and psychology that Young devised in the mid 1960s and early 1970s remain a crucial part of his aesthetic, just as the works he produced to convey those concepts continue to exert influence over all of his subsequent sine wave installations and instrumental compositions.

[1] Of the major surveys, Edward Strickland's *Minmalism:Origins* mentions both works only as asides (perhaps because they don't fit inside the frame of 'origins') and Schwartz's *Minimalists* reduces both works to an appendix entry and a photo caption. Wim Mertens quotes from Young's own statements on the work from this era, but adds no analysis of his own: Wim Mertens, *American Minimal Music: La Monte Young, Terry Riley, Steve Reich, Philip Glass*, trans. J. Hautekiet (London: Kahn & Averill, 1983), 30-31. Keith Potter is slightly more voluble over the three pages he devotes to these works: Keith Potter, *Four Musical Minimalists* (Cambridge: Cambridge University Press, 2000), 76-78. In *Sound and Light*, the monograph on the work of Young and Zazeela, *Map of 49's Dream* is referred to only once outside of their own writings. In general, when the *Dream House* project is mentioned in writings on Young, the discussion is limited to either its origins or its later realisation in the mid 1970s, not the period under review here.
[2] Conrad and Cale have been scathing about what they see as Young's subsequent hijacking of the music produced by the Theatre of Eternal Music - something that they had considered a group endeavour. The account of the Theatre of Eternal Music given in the previous chapter was however aimed at being even-handed towards all the participants and their contributions, while sidestepping this particular issue of authorship. For Conrad's perspective see (amongst others) Tony Conrad, *Four Violins (1964)* (Table of the Elements, 1996), LP record. Also John Corbett, "Minimal Compact," *The Wire*, February 1995. For Young's response to these claims: La Monte Young, *Notes on the Theatre of Eternal Music and the Tortoise, His Dreams and Journeys* [pdf document] (2000 [cited 2nd March 2004]); available from http://www.melafoundation.org/lmy.htm.
[3] Richard Kostelanetz, "Conversation with La Monte Young," in *Selected Writings* (Munich: Heiner Freidrich, 1969), 51.
[4] Jean-Claude Risset and David L. Wessel, "Exploration of Timbre by Analysis and Synthesis," in *The Psychology of Music*, ed. Diana Deutsch (San Diego: Academic Press, 1999), 33.
[5] Kostelanetz, "Conversation with La Monte Young," 56.
[6] Conrad, *Four Violins (1964)*.np.
[7] ibid.
[8] Douglas Kahn, *Noise Water Meat: A History of Sound in the Arts* (Cambridge: MIT Press, 1999), 231.
[9] Young, *Notes on the Theatre of Eternal Music*.14.
[10] Alan Licht, "The History of La Monte Young's Theatre of Eternal Music," *Forced Exposure* 1990, 66.
[11] Kostelanetz, "Conversation with La Monte Young," 59-60.
[12] La Monte Young and Marian Zazeela, "Continuous Sound and Light Environments," in *Sound and Light: La Monte Young and Marian Zazeela*, ed. William Duckworth and Richard Fleming (Lewisberg: Bucknell University Press, 1996), 218.
[13] William Duckworth, *Talking Music: Conversations with John Cage, Philip Glass, Laurie Anderson, and Five Generations of American Experimental Composers* (New York: Schirmer, 1995), 253.
[14] Young, *Notes on the Theatre of Eternal Music*.13.
[15] Essay reproduced in La Monte Young and Marian Zazeela, "Dream House," in *Selected Writings* (Munich: Heiner Friedrich, 1969), 16.
[16] Young, *Notes on the Theatre of Eternal Music*.19.
[17] Young and Marian Zazeela, "Continuous Sound and Light Environments," 218.
[18] ibid. Of course, not everyone found this experience to their liking: "While he was in New York [in 1968] Partch met briefly with Ben Johnson... and visited La Monte Young, a composer with a considerable though largely underground reputation as the earliest exponent of minimalism in music. Young let Partch hear a just-tuned electronic drone that he had set up in his studio. Partch was horrified, and writing to Young a couple of months later - declining his request for a grant recommendation - he confessed: "I realise that I was not pleasant when I met you in your studio. I don't think I could have taken that New York ordeal much better twenty years ago. And I also doubt that if I awoke fresh as the rosy dawn I could stand an

electronic drone very long without suffering." Bob Gilmore, *Harry Partch* (New Haven: Yale University Press, 1998), 348-49.
[19] The ratios are 56:57:58:59:61:62:63:64:66:67:68:69:71:72, Kyle Gann, "The Outer Edge of Consonance: Snapshots from the Evolution of La Monte Young's Tuning Installations," in *Sound and Light: La Monte Young and Marian Zazeela*, ed. William Duckworth and Richard Fleming (Lewisberg: Bucknell University Press, 1996), 174.
[20] ibid.
[21] ibid., 173.
[22] Young, La Monte, liner notes in Various, *Ohm: The Early Gurus of Electronic Music 1948-80* (Ellipsis Arts, 2000), compact disc. 66.
[23] ibid.
[24] Gann, "The Outer Edge of Consonance," 173.
[25] Young, liner notes in Various, *Ohm*. 66. On a technical level, the question of whether drift was still a factor in later sine tone installations might be down to the accuracy of the phase-locked oscillators, or of any other means Young has used to realise these works. Conceptually, Young has not considered drift to be a factor in these later works.
[26] Young and Marian Zazeela, "Continuous Sound and Light Environments," 219.
[27] Edwin Pouncey, "La Monte on Record," *The Wire*, December 1998, 38. The title displays Young's propensity to helpfully include the time and date of the recording or performance in his titles from the mid 1960s onwards.
[28] Dan Graham, *Item 1, Folder* [website] (Ubuweb, 1969 [cited 6th June 2006]); available from http://www.ubu.com/aspen/aspen8/folder.html.
[29] Ironically, Young's article makes no mention of 'drift' or *Drift Studies*, only *Map of 49's Dream.*
[30] La Monte Young, *Notes on the Continuous Periodic Composite Sound Waveform Environment Realizations of "Map of 49's Dream the Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery"* [web site] (Ubuweb, 1969 [cited 6th June 2006]); available from http://www.ubu.com/aspen/aspen8/folder.html.
[31] Kostelanetz, "Conversation with La Monte Young," 35.
[32] John Perreault, "La Monte Young's Tracery: The Voice of the Tortoise," *Village Voice*, 22nd February 1968. As quoted in Edward Strickland, *Minimalism:Origins* (Bloomington: Indiana University Press, 1993), 160.
[33] William Duckworth and Richard Fleming, "Introduction," in *Sound and Light: La Monte Young and Marian Zazeela*, ed. William Duckworth and Richard Fleming (Lewisberg: Bucknell University Press, 1996), 15.
[34] Zazeela states, "Beginning in 1968, the projections were performed with the section *Map of 49's Dream The Two Systems of Eleven Sets of Galactic Intervals*, at which time I titled the slide series *Ornamental Lightyears Tracery*. When the music and slides were performed together in concert, the title of the combined sound and light presentation became *Map of 49's Dream The Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery*." Marian Zazeela, "Ornamental Lightyears Tracery," in *Sound and Light: La Monte Young and Marian Zazeela*, ed. William Duckworth and Richard Fleming (Lewisberg: Bucknell University Press, 1996), 226. Whether by anachronism or omission, there seems to be no particular confirmation of this by Young, although the imagery makes it plausible.
[35] ibid., 227.
[36] ibid., 226.
[37] Young, *Notes on the Continuous Periodic Composite Sound Waveform Environment.*1. Although Young includes an earlier installation at the Pasadena Art Museum, California, from 1968 in his résumé, the exact nature of this work is unclear.
[38] Young and Zazeela, "Dream House," 11.
[39] Young, *Notes on the Continuous Periodic Composite Sound Waveform Environment.*
[40] Young and Zazeela, "Dream House," 12.
[41] Frank Popper, *Art - Action and Participation* (London: Studio Vista, 1975), 151.
[42] La Monte Young and Marian Zazeela, 31 VII 69 10:26 - 10:49 PM Munich from Map of 49's Dream The Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery;

23 VIII 64 2:50:45-3:11 AM the volga delta from Studies in The Bowed Disc, [aka *"The Black Record"*] LP (Munich: Edition X, 1969).
[43] Edward Strickland, *American Composers: Dialogues on Contemporary Music* (Bloomington: Indiana University Press, 1987), 66.
[44] An account of Zazeela and Young's relationship with their *guru* is given in Terry Riley, "The Trinity of Eternal Music," in *Sound and Light: La Monte Young and Marian Zazeela*, ed. William Duckworth and Richard Fleming (Lewisberg: Bucknell University Press, 1996).
[45] Strickland, *Minimalism:Origins*, 158.
[46] Young and Zazeela, "Dream House," 10.
[47] The full title, once it was completed, became *The Two Systems Of Eleven Categories 1:07:40 AM 3 X 67 - ca. 6:00 PM 7 VII 75 from "Vertical Hearing, or Hearing in the Present Tense"*, indicating that the writing took place between October 1967 and July 1975. Gann, "The Outer Edge of Consonance," 161.
[48] In Young's essay "Notes on *The Well-Tuned Piano*" included in the programme notes prepared for the 2001 German premiere of the DVD installation of *The Well-Tuned Piano in The Magenta Lights 87 V 10 6:43:00 PM - 87 V 11 01:07:45 AM NYC*, the *Two Systems Of Eleven Categories* is still described as an unpublished work. However, this essay does quote a large section of *Notes on the Continuous Periodic Composite Sound Waveform Environment Realizations of "Map of 49's Dream the Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery"* showing the continuing relevance of this work to the composer. La Monte Young, "Notes on the Well-Tuned Piano," in *The Well-Tuned Piano in the Magenta Lights 87 V 10 6:43:00 PM - 87 V 11 01:07:45 AM NYC* (New York: MELA Foundation, 2001), 2.
[49] Kostelanetz, "Conversation with La Monte Young," 36.
[50] ibid.
[51] Young, *Notes on the Continuous Periodic Composite Sound Waveform Environment.*
[52] ibid. Given the variety of musical systems ever devised, this particular claim would indeed be difficult to substantiate. It is, of course, hardly surprising that Young might make a comparison between his own work and this established musical tradition that, as noted in the previous chapter, had played such a formative role in his musical development.
[53] ibid.
[54] ibid.
[55] ibid.
[56] ibid.
[57] Gann, "The Outer Edge of Consonance," 161.
[58] Young, *Notes on the Continuous Periodic Composite Sound Waveform Environment.*
[59] Young and Zazeela, "Dream House," 11.
[60] Strickland, *American Composers*, 60.
[61] Carl B Boyer, *A History of Mathematics*, Second ed. (New York: John Wiley & Sons, 1991), 555-56.
[62] Richard D. Fay, "Plane Sound Waves of Finite Amplitude," *The Journal of the Acoustical Society of America* 3, no. 2A (1931): 222-41.
[63] La Monte Young, "Lecture 1960", *Tulane Drama Review* 10, no. 2 (Winter 1965) reprinted in Mariellen R Sandford, ed., *Happenings and Other Acts* (New York: Routledge, 1995), 79.
[64] Kostelanetz, "Conversation with La Monte Young," 40-41.
[65] Duckworth, *Talking Music*, 244.
[66] Harvey Fletcher and W. A. Munson, "Loudness, Its Definition, Measurement and Calculation," *The Journal of the Acoustical Society of America* 5, no. 2 (1933): 82-108.
[67] Kostelanetz, "Conversation with La Monte Young," 56.
[68] Young and Zazeela, "Dream House," 12.
[69] James O. Pickles, *An Introduction to the Physiology of Hearing* (London: Academic Press, 1982), 273.
[70] ibid., 275.
[71] S. S. Stevens, J. Volkmann, and E. B. Newman, "A Scale for the Measurement of the Psychological Magnitude Pitch," in *Psychological Acoustics*, ed. Earl D. Schubert (Stroudsburg:

Dowden, Hutchison & Ross, 1979), 101-03. See also S. S. Stevens, "The Relation of Pitch to Intensity," *The Journal of the Acoustical Society of America* 6, no. 3 (1935): 150-54.
[72] In 1973, Young and Zazeela released an album on the French record label Shandar, renowned for their catalogue of American free jazz (Albert Ayler, Sun Ra) and minimalism (Steve Reich, Terry Riley). Titled *Dream House 78'17"* - another iteration of *Map of 49's Dream* in the form of *VII 73 9:27:27-10:06:41 PM NYC from Map of 49's Dream The Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears Tracery*, performed by the Theatre of Eternal Music, featuring Young, Zazeela, Jon Hassell on trumpet and Garret List on trombone. The B-side was the sidelong *13 I 73 5:35-6:14:03 PM NYC; Drift Study.*
[73] For the 8-day *Dream House* installation at the Nuits de la Fondation Maeght festival at St. Paul de Vence, France, Zazeela and Young were joined in the vocal drone by Terry Riley, with saxophonist Jon Gibson and composer David Rosenboom on viola. Edwin Pouncey, "Life with the Lions," *The Wire* 2003, 34. Various other incarnations included trumpeter Jon Hassell (who maintained a long association with the group) and renowned jazz saxophonist Lee Konitz. For the Documenta 5 art festival in Kassel, West Germany in 1972, Young and Zazeela contributed a ninety-day *Dream House* installation. Duckworth, *Talking Music*, 253. This included a week of daily performances by Young, Zazeela, Hassell and Tony Conrad, who had briefly returned to the fold to perform, and to maintain the tuning of the three sine wave oscillators that drove the installation for the duration. Liner notes, Tony Conrad, *Outside the Dream Syndicate* (Table of the Elements, 2002), compact disc.
[74] Strickland, *American Composers*, 67.
[75] Gann, "The Outer Edge of Consonance," 175.

5. "Making the inaudible audible": Alvin Lucier, 1961-1972

This chapter traces the development of the work of American experimental composer Alvin Lucier from the early 1960s until the early 1970s. Lucier is renowned for compositions that, in his own words, aim to "explore the natural properties of sound and the acoustic characteristics of architectural spaces as musical objectives."[1] Lucier's work during this period is notable for his sustained use of electronics in a live performance context, incorporating amplification, recorded sounds and synthetically produced sounds in his compositions. These works predate his use of the sine tone - a sound that became one of the signature components of his compositions from the mid 1970s onwards. This chapter aims to survey the manner in which Lucier formulated and realised the acoustic phenomena that formed the subject of these earlier works, and his negotiation of concepts such as musical 'language', technology and notions of environment and space. In doing so it will also chart how Lucier's use of resonance and repetition led to a progressive extension of the duration of sounds he employed in these compositions, and explore how this prepared the way for his later adoption of sine waves.

Many of the works in this period sought to explore what Lucier called "the influence of space on sound," where the audition of specific acoustic effects by the audience were to form the substance of the compositions, rather than be present as merely an ornament or artefact.[2] Lucier refers to this process of foregrounding of acoustic phenomena as "making the inaudible audible" as these compositions aimed to focus the attention of listeners onto sounds that he considered were otherwise ignored or left unheard.[3] This emphasis on acoustic effects coincided with an aesthetic of impersonality or distanciation, which worked to de-emphasise the importance of the personality of the composer (and the performer) in order to highlight the natural occurrence of such effects. The development of these two related components of Lucier's aesthetic - exposing the hidden aspects of the sonic landscape, and impersonality - is traced here with reference to the series of works Lucier instigated during this period, up to and including projects which involved explicit visualisations of acoustic phenomena.

Lucier's path to using sine waves initially seems nowhere near as straightforward as that of La Monte Young, given that the scope of Lucier's work covers a broader range of sonic concerns, while still adhering to the objective of making the exploration of acoustic phenomena the subject of his work. Whereas Young's long tone aesthetic seems to point directly to sine tones, the emergence of sine tones within Lucier's compositions comes after the period under discussion here, during which his singular approach to musical language and materials was being devised and developed. By providing an account of Lucier's utilisation of technology and synthetically produced sound, and the emerging themes of space, environment, and the aesthetics of impersonality in his compositions, this chapter aims to provide a clear overview of the concepts that would come to underpin his use of sine tones. As such, it will be focusing on those compositions from this period that are precursors to these later works.

Beginnings

Alvin Lucier's early life has not been scoured for anecdotal evidence (by either himself or his commentators) on the development of his aesthetic to the same degree that La Monte Young's life has. There are plenty of indicators, however, to suggest that Lucier's early years equally played an important role in the development of his mature aesthetic. Born in Nashua, New Hampshire in 1931, Lucier has spent the vast majority of his life in the New England area. Describing his youth as a "New Hampshire childhood of creek-floats, canoe trips (pungent experience of wave motion), mountain hikes and woodland walks," Lucier, not unlike Young, offers his early experiences of listening to sounds in the natural environment as an influence on his work.[4] He attributes part of this appreciation of the sounds of nature to an activity of directed attention that occurred during a summer boys' camp in New Hampshire:

> Late in August, in the evening as we left the dining room, [the camp leader] would suggest that we campers leave thirty seconds apart to walk back to our cabins a route that we had never taken before, and be absolutely quiet and pay attention to the sounds of nature. We would go off alone at dusk and walk on a pathway, over a hill, through the forest, and you would hear evening birds and crickets and peepers and so forth. You would take a journey, and these things would open up to you. You didn't have to do anything but walk by. That was, for me, a very strong experience.[5]

This aspect of listening - that sound events worthy of attention existed as part of the natural environment, and were produced and persisted without the need for human agency or intervention - would later become pivotal in informing Lucier's compositional practice.

Aside from encounters with natural and environmental sounds, both Lucier's parents were keen amateur musicians; his mother played the piano and his father the violin.[6] Their musical interests ran more towards popular composers such as George Gershwin rather than European 'classical' music, let alone the avant-garde. However, an encounter with the music of one of Europe's leading serial composers had a significant impact:

> There was a music store in my small town. I went there once and there was a recording of Schoenberg's *Serenade*, of all things. I bought it and it was shocking. It didn't make any sense, but there was something about it that kept my interest. At that point I decided I was interested in challenging things.[7]

After completing high school at the Portsmouth Abbey School, Lucier studied composition at Yale University in New Haven, Connecticut, and was drawn into the musical milieu of the era: "In those days if you studied at an Eastern university, you were naturally aimed across the Atlantic"; as a result, the music of proto-experimental American composers such as Charles Ives, Harry Partch or John Cage (all of whom Lucier would later find influential) was barely considered.[8] Rather than following the prevailing trend towards serialism of the academy of the 1950s, Lucier was instead drawn to the music of early twentieth century composers such as Bartok, Hindemith, and the neo-classicism of Stravinsky. Alongside his composition studies, Lucier played snare drum in the Yale Band and percussion with the Yale Concert band.[9]

After Yale, Lucier continued his graduate studies at Brandeis University in Waltham, Massachusetts. On completion in 1960 Lucier received a Fullbright Scholarship, and following the path of many American composers of his and previous generations, headed for Europe, travelling to Rome to attend summer sessions at the

Benedetto Marcello Conservatory. Lucier expected that he would continue to compose in the neo-classical style.[10] However, rather than being a catalyst for the production of new works, his experiences in Europe triggered what Lucier has described as a "predictably American identity crisis" which altered his course:

> I heard a whole slew of pieces by European composers, including Nono, Berio and Stockhausen, and it seemed to me that I was hearing native speakers speaking their own musical language (and dealing with their own musical burdens, too). I started feeling that the composers who were admired in America were imitating European models, that the American composers were talking in a foreign accent. So it seemed to me that the twelve-tone or serial idea came from a different place than I did. It may have been my inadequacy at not being able to work satisfactorily in those particular systems, but it was a blessing because it gave me the strength to stop trying. And I did stop. I just stopped cold.[11]

As was the case with La Monte Young, it took a visit to Europe for Lucier to experience and appreciate contemporary music by American composers. Lucier credits a performance of John Cage's *Music Walk with Dancers* (1958) given by Cage, Carolyn Brown, Merce Cunningham, and David Tudor, at La Fenice Theatre in Venice in September 1960, as pivotal for redirecting his musical thinking.[12] Apart from the sonic and performative challenges Cage's music inspired, the concert also influenced how Lucier perceived the relationship between himself and his compositions: "Until that time I had followed the conventional pattern of composer-performer-audience relationships. One would compose a work, wait for some soloist, ensemble or orchestra to perform it, then hoped that the audience liked it".[13] In contrast to that model, Lucier was drawn to the self-sufficiency afforded by the kind of live electronics employed by Tudor:

> Tudor would have a table of electronics. It was his little orchestra. He could perform his music by himself. For me at that time this was extremely interesting and very important. You didn't have to rely on established musical institutions such as the symphony orchestra. Tudor made all his devices with inexpensive electronic components, everything he used was homemade. That was very inspiring.[14]

Coming at a time when Lucier was questioning his relationship to the European music allegiances of his education, the concert by Cage, Cunningham, Brown and Tudor served to consolidate his change of direction: "After that, I decided to do something totally different that would seem to be something my own."[15]

Lucier's growing sense of detachment from the European avant-garde was extended the following year when he travelled to the Darmstadt Festival for New Music with fellow American composer Frederic Rzewski, attending concerts and composition seminars. He was strongly impressed by Tudor's performance of La Monte Young's *X to Henry Flynt* on a small gong, under the disbelieving gaze of Cage's former European advocate Pierre Boulez, and also by a student performance of Young's *Poem for Chairs, Tables, Benches, etc.*[16] Lucier was struck also by the confusion with which this new music was met by stalwarts of European modernism, such as his fellow attendees Karlheinz Stockhausen and Theodore Adorno, further indicating for him a disjunction between the prevailing European avant-garde and contemporary experimental and proto-Fluxus music.[17]

These experiences with new American music preceded Lucier's first attempts to compose in a new medium. Through the Fullbright office in Rome, Lucier obtained the opportunity to spend two weeks at Studio Fonologia, the renowned electronic music studio of Radio Audizioni Italia (RAI) in Milan.[18] The studio had been a centre for tape composition under the directorship of composer Luciano Berio, and along with the RTF (Radiodiffusion-Television Française) studio established in 1951 by Pierre Schaeffer in Paris, and the WDR electronic music studio in Cologne operated by Robert Beyer, Herbert Eimert and Werner Meyer-Eppler (and later Karlheinz Stockhausen), represented the European vanguard of electronic and tape composition throughout the 1950s and 1960s.[19] America, of course, had its own electronic music institution in the form of the Columbia-Princeton Electronic Music Centre, established by Vladimir Ussachevsky, Otto Leuning and Milton Babbitt.[20] Alongside this, the increasing availability and affordability of tape recorders in the early 1960s had lead to an increase in the popularity of works on tape, and also compositions for tape and instruments, around the world.[21]

While excited by the physical aspects of working with sound on tape such as cutting and splicing, the prevailing attitude to composition at the studio contravened the notions of non-intentionality Lucier found implicit in Cage: "Control and possibility were the words they used to use a lot. We've got all the possibilities and we control them. The idea of Cage is that you have all those possibilities but you don't control them, and if you don't control them something wonderful is going to happen."[22] Lucier deemed his tape composition experiment to be unsuccessful, and it remained unfinished until after he returned to America in 1962 to teach at Brandeis University (where he was also appointed as choral director).[23]

Although Lucier has downplayed its importance, this tape piece would become his first work with electronics: *Elegy for Albert Anastasia* (1961-63).[24] Described as a work 'for electromagnetic tape using very low sounds most of which are below human audibility', it consists of a succession of subsonic rumblings and deep reverberances of unknown origin, although the character of the sounds used and the subtlety of the transformations involved suggest a restricted set of sources. While it retains many similarities with other works on tape from that era, it reflects his clear break not only with neo-classicism, but composition for traditional instrumentation. With its use of sonic material 'below human audibility' it also posits the beginning of Lucier's focus on sounds and sound sources which are hidden, ignored or difficult to hear or access, if only notionally.

Shortly after his return to the USA Lucier attended a concert at the New York City Town Hall with performances of compositions by John Cage, and two other experimental composers of the 'New York School' - Earle Brown and Morton Feldman. A subsequent introduction to Feldman at a party led to Lucier directing the Brandeis chorus in a concert of choral work by both Feldman and Brown.[25] It was at this concert that Lucier met composers Robert Ashley (b. 1930) and Gordon Mumma (b. 1935); both had travelled from Ann Arbor, Michigan, to New York to attend the performance, as opportunities to hear performances of Feldman's work at that time were extremely rare.[26]

Ashley and Mumma were at that stage members of the ONCE group, a collection of artists from the American Midwest with backgrounds in film, music, theatre and the visual arts. The group had grown from the annual ONCE festival - a multimedia outpouring of ideas and performances - which was started by Roger Reynolds, George Cacioppo and Donald Scavada in 1957.[27] Together Ashley and Mumma had established the Cooperative Studio for Electronic Music in Ann Arbor in 1958. Both had worked with live electronics, and Mumma had also collaborated with David Tudor on several projects.[28] Rather than pursuing tape music, or composing for the chorus, Lucier would also take up live electronics, but from a different perspective.

Amplifying alpha

Lucier considers his first significant composition after his return from Europe to be *Music for Solo Performer* (1965), designated as being 'for enormously amplified brain waves and percussion.'[29] Although it predates his work with acoustic phenomena, *Music for Solo Performer* is an important work in that is establishes many of the predominant conceptual themes that run through his oeuvre, such as notions of intentionality, his attitude towards performance, and his relationship to technology. As with *Elegy for Albert Anastasia*, it is crucial for following the progressive repositioning of notions of audibility and source material within Lucier's work. It also inaugurated the relationship between Lucier's aesthetics and his preoccupation with formal scientific experimentation.

The work has its genesis in a series of discussions between Lucier and Edmond Dewan, a physicist from the Air Force Cambridge Research Laboratory in Bedford, Massachusetts. Dewan had been researching the relationship between brainwave frequencies and the visual rhythms created by aeroplane propellers, as this was thought to be a cause of blackouts, dizziness and epileptic fits in pilots.[30] Dewan was a keen amateur musician, and had approached several other faculty members at Brandeis in order that they might find a musical application for his electroencephalograph (EEG) - the device used for detecting and examining brain rhythms.[31] Dewan also outlined the phenomenon of the alpha rhythm or alpha wave, which could be seen in the electrical oscillations produced by the brain in a rested, non-visualising state (that is, with eyes closed). Struck by the imagery and theatricality of Dewan's brainwave research, along with the serendipity of the offer, Lucier accepted his invitation: "I did not have the inclination to learn electronics to the extent of designing my own equipment. I had been on the constant lookout for existing equipment I could use for musical purposes."[32]

Alpha brain waves or rhythms are characterised as having a frequency of between eight and thirteen Hertz, and are often described as being indicative of a relaxed state of consciousness - "awake, relaxed, eyes closed" - sometimes likened to a meditative state.[33] German psychiatrist Hans Berger made the first recordings of brain waves in 1928. Using an electrocardiograph attached to silver wires inserted into a subjects' scalp, he identified a rhythmic pattern of electrical discharge with a frequency of approximately ten cycles per second.[34] English pathologists Adrian and Matthews at Cambridge University later confirmed this finding as to the rhythmic character of the electrical activity of the brain in 1934, and since that time electroencephalography has been used to investigate the electrical functionality of the brain.[35] The characterisation of this rhythmic oscillation in the electrical discharge of the brain as a form of wave provides a concise form of visualisation of brain function. The wave analogy also equates the somewhat fluctuating pattern of the human brain's electrical activity with the regular and continuous oscillations of sine waves.

Music for Solo Performer contains the first use of waves and wave metaphors in Lucier's work, even though brainwaves are not in themselves audible. The average frequency of alpha waves is approximately ten hertz - well below the level of audibility. Instead of being a source of sound, Lucier considered the use of alpha waves in *Music for Solo Performer* as a "control or energy idea".[36] The kind of energy or control it could provide was determined by the difficulty in maintaining the alpha rhythm, susceptible as it is to eye movement, mental activity and external stimuli.[37] This difficulty in maintaining an alpha state during performance not only provided Lucier with an indeterminate situation in line with the influence he had drawn from Cage's performances - it determined the parameters of the work.

Performances required Lucier to be seated while an assistant attached electrodes to his scalp, which were in turn connected to the EEG equipment.[38] The output from the EEG was connected to a mixer and heavily amplified before being distributed to an array of loudspeakers, each of which was used to activate a percussion instrument:

> I used the alpha to resonate a large battery of percussion instruments including cymbals, gongs, bass drums, timpani, and other resonant found objects. In most cases it was necessary to physically to couple the loudspeaker to the instrument, although in the case of highly resonant bass drums and timpani the loudspeaker could be an inch or so away. Placing loudspeakers in trash cans or cardboard boxes worked extremely well, as did using cheap small speakers face down on snare drums or taped against windows.[39]

The significance of brainwaves in *Music for Solo Performer* was not their inaudibility, but the very fact that their existence could be registered through their employment as a form of stimulus within a system. The bursts of amplified alpha waves produced trains of pulses rather than a constant signal, and were of such low frequency that they caused the loudspeaker cones to behave as pistons. This meant that the instruments were sometimes activated through physical contact with the moving speaker diaphragm, as well as by the sounds they produced. The system also incorporated threshold switches that would trigger the playback of an additional pre-recorded tape of sped-up alpha signals.[40] The brainwaves, amplified, produced the surges and thumps of the speaker cones, which in turn caused the percussion instruments and other reverberant objects positioned around the performance space to rattle, vibrate, buzz and boom.

As a musical performance *Music for Solo Performer* presented something unique. The performer was required to sit with their eyes closed, unmoving, and remain relaxed so as to produce alpha rhythms. The only indication for the audience that there was a causal connection between the immobile performer and the sounds produced by the percussion instruments came with the gradual recognition of a correspondence between the performer opening their eyes (thus halting the flow of alpha) and the cessation of sound.[41] Lucier found that through practice he could alternate between short bursts and longer sustained phases of alpha production, producing different results from the instruments. This experience of performing in such a relaxed or meditative state completely changed his conception of composition and performance, and lead to what he called an "attentive rather than manipulative attitude towards materials".[42]

Lucier gave the debut performance of *Music for Solo Performer* as part of a concert he had organised at Brandeis for John Cage and Christian Wolff in 1965. The programme included Wolff's *For 1, 2 or 3 People* (1964) and Cage's *0'00"* (1962), plus *Rozart Mix* (1965) - a new Cage tape work composed for the occasion. Tellingly, Lucier staged the concert at the Rose Art Museum at Brandeis rather than the music department, sensing a lack of interest from his colleagues.[43] *Music for Solo Performer* has since been credited as the first musical composition to incorporate the use of amplified brainwaves, influencing a large number of works from the mid-1960s onwards, many of which utilised a combination of brain rhythms, bio-feedback, synthesisers and meditative states.[44] However, unlike many of those works, Lucier was not interested in exploring bio-feedback, but rather in transplanting the conditions of a subject undergoing an EEG into a performance setting: "What I cared more about was the feeling of the person in that particular situation - the person sitting there without having to make a single muscular motion, yet showing something, unobserved, I mean that you cannot observe from outside. It's a very intimate situation."[45] This desire to make the 'hidden' in some way manifest would emerge as a major theme in Lucier's subsequent compositions.

With *Music for Solo Performer* a number of key factors begin to emerge in Lucier's work, specifically in relation to materials, performance situations, and the manner in which an artist or composer exercises control over their compositions. It is indicative of a developing theme of *impersonality* within Lucier's aesthetic. This trend had been heavily influenced by Cage, who called for the restraint or withdrawal of the personality of the composer in relation to the work. Cage proposed that a composer should "give up the desire to control sound, clear his mind of music, and set about discovering means to let sounds be themselves rather than vehicles for man-made theories or expressions of human sentiment."[46] Given this statement, a composition such as *Music for Solo Performer* - where percussion instruments were activated at a distance by variable brain rhythms attained through repose - can be seen as a prime example of the kind of musical situation Cage had espoused.

This aesthetic of impersonality had a number of outcomes. Firstly, it served to *depersonalise* the relationship between a given composition and the sounds it produced, and therefore served as a mechanism for drawing attention away from notions of personal expression and onto a consideration of sound as the subject of the work itself.[47] This distanciation of the composer was apparent in *Music for Solo Performer*, which was more akin to a process for generating sonic events than a singular completed artwork. Secondly, the processural nature of the work also meant that performers were placed in an impersonal relationship to the sounds they produced. Where traditionally a musician executed a specific realisation of a given work, the performer of *Music for Solo Performer* was a participant in a procedure of which the exact outcome was undetermined. Further, the stress on process democratised the relationship between artist and audience through the common activity of listening, as any knowledge of a given work could only be obtained through auditing the process in real time; performers were no more privy to the unfolding of the sounds of the work than the audience.

Of course, the use of brainwaves themselves is hardly impersonal - in fact they are deeply personal; but an examination of Lucier's use of the EEG is crucial for understanding how this notion of impersonality also extended to the tools he used for realising his compositions. As mentioned earlier, Lucier had been casting around for ideas linked to 'found' or pre-existing equipment, but in *Music for Solo Performer* he not only employed 'found' equipment in the form of the electroencephalograph, through transferring the EEG procedure onto the concert stage he also used an equally 'found' situation:

> The brainwave piece is really not much more than the EEG situation that is carried on every day all over the world. In that sense it's simply EEG, sensing the brainwaves. But when you do an EEG on somebody, you hide it. I mean it's in a hospital, and the people who do those things don't care about the situation; they care about the results... they pass by the doing. And they do it right, but I'm interested in the fact that they do it and what the human situation is of that person whose having the EEG, so I just think of it as a piece of art.[48]

Appropriating what he describes as the 'EEG situation' provides Lucier with the key sense of distance, using the EEG apparatus as a method of investigating the relationship between performer and instrument. Beyond the simple transplanting of the EEG situation from hospital to concert hall, a crucial part of this transformation of a medical event into an artistic one lies in Lucier's overturning of its basic function. Rather than visualising brainwave patterns, the amplified electrical signal of the EEG is used to sound instruments, effectively shifting the emphasis from deriving an outcome (measurement, diagnosis) to an investigation or display of process (relaxing, being attentive). As such it is the first of a number of Lucier's pieces which recontextualise the situations and tools of scientific inquiry, all of which maintain a similar approach in terms of how they recontextualise pre-existing situations.

Lucier's use of everyday or pre-existing situations as artistic materials finds parallels in the work of Allan Kaprow, and his 'happenings' and 'environments' of the late 1950s and 1960s. A former student of Cage, Kaprow employed chance, indeterminacy, and open ended structures in his works that endeavoured to collapse the distinction between audience and artist through audience participation.[49] By drawing on commonplace scenarios, locations and objects as inspiration, Kaprow aimed to democratise artistic participation through the capitulation of the category of art into the activities of everyday life (and vice versa). Similarly, Lucier drew everyday elements and situations from the contemporary technologised landscape onto the concert stage for *Music for Solo Performer*.

The use of the EEG reflects an emerging consideration of environmental factors in Lucier's work, and in the encounters between technologies and the environments in which they appear. Drawing out the nature of this relationship is pivotal as it is addressed in many of Lucier's works following *Music for Solo Performer* in their explorations of the behaviour of sound in space. Procedurally, Lucier does not draw a distinction between his compositions that use non-musical technology and other more traditional or historical artistic practices.[50] In proposing and developing his theory that his artwork is a specific response to his environment, he undercuts the idea that technology might be a condition or force imposed from without. Rather than glorifying technology for technology's sake, Lucier's stance is attributable to his acknowledgement of the prevalence and pervasiveness of technological artefacts in everyday life. For Lucier, any artwork that incorporates such artifacts is simply an example of an artist drawing inspiration from their surroundings: "We're born and brought up in a landscape... If you worked in a medical centre EEG would be just like a tree; it's what you see every day. And it's touching: a composer in the 19th century is talking about the landscape that he's in; the trees and the poetry - and I'm just doing that."[51] For Lucier his reflection on people's everyday experiences with technology has transformed his conception of technology in general: "I don't think of technology as technology. I think of it as landscape."[52]

This subsuming of technology into the category of landscape has some specific outcomes in developing the theme of impersonality in Lucier's work. It serves to both normalise technology through presence, familiarity, and through persistence on one hand, while (by the very same mechanism) serving to technologise the landscape on the other. It also proposes that everyday technology is not separate from the environment, but instead forms one of its constituent parts. Rather than regarding terms such as 'landscape' and 'environment' solely as representative of attributes of the natural world (with perhaps the inclusion of the built environment), Lucier's environment encompasses the synthetic objects within it. For Lucier, a pre-existing technological artefact, such as the EEG, is encountered by him as a feature in this landscape, and its existence would no more constitute an act of intentionality on his part than the presence of geographical features, or animals and plants. Therefore, employing pre-existing materials to create an artwork or composition, as opposed to designing or fabricating one's own, makes the use of found technology another mechanism through which Lucier's aesthetic of impersonality or distanciation could be realised.

Music for Solo Performer is one of two early works that draw on what could be described as 'natural' forms of electrical energy. The second of these was *Whistlers* (1966), a work that was later withdrawn by Lucier. *Whistlers* derived its sounds from "the spinning electromagnetic fields above the Earth" (more commonly referred to as audio frequency range electromagnetic phenomena), with the title itself taken from the name given to the sound made by lightning strikes in the ionosphere.[53] Although the composition called for live performers to electronically process the electromagnetic disturbances as received through radio antennae, the difficulty of obtaining clear signals due to weather, electrical interference or the built environment meant that the work instead received presentations as a tape piece.[54]

Whistlers and *Music for Solo Performer* are in some ways parallel compositions as they both tap into naturally occurring electrical phenomena - 'found' sources of electricity. Similarly, they both rely on materials for sound production that are 'hidden' and difficult to access. Then again, in terms of the proximity of those sources, they represent the opposite extreme cases, with one utilising the electrical discharge captured from inside the brain, where the other sources its electricity from the outer layers of the earth's atmosphere.

Lucier presented *Whistlers* as a tape piece at the First Festival of Live-Electronic Music in 1967, which was presented by the Department of Music at the University of California, Davis and the Mills College Tape Centre, Oakland California.[55] The three-day concert series included performances by Robert Ashley, Larry Austin, David Behrman, Toshi Ichiyanagi, Gordon Mumma, and David Tudor.[56] Lucier had strengthened his association with Ashley, Mumma and Behrman the previous year, having invited them to perform at a second concert he staged at the Rose Art Museum following the success of Cage's visit in 1965. Sharing a common interest in live electronics, they formed the Sonic Arts Group (later the Sonic Arts Union) an umbrella term under which they each maintained their distinct compositional presence, but which allowed them to share equipment and assist each other in performing their works in concert, a practice they would continue until the mid 1970s.

In examining the works that followed *Music for Solo* Performer and *Whistlers*, Lucier has himself identified four themes under which his resulting compositions can be grouped (although there are a small number of works which inevitably fall outside this categorisation): (1) the exploration of the acoustic characteristics of natural and architectural spaces; (2) the modification of the human voice by electronic means; (3) the visualisation of sound, and; (4) the exploration of the spatial characteristics of sound itself.[57] The remainder of this chapter will examine primarily the works which correspond to the first two themes, all of which were composed before Lucier began to use sine tones, in order to investigate how these works incorporate and extend his approaches to technology, environment and composition first developed in *Music for Solo Performer*. Further, by charting the shift in the types of sounds found in his compositions - from short clicks to the prolonging effects of resonance - it also illustrates Lucier's gravitation towards the use of continuous sounds, one pointer towards his later use of sine waves.

Articulating spaces

Although not specifically included in the category of works that deal with what Lucier has termed 'articulating spaces,' but none the less a clear precedent, is *Shelter* (1967), "for vibration pickups, amplification system and enclosed space."[58] In what Gordon Mumma has described as "musical seismology," an audience in a dark and quiet room or structure experienced the ambient sound events or planned performances taking place outside. The minute vibrations caused by these external sound events were picked up by sensors attached to the inside walls and surfaces before being amplified and fed to loudspeakers, so that the audience heard sounds altered by the physical characteristics of the materials through which they had travelled.[59] *Shelter* effectively inverts the situation of *Music for Solo Performer* through internalising sounds from outside the audience's location, rather than externalising the inner rhythms of the brain out into the concert space. As the work incorporates the amplifying of very small phenomena with the modification of sounds filtered through architectural materials, it is another example of Lucier emphasis of notionally inaudible or 'hidden' sounds. *Shelter* also forms a bridge between the earlier compositions that utilised the acquisition and amplification of vibration via technology, and the following works that explore the potential for physical spaces to be used as acoustic modifiers.

Chambers (1968) more explicitly investigated the interactions of sounds with their immediate environment. Found objects such as bottles, seashells, suitcases, and teapots, were treated as portable environments, and made to sound by placing small battery-operated devices inside them, such as radios, cassette recorders and mechanical toys. Lucier initially conceived of *Chambers* as a work for blown conch shells, where performers would move about outside, exploring their environment, all the while maintaining communication with each other through sound. While listening out for the sounds of other performers, Lucier noticed the effects of resonant characteristics of the physical environment, as ambient sounds such as the tyres of passing trucks would seem to take on the same pitch as the tone from the blown shells.[60] In incorporating this effect into his work on a smaller scale Lucier produces what he describes as a series of "rooms within rooms which impinge their acoustic character upon each other" as recorded or transmitted sounds from one environment were played back and modified inside another.[61]

Resonance plays an important role in *Chambers*, as it is the effects of resonance on the sounds played inside each of Lucier's portable environments that provided their individual 'acoustic character'. Resonance is the intensification and prolongation of a sound by reflection, and is an important aspect of the propagation of sound in space. The effects of resonance are determined by the physical properties of spaces - whether they are rooms, seashells, bottles or musical instruments. Factors such as the volume of a space and the materials of which its surfaces are comprised determine which frequencies within a sound will be reflected or amplified, and which frequencies will be absorbed or reduced in amplitude, resulting in an alteration of timbre. As a consequence of resonance, the physical properties of spaces are imprinted upon the sounds that occur within them.

Chambers had parallels to *Music for Solo Performer* in that they both involved the sounding of a variety of resonant objects. However, in *Chambers*, the focus was not so much on the mere fact of resonance or sounding, but on the transformations performed on sounds brought about by resonance: in recognising the changes in timbre by the attenuation or amplification of particular frequencies due to the physical properties of the object being sounded.

Lucier places considerable importance on using found materials as a way of emphasising the nature of the acoustic phenomenon he is aiming to investigate: "One could conceivably build an environment that would do specific things to sounds but I'm not interested in that. I don't want to change anything. I simply want to find out what these environments do to sounds, so it's to my advantage not to make but to take what I can find, and in that way each performance will tell me something."[62] Intervention on the part of the composer would only serve to cloud the aim of the piece, which with *Chambers* is the highlighting of the transformative effects of resonance.[63]

Lucier's next work, *Vespers* (1968), would expand from the use of miniature environments, to 'exploring' an entire room with sound. It is a work for "acoustic orientation by means of echolocation", its title chosen to pay homage to the common bat of the family Vespertilionidae and to the "sanctifying atmosphere" of the Catholic evening service.[64] *Vespers* involved the use of hand-held echolocation devices called Sondols (*son*ar *dol*phins), which had been developed by Listening Incorporated, an electronics company in Arlington, Massachusetts, involved with researching dolphin sounds.[65] The Sondols had been designed for use by boat owners, acoustic architects and the blind, and consisted of a pulse-wave oscillator housed inside a cylindrical body with a metal speaker at one end. Apart from an on/off switch, the sole control was a dial for manually adjusting the rate of the pulses.[66] In operation the Sondols emitted a high-intensity, directionally-focused click, which produced echoes by bouncing off surfaces in the environment. Lucier found that by listening to minute modifications to the pulse wave it was possible to gather information about his surroundings and the objects within it using only sound: "You could go outside and send these pulses out, and with the echo you could hear the trees. You could hear trees and you could hear buildings with the echoes that came back to you. The sound of glass is different than the sound of wood. The pulses get squashed... when they strike something, and they change a little bit when they come back to you."[67]

Vespers was inspired by the work of biologist Donald R. Griffin and his book *Listening in the Dark*, which detailed his research into the use of sonar by bats in navigation and hunting.[68] Lucier was struck by this functional role for the sounds produced by animals such as bats and dolphins, which rather than being used as a means of communication, was instead a method for gathering information about their environment, an idea he subsequently incorporated into *Vespers*.[69] Using the Sondols, blindfolded performers negotiated their environment by listening to the echoes of the clicks returning from the surfaces within the performance space. By adjusting the rate of the outgoing clicks in response to the returning echoes, performers slowly scanned their surroundings and the objects contained within them with sound, building a representation of the space by means that Lucier likened to a kind of 'sound-photography.'[70] Lucier stresses the task-like role of the performers in carrying out the echolocation: "They shouldn't just play the instruments as instruments, they shouldn't decide to speed up or down for musical effect. That kills the performance immediately. It has to be based on survival and task."[71] The actions of the performers in effect became a mechanism for focusing audience attention onto an acoustic phenomena usually discounted in traditional musical listening - the behaviour of echoes in space. In order to refine their technique, Lucier suggested performers draw from other "experts in the art of echolocation in the animal kingdom."[72] However, where animals such as bats and dolphins use ultrasonic sound, *Vespers* employs sounds in the human audible range. As such, the process of making audible the ultrasonic sounds of animal echolocation involved a transposition downwards in pitch from the 'inaudible' (in human terms) to the audible clicks produced by the Sondols.

The relationship between performer and score was important in determining the part depersonalisation played in *Vespers*. The significance Lucier places on impersonal, task-like performance in *Vespers* finds a parallel in the description of performance given by Richard Schechner, based as it is in notions of distanciation. Schechner uses the term 'restored behaviour' to define the relationship between performer and role.[73] Restored behaviour is likened to a costume or mask, in that it can be put on and taken off, creating a distinct definition between role and individual. For Schechner, this distance allows for an externalised, impersonal, and malleable relationship between performer and text: "[restored behaviour] can be seen from the outside, and changed... [and] a score can change because it's not a 'natural event' but a model of individual and collective human choice."[74]

In 'putting on' their role as echolocators, performers needed to be able to oscillate between performing their role as 'bat impersonator' and monitor their own auditory perception for the acoustic effects of reverberation and echo. Although the performers' role is to elucidate those same acoustic phenomena for an audience, the work itself is basically a frame or mechanism for calling attention to those events, not a staging of bat impersonations. Introducing the task of echolocation is instead a means for performers to fulfill the requirements of the work without recourse to either improvisation or traditional musical language. That the architecture, rather than the performers, was responsible for producing the acoustic phenomena further served to depersonalise the sound world of *Vespers*.

Vespers is the first of three works that can be characterised as compositions that produce acoustic responses from environments realised via the transformation of projected sound. It also introduces two important themes in Lucier's work, most clearly manifest in the sound of the Sondols: the use of what might be considered simple, non-musical sounds, and the use of repetition. In the synthetic sound of the pulse wave, Lucier found a technical, utilitarian sound, one he considered to be free of any qualities that could be associated with musical character or expressiveness. This was then used as a kind of neutral trigger, accentuating his goal of making echoes, not the activating sounds, the primary focus of the work. Lucier's score does allow for the use of other sound sources in the absence of Sondols, such as tongue-clicks, finger-clicks and footsteps (which even in their human origins retain a certain impersonality through their commonality), toy crickets, and "portable generators of pulsed sounds, thermal noise or 10 kHz pure tones."[75]

Repetition played a crucial role in hearing and assessing the acoustic effects realised in *Vespers*. As the Sondols generated chains of identical pulses, both the audience and performers could more easily perceive the modifications to these 'trigger' sounds caused by the effects of resonance. As a portable piece of technology, the Sondols provided not just repetition, but repeatability - a baseline sound or tool that could then be used for the acoustic scanning of different performance spaces, allowing for the acoustic characteristics of each space to define the sonic content of each performance.

In *Vespers*, Lucier emphasises the importance not of the sound projected (the initial sound, the question) but of the echo, the response - and in realising this aspect of the work both performers and audience members are asked to be attentive to the effects of the environment on sounds. While these environmental phenomena can be easily described in terms of cause and effect (pulses of sound echo off walls and objects), *Vespers*, along with the following works for articulated spaces, function through these processes of repetition (here through the use of synthetic sound) and transformation (by the acoustic properties of the spaces).[76]

Processes of repetition and transformation come to the fore in *"I am sitting in a room"* (1970). Although commonly dated to 1970, the first version of this piece was made in 1969 in the Electronic Music Studio at Brandeis University, shortly before Lucier left to take up a position at Wesleyan University in Middleton, Connecticut.[77] One of Lucier's best known works, *"I am sitting in a room"* is a tape piece, and begins with Lucier reading a short text that in many ways serves as the score:

> I am sitting in a room different from the one you are in now. I am recording the sound of my speaking voice and I am going to play it back into the room again and again until the resonant frequencies of the room reinforce themselves so that any semblance of my speech, with perhaps the exception of rhythm, is destroyed. What you will hear, then, are the natural resonant frequencies of the room articulated by speech. I regard this activity not so much as a demonstration of a physical fact, but more as a way to smooth out any irregularities my speech might have.[78]

Unlike the previous works, which utilised relatively specific and in some cases esoteric electronic equipment (electroencephalographs, Sondols, antennae, sensors), *"I am sitting in a room"* employs readily available technology, requiring two tape recorders, a microphone, amplifier and loudspeaker. Lucier recorded the initial statement onto one tape recorder before playing it back into the space through a speaker placed in the position where he had been seated. As the statement was replayed through the speaker, it was recorded through the microphone onto the second tape recorder. This section of tape was then removed from the recorder and spliced onto the reel of the first recorder. The new recording was then played, and the process repeated.[79] When all of the recordings were edited together in sequence, they became a document of the sound of a human voice being replaced by the gradual imposition of the resonant 'signature' of a room. As the statement is played into the room through a loudspeaker, the room acts as a filter, modifying the speech sounds. Each iteration of this process moves the sound one step further along a path from intelligibility to unintelligibility, until the clearly enunciated words have been transformed into a continuous, complex melodic and harmonic flow, with only the ghost of the initial cadences to remind us of their origins.[80]

"I am sitting in a room" slowly plays out a series of interactions between the human voice and its surroundings, as it is the frequencies present in the recording that correspond to the resonant frequencies of the room are repeatedly reinforced, while all others are slowly attenuated. As such the work delivers an intimate portrayal of the sonic possibilities contained in architecture as it explores the relationship of sound to space, enacted in the relationship of frequencies to dimensions. *"I am sitting in a room"* is equally an exploration of the process of recording itself, as each time the microphone and tape recorder captures the sound from the speaker, it re-structures the properties of the sound according to its technical limitations.

Although he had initially experimented with a range of different sounds, Lucier settled on speech, as it was "common to just about everybody" whilst also being "extremely personal".[81] Lucier himself has a speech impediment, and his stutter lends the piece its own unique rhythmic formations. The use of voice as the source sound for articulating the resonant characteristics of a room is pivotal, as it contains a broad spectrum of frequencies. The process of activating the sound of the room has two distinct aspects. On one hand it is a process of reduction through progressive cancellation, as frequencies that do not match the resonant modes of the room are gradually pared away. On the other it is a process of elongation, as the frequencies contained in speech sounds that match those of the room are reinforced and their durations prolonged through the effects of resonance. As it bounces from wall to wall, the room is rung like a bell by vocal sound.

Even though *"I am sitting in a room"* is a work for audiotape, its gradual shift from 'voice sound' to 'room sound' slowly confounds any notion of linearity. Initially *"I am sitting in a room"* is profoundly linear, with the changes from one repetition to the next easy to follow. However, as the intelligibility of individual words begins to break down, the distinction between one iteration and the next begin to blur as the sound of the room begins to assert itself. Any imperative to track the progressive changes eventually breaks down, and the audience is instead invited to listen to the effects of this approach to making sound: continuous ringing clusters of bell-like reverberations. As the sounds move from the personal speaking voice to the impersonal sound of room resonance, it similarly enacts a shift from the sequential to the spatial. This gradual shift from 'voice sound' to 'room sound' via microphone and speaker in *"I am sitting in a room"* enacts Lucier's impersonal aesthetic, shifting emphasis away from the prominence of the composer or the performer onto spatial and situational factors. The process of sonic recycling in *"I am sitting in a room"* performs the same role as the task of the echolocating performers in *Vespers*, where the focus is on the execution of the procedural aspects of the composition, rather than the attainment of any particular end goal state. In the gradual evocation of room resonance, *"I am sitting in a room"* exposes its mechanism of transformation, and highlights Lucier's increasing orientation towards process-based works.

The piece was often accompanied in concert by the slide-projection work *Room* (1969), by Lucier's then wife, the sculptor and photographer (and later video artist)

Mary Lucier. *Room* subjected a black and white Polaroid photograph of the room in which Lucier had made his recordings to a parallel process of reduplication. These images were then transferred to slides for projection. With each re-photographing errors in alignment between camera and photograph gradually enlarged and distorted the original image, until pictorial representation gave way to abstraction.[82]

Where *Vespers* extended clicks into echoes, and *"I am sitting in a room"* extended the duration of speech sounds through the effects of resonance, *Quasimodo the Great Lover* (1972) employed both echo and reverberation to extend not only the duration but the location of sound. The work was influenced by recordings of the sounds of humpback whales made by biological acoustician Roger S. Payne, which Lucier first heard at a lecture given by Payne at the University of California in 1969.[83] Lucier was impressed not only by the whale sounds themselves, but by the ability of whales to communicate with each other by sending sounds over great distances. The velocity of sound in water is approximately four times that of air, and researchers have recorded whale sounds travelling over 100 kilometres.[84] The title refers to the hunchbacked bell-ringer from Victor Hugo's 1831 novel *Notre-Dame de Paris* (and therefore to another means for communicating sonically over long distances), and alludes to the role that 'whale song' is thought to play in mating.[85]

Quasimodo the Great Lover, like *"I am sitting in a room,"* makes use of commonly available sound equipment. A number of separated spaces were connected in sequence by a relay system of microphones, amplifiers and loudspeakers. Performers produced sounds in one space that were captured by the microphone and reproduced in a second space through a loudspeaker. This sound was then captured by another microphone and transferred to a third space, and so on, passing through a succession of spaces before reaching the audience. As the sounds travelled through each individual space they became progressively transformed by the acoustic properties of the environments and of the sound equipment. Lucier encouraged using not just 'designed' spaces such as rooms and corridors, but natural spaces such as canyons and wooded areas. He also allowed for variations in the amplification system, such as the use of loops for recycling sound back into particular spaces, and for the intersection of two or more chains of microphones and speakers.[86]

In *Quasimodo the Great Lover*, performers are asked to use the calls of humpbacks as a model for their own sound production, such as strings of short pulses, and upward and downward sweeping tones.[87] For his own performances Lucier settled on the use of whistling sounds, as his initial inclination to use vocal sounds produced results he described as "awkward and grotesque" and indicative of human expression.[88] Unlike the complex vocally produced sounds, whistling also yielded a simple sound against which the superimposition of spatial signatures could be more easily distinguished. As in *Vespers* performers were presented with the task of elucidating the acoustic characteristics of the spaces through which their sounds travelled by forming successions of sound events where "each event within a set is subject to gradual, repetitive, and cumulative variation."[89] This meant a progressive alteration of the sound in terms of its duration, pitch and volume so as to highlight the relationship between the "original sound event, its change, and the environments through which it travels."[90] Each sound was to be gradually extended in duration until it and the resulting echoes and reverberations overlap. Similar to the gradual effacement of vocal sound in *"I am sitting in a room"*, this process again shifts focus away from the 'instrumental' sound, casting it as a kind of stimulus, and onto the effects that it produces within this system. So with *Quasimodo the Great Lover* even the 'personality' of instruments is reduced in order to clearly realise the acoustic phenomena that form the subject of the composition, and to provide sufficiently depersonalised material with which to work.

Michael Nyman points out that *Quasimodo the Great Lover* is the obverse of what he refers to as the 'enclosed-space' works, such as *Vespers*, in that sound is conveyed from the place of performance to listeners situated at a distance.[91] The enclosed-space works also constitute closed systems, particularly *"I am sitting in a room"*, unlike the open structure of *Quasimodo the Great Lover* which makes allowances for the inclusion of incidental and environmental sounds to be incorporated within the piece. Perhaps of greater importance is the different ways that these open and closed systems transform the sounds that occur within them. Whereas the reductive process of *"I am sitting in a room"* gradually breaks down the complex frequency mix of the human voice via room resonance, in *Quasimodo the Great Lover* a simple sound gradually increases in complexity due to the accretion of echoes and reverberations.[92]

In fact, there was a progressive extension of the duration of sounds in this series of compositions, starting with the introduction of repetition of sounds of an extremely short duration (*Vespers*), the extension of duration through the effects of resonance and the use of recording technology (*"I am sitting in a room"*), and then through the gradual elongation of source sounds coupled with the prolonging effects of reverberation (*Quasimodo the Great Lover*). As they approach their conclusion, two of these works (*"I am sitting in a room"* and *Quasimodo the Great Lover*) gradually bring about the conditions of constant sound, a precedent for Lucier's later use of continuous sounds such as feedback and sine tones. In all of these works, sound is employed in a functional way, as a kind of tool or stimulus. However, while electronically generated sound is ostensibly being used for echolocation, activating resonant frequencies, smoothing out vocal irregularities, or communicating over long distances, in all cases its main role is to help produce effects which bring the otherwise 'hidden' behaviour of sound in space to the fore.

Altering vocal identities

Whereas the first group of compositions focussed on interactions between sound, space and environment, the works that explored the "modification of the human voice by electronic means" formed a series of exchanges between vocal sound and technology.[93] Compared to many of the works already surveyed, these works required a much more 'hands on' manipulation of electronic equipment. In all of these works electronic technology replaced the role that space and architecture played in the previous works, in that the technology itself functioned as the agent of transformation. However, with these works there was a tension between the performance of the initial vocal sounds and the control of the means of sonic modification, as in each case the manner in which the electronic devices were manipulated was in itself performative.

Lucier has stated that his interest in working with the voice stemmed from the peculiarities of his own speech.[94] He has described these works as effecting the "alteration of vocal identities", and issues relating to the efficacy of speech sounds as a mechanism for conveying meaning and identity are explored differently in each work.[95] *North American Time Capsule* (1967), for voices and vocoder, was a kind of poetic repository where performers used vocal sounds and the sounds of instruments and objects around them to "describe for beings far away from the earth's environment either in space or in time" their social and cultural surroundings.[96] Although initially conceived of as a live performance work, it is better known from the recorded version Lucier made in 1967 with the assistance of members of the Brandeis Chamber Chorus and other Brandies students. This recording was made using an experimental vocoder (*vo*ice en*coder*) developed by Sylvania Applied Research Laboratories in Waltham, Massachusetts.[97] The vocoder is an electronic device for encoding speech into digital form and for resynthesising encoded messages into artificial speech, and were principally designed for making secure voice communication over telephone lines. By presenting listeners with an encoding without a subsequent decoding, *North American Time Capsule* confounds the intended function of the vocoder, recasting a secretive communications device as a generator of synthetic sound.

For the recording of *North American Time Capsule* Lucier used not one but three voices as his audio input, each entering at a different stage of the digitising process. Each voice was responsible for determining a separate characteristic of the information to be encoded: the first voice provided the spectrum of sounds to be analysed; the second the pitch; and the third the distinction between voiced and unvoiced or 'noise' sounds.[98] The output was a composite sound formed through this imposition of one vocal quality upon another. The output was further modified through the addition or removal of band pass filters, alterations to filters in the spectrum analyser which affected spectral resolution, and manual adjustments to pitch and sample hold. The recording used eight channels of material and produced a jittery hubbub of robotic twitters and hushed machine utterances bordering on glossolalia - humorously garbling the vocal distinctions of spoken and whispered, tone and noise, pitched and unpitched. Despite the amount of electronic modification involved, Lucier noted how the processing revealed the "rhythmic strength of human language."[99] This phenomenon would later recur in "*I am sitting in a room*", where the rhythmic markers of speech would still be evident after numerous iterations.

North American Time Capsule was Lucier's first commercially available recording, appearing on the compilation record *Extended Voices: New Pieces for Chorus and for Voices Altered Electronically by Sound Synthesizers and Vocoder*, part of the renowned "Music of Our Time" series for Odyssey Records. The album was effectively a contemporary survey of experimental practices of voice and electronics interaction, and placed Lucier's work alongside compositions by Robert Ashley, John Cage, Morton Feldman, Toshi

Ichiyanagi and Pauline Oliveros, and performances by David Tudor and Gordon Mumma.[100]

Lucier's subsequent compositions explored the relationship between vocalist and vocal identity from opposite angles - first by removal, then by impersonation. Where *North American Time Capsule* requires the intimate involvement of a performing, controlling hand in the operation of the vocoder, *The Only Talking Machine of Its Kind in the World* (1969) instead necessitated a stuttering or lisping speaker to reveal their intimate speech patterns to an audience. To perform a progressive depersonalisation of the speaker's vocal idiosyncrasies, a tape delay system constructed during the performance by other players recirculated the speech in order to iron out any anxiety caused by public speaking. In *The Duke of York* (1971) a vocalist and a 'synthesist' worked together to produce a representation from their combined memories, rendered in sound. The vocalist aimed to mimic as accurately as possible the sounds from a range of preselected material such as popular songs, speeches and passages from books, film, and television.[101] Using a synthesiser, the second performer made alterations to pitch, timbre, range, envelope, vibrato and echo to align the sounds of the vocalist with their own particular memories of the original. Once an alteration had been made by the synthesist, it remained in effect for the duration of the performance, forming what Lucier termed "layers of partial identities."[102] The end result of this process was the construction of a "composite vocal image" formed from the memories of the two performers.[103]

While still largely a task-orientated work, *The Duke of York* relied heavily on the personal talents of its performers. As a setting for vocalist and accompanist, it also presented a far more traditional image of a musical performance than his other compositions surveyed so far (despite Lucier's claim that the synthesists role is essentially a non-musical one). In order to realise its goal of vocal simulation, it drew on both the vocalist's talent to assume and convey the 'vocal identity' of the original material, and the capacity of the synthesist to respond to and modify the voice to match their own particular set of memories that related to those songs or sounds. Unlike the gradual process of depersonalisation of speech that occurred in both *"I am sitting in a room"* and *The Only Talking Machine of Its Kind in the World*, there was a continuous oscillation between the intimate nature of memory and the impersonal processes of mimicry and electronic synthesis. However, just as the 'composite identity' of a real or imaginary person was constructed from a succession of vocal traces dispersed within a profusion of synthetic sound, any vestiges of the performers' traits became similarly dispersed throughout the work.[104]

The increasing availability of portable analogue synthesisers in the early 1970s, such as the MiniMoog and the ARP, made the live performance of works such as *The Duke of York* possible. Lucier saw the real-time, voltage-controlled aspects of the electronic synthesiser as emblematic of the "American idea" of electronic music, as opposed to the tape spliced, collage compositions from the European studios.[105] However, *The Duke of York* was also an American work in another way; in exploring the evocation of memory as sound, it was intimately tied to the American popular culture milieu, which was (and is) saturated with forms of representation and recording.

As mentioned earlier, there is a difference in the way Lucier's aesthetic of impersonality was enacted in these works compared to the works for articulating spaces, partly because each piece involved a greater manipulation of complex electronic equipment on the part of the performers. All these compositions use the human voice as their starting point, implying at least some small amount of association between the vocal sound and its personal origin. Just as electronic technology replaced the spatial and architectural as the agent of transformation in these works, Lucier's aesthetic of impersonality would also be realised through the performers' involvement with technology.

All three works approach impersonality and identity in different ways. The interaction, or rather the interjection of voices and vocoder of *North American Time Capsule* produced an undecoded multiple output; individual identity was scrambled at the point where three voices attempt to occupy a single channel of communication. *The Only Talking Machine of Its Kind in the World* disguised personality in the therapeutic, as personal idiosyncrasies of speech were dispersed through a network of iterations, thus de-emphasising the 'problematic' speaker as their originator. In *The Duke of York* individual memories became subsumed into a multiple, synthetic identity. Just as the technological was substituted for the spatial as the agent of transformation, it also became the mechanism for providing the essential distance between the intimate vocal sounds of the performer and the requirements of the composition.

Although *North American Time Capsule* maintained a scramble of pitches, noises and vocal rhythms for its duration, both *The Only Talking Machine of Its Kind in the World* and *The Duke of York* produced a gradual progression from regular speech sounds to complex synthetic textures. They also shared many of the same hallmarks of process found in *"I am sitting in a room"* and *Quasimodo the Great Lover*; a simple sound input (speech, whistles), which was transformed over successive iterations, sometimes to unintelligibility, as a means of highlighting the nature of the processes involved, be they physical or technological.

'Seeing' sounds

In 1972 Lucier began a series of works that dealt specifically with the visualisation of sound. The first of these, *The Queen of the South* (1972), again saw Lucier drawing inspiration from scientific experiments and procedures, just as he had previously with the use of the EEG for *Music for Solo Performer*. Lucier is upfront about the influence of scientific experiments and demonstrations of acoustical phenomena, claiming that he does "little more than frame them in an artistic context."[106] With *The Queen of the South*, and all of the later works in the visualisation series, the didactic component of Lucier's aesthetic would become more apparent, much in the same manner as the acoustic phenomena he is aiming to produce for the audience. Rather than aiming to refocus the audience's collective ear onto a particular activity of sound, the works in this series are attempts by Lucier to display visually the effects of sound that he found so captivating. In effect, it literalises his aim to reveal the hidden aspects of sound.

The Queen of the South called for a surface such as glass, wood, or steel strewn with small grains or powder to be excited by sound. This formed the strewn material into shapes determined by the resonant modes of the surface. The piece drew on the vibrating steel plates of eighteenth century acoustician Ernst Chladni, but also importantly on the twentieth century visualisations of sound by Swiss physician and natural scientist Hans Jenny (1904-1972).[107] Jenny, an adherent of Anthroposophy, had taught science at the Rudolph Steiner School in Zurich for four years before beginning his medical practice.[108] Following Steiner's lead, Jenny posited that periodic phenomena underpinned human existence, and were evident at every level of being, matter and area of investigation.[109] Jenny pioneered the field of 'Cymatics' (from Greek *kyma*, wave) - which he described as the study of the effects of vibration - and considered the visualising of sound as a key method of giving "tangible expression" to the phenomenology of vibration.[110]

Jenny's investigation primarily explored the effects of sound in the acoustic and lower ultrasonic range on a variety of vibrating solids such as sand, quartz sand, and

Lycopodium powder (spores of the club moss), along with other mediums such as mercury, glycerine, and gases.[111]Much of his work involved the vibration of steel plates using piezoelectric, or crystal, oscillators, to 'irradiate' materials into motion. The results present an astonishing catalogue of wave shapes, nodal patterns and vibration models. In schematising his research, Jenny defined a "triadic phenomena of vibrational processes": periodicity, pattern and kinetics. Together they formed a "threefold unity" where "the three fields - the periodic as the fundamental field with the two poles of figure and dynamics - invariably appear as one." [112] This in turn functioned as an ontology that combined any and all periodic function, from histology, cell physiology, morphology, biology, to geology and mineralogy, atomic physics and astronomy.

Apart from its metaphysical aspects, Jenny saw a pragmatic role for his visualisation procedures. He developed the tonoscope - an acoustic instrument for observing vibrating materials, consisting of a diaphragm stretched across a simple resonator - which could be used for teaching the deaf to speak by way of providing a visual reference for tone production.[113] Visualisation could also aid aesthetic enhancement, as listeners could train themselves to synaesthetically "hear by seeing". Jenny noted the effects of a Bach toccata and Mozart's *Jupiter Symphony* on a fluid medium: "The vibrational figures appear indirectly in the layers of fluid. They are entirely characteristic of the music being played. However, the eye is unaccustomed to seeing music and is a first lost without the guidance of the ear. But with the ear to prompt it, the eye experiences these tonal events in full visual detail."[114]

Lucier's score bears some of Jenny's influence in its combination of didacticism and self-improvement, exercised through a kind of synaesthesia. The task Lucier sets for performers is "to put sounds into a material and experience the modes of vibration of the sound in that material" and to observe the changes in pattern caused by the interactions of the sounds and the materials.[115] In working together to bring about a range of visual phenomena, performers are asked to "make musical activity either to discover in real time the visual images characteristic of the identity of the performing ensemble... or make pre-determined patterns" listing a range of imagery from currents, vortices, rivulets, and flowers, to crypts, embryos, mirrors, calendars, and stigmata.[116]

For his own realisations of *The Queen of the South* Lucier used a large square of aluminum, glass or wood scattered with sand, tea, coffee, salt or rice.[117] For a sound source, he used electronic sine wave oscillators, as acoustic instruments lacked both the power to effectively move the materials, and the ability to sustain sounds for long periods. "I find that those sustained, continuous oscillator sounds, once you get them started, don't relent, they don't have to breathe, they can really push the grains of sand around on the plate."[118] Also, as the oscillators were connected directly to the plate using audio transducers the sounds were not audible until they were in the material, unlike acoustic instruments. This created a stronger causal relationship between the sounds and the images they formed.[119] Video cameras and monitors were then used to "verticalise and enlarge" the images produced by the vibrating media.[120]

Despite its emphasis on visualisation techniques, *The Queen of the South* has parallels with Lucier's other early works. It has much in common with the 'sound-photography' of *Vespers*, in that 'images' were elicited from an environment using sound. However, in *The Queen of the South* the images are visual and two-dimensional, and the environment a solid medium. As an investigation of the propagation of sound waves in solid materials *The Queen of the South* sees the sound conducting walls of *Shelter* laid flat, but with their role shifted from filtering to patterning; further, the "micro-seismic" activity previously obtained from sounds in the outside environment is instead generated by sine tones. As with the voice pieces, electronic technology provided a large percentage of the transformative aspects of *The Queen of the South*, enacting the synaesthetic aspects of the piece through a series of transductions from one medium to another. However, this was not just a simple transformation from sound to sight, but from electronic sound signals, to mechanical vibrations in a physical medium, to electronic video images. Lucier cites these translations from one medium to another as a crucial part of his reframing process from scientific experiment to artwork.[121]

Perhaps most importantly for this survey, *The Queen of the South* is the link between Lucier's earlier works and his later works - works that explore the spatial characteristics of sound, many of which utilise sine waves. It marks the introduction of sine waves into Lucier's work, which had been selected for both their mechanical and synthetic properties. Where previous compositions affected the progressive extension or prolongation of the duration of sounds through resonant or technological procedures, a constant sound is used here to affect other media. However, just like the brainwaves of *Music for Solo Performer*, sine waves are used as a source of activation - a motor for stimulating resonance - rather than for their specific sonic qualities, making *The Queen of the South* a precursor to later works such as *Music on a Long Thin Wire* (1977). In the use of the interactive effects of sound signals for pattern making, Lucier introduced an interest in interference phenomena, specifically the phenomena of acoustical beating.[122] This indicated a significant departure from his work with voices and spaces, and leads directly into his sine wave works of the remainder of the 1970s and into the 1980s.

[1] Alvin Lucier, "The Propagation of Sound in Space," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 430.
[2] Douglas Simon, "Interviews with Douglas Simon," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 108.
[3] Alvin Lucier, "The Tools of My Trade," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 448.
[4] ibid., 466.
[5] Arthur Margolin, "Conversation with Alvin Lucier," *Perspectives of New Music* 20, no. 1 & 2, Spring-Summer (1981): 52.
[6] Frank J. Oteri, *Sitting in a Room with Alvin Lucier* [pdf document] (2005 [cited May 1 2007]); available from http://www.newmusicbox.com/72/interview_lucier.htm.
[7] ibid.
[8] William Duckworth, "Interview with William Duckworth," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 22. Lucier found the absence of any mention of Ives particularly poignant as he had also been a Yale graduate. Stuart Feder, *The Life of Charles Ives* (Cambridge: Cambridge University Press, 1999), 61.
[9] Duckworth, "Interview with William Duckworth," 24.
[10] Lucier, "The Tools of My Trade," 440.
[11] Margolin, "Conversation with Alvin Lucier," 52.
[12] Alvin Lucier, "Origins of a Form: Acoustical Exploration, Science and Incessancy," *Leonardo Music Journal* 8 (1998): 5.
[13] ibid.
[14] Alvin Lucier, "Thoughts on Installations," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 520.
[15] Oteri, *Sitting in a Room with Alvin Lucier*. 3.
[16] Duckworth, "Interview with William Duckworth," 28.
[17] ibid. Michael Nyman in part traces this disjunction to issues of identity, highlighting the importance the composers of the European avant-garde placed on the ability of a given composition to establish its specific and predetermined identity in performance, in sharp contrast to the kind of indeterminate performance situations Cage's work had inspired. See Michael Nyman, *Experimental Music: Cage and Beyond* (New York: Schirmer, 1974), 9.
[18] Lucier, "The Tools of My Trade," 442.
[19] Peter Manning, *Electronic and Computer Music* (Oxford: Oxford University Press, 1985).
[20] Herbert Russcoll, *The Liberation of Sound* (Englewood Cliffs: Prentice Hall, 1972), 92.
[21] Gordon Mumma makes a case for the prevalence of compositions for instrument and tape music having become almost an international style, stating that between 1955 and 1960 works were produced in Belgium, England, Germany (Mauricio Kagel, Stockhausen), Italy (Luciano Berio, Luigi Nono), the Netherlands, Japan, and the US, with post-1960 additions from Argentina, Australia, Austria, Brazil, Canada, Czechoslovakia, Denmark, Finland, Greece, Iceland, Israel, Mexico, Poland, Spain, Sweden and Yugoslavia. Gordon Mumma, "Live-Electronic Music," in *The Development and Practice of Electronic Music*, ed. Jon H. Appleton & Ronald C. Perera (Englewood Cliffs: Prentice Hall, 1975), 293.
[22] Oteri, *Sitting in a Room with Alvin Lucier*. 3. Lucier, "The Tools of My Trade," 442.
[23] Alvin Lucier, "Notes in the Margins," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 498.
[24] Duckworth, "Interview with William Duckworth," 26. Lists of Lucier's compositions often date *Elegy for Albert Anastasia* from 1962-65. However, the 2002 compact disc release *Vespers and other early works* (New World Records 80604-2) lists the recording date as 1961, with a later remix of the material at the Electronic Music Studios, Brandeis University in 1963. Certainly by any of Lucier's own accounts his visit to Studio Fonologia took place in 1961.
[25] Atelier Post-Billig, *Alvin Lucier - a Sound Waves Artist* (Ubuweb, 2001 [cited August 15 2004]); available from http://www.ubu.com/sound/lucier.html.
[26] ibid.

[27] Cole Gagne and Tracy Caras, *Soundpieces: Interviews with American Composers* (Metuchen: The Scarecrow Press, 1982), 16-17.
[28] David Ernst, *The Evolution of Electronic Music* (New York: Schirmer, 1977), 183.
[29] Lucier's own list of works shows eight compositions between *Elegy for Albert Anastasia* and *Music for Solo Performer*, all for traditional instruments. As mentioned, Lucier puts little stock in his works before 1965, but at least one work - *Action Music* (1962) - had caught the attention of David Tudor, who performed it at the San Francisco Tape Music Centre in 1964. See Pauline Oliveros, "Poet of Electronic Music," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 8.
[30] Alvin Lucier, "Statement On: Music for Solo Performer," in *Biofeedback and the Arts: Results of Early Experiments*, ed. David Rosenboom (Vancouver: ARC Publishing, 1976), 60.
[31] Simon, "Interviews with Douglas Simon," 46.
[32] Lucier, "Origins of a Form," 6.
[33]The three main other forms of brain waves or rhythms are delta (0.5 - 4 Hz - generally associated with sleep); theta (5–7 Hz - light sleep or dreaming); and beta (18 - 30 Hz - active, waking consciousness), although some slight variation (+/- 1 Hz) can be found between descriptions and examples. Erol Basar, *Brain Function and Oscillations Volume 1: Brain Oscillations. Principles and Approaches*, ed. Hermann Haken, *Springer Series in Synergetics* (Berlin: Springer-Verlag, 1998), 34. Descriptions of alpha can also vary - not that attempts to reach consensus have not been made: "The International Federation of Societies for Electroencephalography and Clinical Neurophysiology (IFSECN) proposed the following definition: 'Rhythm at 8-13 Hz occurring during wakefulness over the posterior region of the head, generally with higher voltage over the occipital areas. Amplitude is variable but is mostly below 50 μv in adults. Best seen with eyes closed and under conditions of physical relaxation and relative mental inactivity. Blocked or attenuated by attention, especially visual, and mental effort (IFSECN 1974)'." Ernst Neidermeyer, "The Normal EEG of the Waking Adult," in *Electroencephalography: Basic Principles, Clinical Applications and Related Fields*, ed. Ernst Neidermeyer and Fernando Lopes da Silva (Baltimore: Urban & Schwarzenburg, 1981), 72.
[34] Leonard A Stevens, *Explorers of the Brain* (London: Angus & Robinson, 1973), 206. Curiously, Berger's interest in brain function was allegedly triggered by an episode of 'spontaneous telepathy' experienced by his sister, who believed she had received a mental image of his impending demise on the same day he had been in physical danger during military service. See Stevens, 202.
[35] ibid., 212. The hypothesis that the brain possessed a rhythmic quality - be that electrical or otherwise - has at least one if its origins in 1749, in the writings of English philosopher Dr David Hartley. He applied a distinctly Newtonian model of mechanical motion to the question of brain function. Hartley proposed that mental phenomena were derived from the movements of tiny structures within the brain called *vibratiuncles*. Oscillations and superimpositions of these structures were due to the flow of "ethereal vibrations" from the brain via the nerves, which in turn modulated the nature of thought and perception. By 1791 the electrical aspects of the human body had been confirmed by the experiments of Luigi and Lucia Galvani through their demonstrations of nervous stimulation by electricity. However, English physicist Richard Caton made the discovery that the brain itself was a generator of electric currents in 1875. W. Grey Walter, *The Living Brain* (Harmondsworth: Penguin, 1961), 48. Basar, *Brain Function and Oscillations*, 31.
[36] Simon, "Interviews with Douglas Simon," 48.
[37] Luckily a musical situation seems appropriate for the use of alpha, compared to other activities: "Alpha attenuation due to auditory, tactile, and other somatosensory stimuli or heightened mental activity (such as solving difficult arithmetical problems) is usually less pronounced than the blocking effect with eye opening." Neidermeyer, "The Normal EEG of the Waking Adult," 74.
[38] Lucier describes the EEG set-up borrowed from Dewan: "two Tektonic Type 122 preamplifiers in series, one Model 330M Kronhite Bandpass Filter, which had been set for a range of from 9 to 15 Hz, one integrating threshold switch, electrodes, appropriate connectors, etc." Lucier, "Statement On: Music for Solo Performer," 60.

[39] ibid.,61.
[40] ibid.
[41] Joel Chadabe, *Electric Sound: The Past and Promise of Electronic Music* (Upper Saddle Hill: Prentice Hall, 1997), 96. Lucier has acknowledged that the title *Music for Solo Performer* is actually a misnomer, as an assistant was required to attach the electrodes, and to operate the amplifier controls, routing the alpha signal to different loudspeakers. Lucier did eventually manage to perform a completely solo version in which he was able to randomly adjust the controls without breaking his production of alpha waves.
[42] Lucier, "The Tools of My Trade," 442-44. Interestingly, the meditative state itself may have played a larger role in *Music for Solo Performer* due to its effect on skin conductivity. Studies into the physiological changes brought about in experienced mediation practitioners, such as Buddhist monks, showed that not only did the test subjects produce alpha brain waves, but their skin resistance to electricity increased markedly (sometimes by as much as four times), accompanied by a reduction in heart-rate by approximately three beats per minute on average. So the restful state actually aided not only the production of alpha waves, but also the reception of alpha waves through the scalp. Robert Keith Wallace and Herbert Benson, "The Physiology of Meditation," in *Altered States of Awareness* (San Francisco: W. H. Freeman & Co., 1972), 129.
[43] Lucier, "Notes in the Margins," 498.
[44] For a range of approaches to the use of brain rhythms and biofeedback in composition see David Rosenboom, ed., *Biofeedback and the Arts: Results of Early Experiments* (Vancouver: ARC Publishing, 1976). Also Manford L. Eaton, "Bio-Music," *Source: Music of the Avant-Garde* 5, no. 1 (1971). In the further reaches of scientific research, some have posited an increased potential for self-knowledge in the oscillations of alpha waves; see Elmer & Alyce Green, *Beyond Bio-feedback* (New York: Delacorte Press, 1977).
[45] Robert Ashley, "Landscape with Alvin Lucier," in *Music with Roots in the Aether: Interviews with and Essays About Seven American Composers*, ed. Gisela Gronemeyer & Reinhard Oehlschlägel (Köln: MusikTexte, 2000), 80.
[46] John Cage, "Experimental Music," in *Silence* (Hanover: Wesleyan University Press, 1961), 10.
[47] *Depersonalisation* in this context is understood as the process or means by which *impersonality* is achieved or enacted, as in "to make impersonal", and not in the psychological sense of "to cause an individual to feel non-human", and especially not as a synonym for *dehumanisation.* "Depersonalise", *Macquarie Dictionary*, 3rd ed. 1997.
[48] Ashley, "Landscape with Alvin Lucier," 79.
[49] Allan Kaprow, *Essays on the Blurring of Art and Life* (Berkeley: University of California Press, 1993), 54-55.
[50] Ashley, "Landscape with Alvin Lucier," 83.
[51] ibid.
[52] ibid.
[53] Will Johnson, "First Festival of Live-Electronic Music 1967," *Source: Music of the Avant-Garde* 2, no. 1 (1968): 51. Lucier's later work *Sferics* (1981) shares many of the characteristics of *Whistlers.*
[54] Mumma, "Live-Electronic Music," 332. For an account of the difficulty of performing *Whistlers* live see Oliveros, "Poet of Electronic Music," 10.
[55] Johnson, "First Festival of Live-Electronic Music 1967," 50.
[56] ibid., 55.
[57] Lucier, "The Tools of My Trade," 444-54.
[58] Lucier, "The Propagation of Sound in Space," 434.
[59] Mumma, "Live-Electronic Music," 332.
[60] Simon, "Interviews with Douglas Simon," 62.
[61] Lucier, "The Propagation of Sound in Space," 434.
[62] Simon, "Interviews with Douglas Simon," 66.
[63] There are a number of parallels between *Chambers* and David Tudor's composition *Rainforest* (which dates to the same year - 1968) in that both works attend to the resonant properties of objects as a means for transforming electronic sounds and recorded sounds. The environmental aspects of *Rainforest* was realised through the physical distribution of a large number of objects

that were sounded simultaneously through the use of electronic audio transducers, unlike the acoustic stimulation of individual environments of *Chambers*.

[64] Alvin Lucier, "Vespers," in *Electronic Music: A Listener's Guide*, ed. Elliott Schwartz (London: Secker & Warburg, 1973), 240. The rather expansive subtitle of the work states: "for any number of players who would like to pay their respects to all living creatures who inhabit the dark and who, over the years, have developed acuity in the art of echolocation, id est, sounds used as messengers which, when sent out into the environment, return as echoes carrying information as to the shape, size and substance of that environment and the objects in it." Alvin Lucier, *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 312.

[65] Lucier, "Vespers," 239.

[66] Alvin Lucier, *Ostrava Days 2003 - Alvin Lucier Lecture, August 13, 2003* [web site] (2003 [cited 10 May 2007]); available from http://ocnmh.cz/days2003_lectures_lucier.htm.

[67] ibid.

[68] Simon, "Interviews with Douglas Simon," 76.

[69] Lucier, "Vespers," 239.

[70] ibid.

[71] Thom Holmes, *Electronic and Experimental Music: Pioneers in Technology and Composition*, Second ed. (New York: Routledge, 2002), 194.

[72] Lucier, *Reflections*, 314.

[73] "Restored behaviour is the main characteristic of performance. The practitioners ... assume that some behaviours - organised sequences of events, scripted actions, known texts, scored movements - exist separate from the performers who 'do' them." Richard Schechner, *Between Theater and Anthropology* (Philadelphia: University of Philadelphia Press, 1985), 35-36.

[74] ibid., 37.

[75] Lucier, *Reflections*, 314.

[76] A recording of *Vespers* was included on the LP *Electronic Sound* (Mainstream MS-5010, 1972) and featured compositions by all four members of the Sonic Arts Union: Robert Ashley, *Purposeful Lady Slow Afternoon* (1967); David Behrman, *Runthrough* (1967); Gordon Mumma, *Hornpipe* (1967). *Electronic Sound* was record number 16 in the "Time–Mainstream Contemporary Sound Series" produced by composer Earle Brown between 1960 and 1973. Across the eighteen albums the series featured a veritable who's who of the avant-garde and experimental music world. See David J. Hoek, "Documenting the International Avant Garde: Earle Brown and the Time-Mainstream Contemporary Sound Series," *Notes: Quarterly Journal of the Music Library Association* 61, no. 2 (2004).

[77] Nicolas Collins, liner notes, *I am sitting in a room*, Lovely Music LCD 1013 (1990).

[78] From the score of "I am sitting in a room", Lucier, *Reflections*, 322.

[79] ibid., 80. Interestingly, the recycling procedure Lucier employed for "I am sitting in a room" was another idea which came from Edmond Dewan, who had heard loudspeaker designer Amar Bose describe a similar process. Lucier, "The Tools of My Trade," 462.

[80] The version Lucier recorded in 1970 had sixteen repetitions, Holmes, *Electronic and Experimental Music*, 81. A later version recorded in 1980 has thirty-two repetitions.

[81] Simon, "Interviews with Douglas Simon," 98.

[82] "The original image is transformed by such factors as a slight enlargement in the copying process: being multiplied each time by itself, a tiny ratio in the first copy becomes mammoth growth by the fifth generation, and by the thirteenth generation, pictorial elements have become totally abstract. Loss of detail and increased contrast are progressively pronounced. Dirt, dust, scratches, and other imperfections are magnified. The familiar is pushed out of the frame from the centre as new, self-generated shapes take over. As the technology fails to hold, we see an image continually disassembling itself." Mary Lucier, "Organic (1978)," in *Mary Lucier*, ed. Melinda Barlow (Baltimore: Johns Hopkins University Press, 2000), 242.

[83] Simon, "Interviews with Douglas Simon," 110. Payne had previously studied owls and bats (and ironically how moths evade bat sonar), and along with Scott McVay is credited with the discovery that humpback whales (Megaptera novaeangliae) produced the idiosyncratic patterns of sounds known as 'whale song'. An album *Songs of the Humpback Whale* (CRM Records SWR 118, later re-released on Capitol Records) featuring whale recordings made by Payne and Frank

Watlington was released in 1970, and is widely considered to be responsible for the popularisation of 'whale songs' and for bringing the plight of humpbacks and other whales which had been hunted to the edge of extinction into the mainstream. On the downside, of course, was the wholesale interpolation of whale sounds into new age music. See Roger Payne and Scott McVay, "Songs of Humpback Whales," *Science* 173, no. 3997 (1971).

[84] John Hildebrand, "Impacts of Anthropogenic Sound," in *Marine Mammal Research: Conservation Beyond Crisis*, ed. John E. Reynolds, et al. (Baltimore: Johns Hopkins University Press, 2005), 113.

[85] David A. Helwig et al., "Humpback Whale Song: Our Current Understanding," in *Marine Mammal Sensory Systems*, ed. Jeanette A. Thomas, Ronald A. Kastelein, and Alexander Ya. Supin (New York: Plenum Press, 1992), 459. Ironically, like *Vespers*, there is again a link to Catholicism, as 'Quasimodo Sunday' is the first Sunday after Easter (named for the Mass on this day which begins with the words *Quasimodo geniti infantes*, 'as new born babes').

[86] Lucier, *Reflections*, 330.

[87] ibid., 328.

[88] Simon, "Interviews with Douglas Simon," 106.

[89] Lucier, *Reflections*, 328.

[90] ibid.

[91] Nyman, *Experimental Music*, 108.

[92] Simon, "Interviews with Douglas Simon," 106.

[93] There are not hard and fast borders between these two themes. For example, *"I am sitting in a room"* could be judged as much a product of technological reproduction as it is room resonance.

[94] Thomas Moore, *Alvin Lucier in Conversation* [web site] (1983 [cited April 25 2007]); available from http://research.umbc.edu/~tmoore/interview_frame.html?/~tmoore/lucier.html.

[95] Lucier, "Statement On: Music for Solo Performer," 61.

[96] Alvin Lucier, "North American Time Capsule," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 422.

[97] ibid.

[98] ibid., 420.

[99] ibid., 424.

[100] Extended Voices: New Pieces for Chorus and for Voices Altered Electronically by Sound Synthesizers and Vocoder (Brandeis University Chamber Chorus; Alvin Lucier, director) from the series, "Music of Our Time," CBS Odyssey Records, 32 16 0155 (mono), 32 16 0156 (stereo), 1968. The other compositions were: *Sound Patterns* (Pauline Oliveros), *Solos for the Voice 2* (John Cage), *She Was A Visitor* (Robert Ashley), *Extended Voices* (Toshi Ichiyanagi), *Chorus And Instruments II* and *Christian Wolff In Cambridge* (Morton Feldman).

[101] Lucier, *Reflections*, 332.

[102] ibid., 334.

[103] Moore, *Alvin Lucier in Conversation.*

[104] Simon, "Interviews with Douglas Simon," 118.

[105] ibid.

[106] Lucier, "Origins of a Form," 8.

[107] ibid.

[108] Hans Jenny, *Cymatics: The Structure and Dynamics of Waves and Vibrations*, trans. D. Q. Stephenson (Basel: Basilius Press, 1967), np.*Cymatics* is dedicated to "the memory and research of Rudolph Steiner."

[109] ibid., 12.

[110] ibid., 14-15. Jenny also made a number of films of his experiments, which were exhibited in Euproe in the early 1970s, along with his photographs. Jonathan Benthall, *Science and Technology in Art Today* (London: Thames and Hudson, 1972), 156-7.

[111] Jenny, *Cymatics*, 93.

[112] ibid., 176-77.

[113] ibid., 81-82. The idea of using visualisation techniques as an aid to teach deaf people to speak has a precedent in Alexander Graham Bell's designation of the phonautograph as a 'hearing machine' to provide a visual reference for deaf speakers in the nineteenth century. See Jonathan

Sterne, *The Audible Past: Cultural Origins of Sound Reproduction* (Durham: Duke University Press, 2003), 37-40.
[114] Jenny, *Cymatics*, 86.
[115] Simon, "Interviews with Douglas Simon," 138.
[116] Lucier, *Reflections*, 350.
[117] Lucier, "Origins of a Form," 8-9.
[118] Simon, "Interviews with Douglas Simon," 148-50.
[119] ibid., 148.
[120] Lucier, *Reflections*, 352.
[121] Simon, "Interviews with Douglas Simon," 140.
[122] Lucier, *Reflections*, 350.

6. Hearing and seeing the shapes of sounds: Alvin Lucier, 1973-1984

By 1973 Lucier had begun the first in a new series of works that were aimed at exploring what he termed the "spatial characteristics of sound itself."[1] These pieces marked a significant shift in Lucier's sound resources and compositional imperatives, enacting new relationships between the spatial and the sonic through his examination of acoustic phenomena. These works also coincided with a range of other new compositions that continued the theme of sound visualisation, which Lucier had begun with *The Queen of the South*. Many of these new works employed sine waves or continuous, sine-like sounds in their explorations of natural acoustic phenomena.

In order to chart this new period in Lucier's output, this chapter will concentrate on these sine wave pieces from the early 1970s until the early 1980s, beginning with the initial version of *Still and Moving Lines of Silence in Families of Hyperbolas* (1973-74) and ending with the later, revised version (1984). Apart from being the first work which fully embraced sine waves as a sound source, the first version of *Still and Moving Lines of Silence in Families of Hyperbolas* proved to be a highly generative work, providing the basis for a number of subsequent compositions which explored acoustic phenomena such as standing waves, beating patterns and the movement of sound in space.

The significance of sine tones in the compositions of this period has not been discussed in other commentaries on Lucier; this is surprising given that sine tones are such a prominent feature of Lucier's work in the period under discussion, and also of subsequent compositions.[2] Focusing on both the practical and theoretical aspects of sine waves highlights important aspects of Lucier's compositional practice, and provides a means to investigate the functional notions of sound, technology and the environment in his oeuvre.

Still and moving sines

In its initial form, *Still and Moving Lines of Silence in Families of Hyperbolas* (1973-1974) presents a vastly different musical experience compared with the works that preceded it. More than simply a musical composition, it was instead a multifaceted listening context for both demonstrating and exploring how sound is distributed in space. Although it is described as a composition for "singers, players, dancers and unattended percussion," the primary sonic component consists of sine tones, either singly or in combinations. Of course, as indicated in the previous chapter, Lucier had employed sine tones for the first time in *The Queen of the South*, primarily for their mechanical and durational properties, but *Still and Moving Lines of Silence* marks the first time that sine tones are called upon specifically for their sonic qualities, and used to elicit specific acoustic phenomena.

The exploration of the relationship of sound to space is pivotal to Lucier's conception of *Still and Moving Lines of Silence*: "The piece exists almost completely on a spatial plane. What's important is the making of simple to complex and still to moving sound geographies with sine waves."[3] To do this, Lucier constructs what he has described as a "sound environment" using sine wave oscillators.[4] These would be distributed to an array of four loudspeakers dispersed throughout the space, establishing the sonic context within which the performances would occur.[5]

Still and Moving Lines of Silence is primarily involved with exploring the range of acoustic activity associated with the phenomena of standing waves, specifically the physical distribution of sound, the movement of sound in space, and the phenomenon of acoustical beats - both in and of themselves and as indicators of other acoustic processes. As indicated in previous chapters, standing waves were a structural feature of La Monte Young's *Map of 49s Dream* and his *Dream House* sound environments, and Lucier has acknowledged Young's influence on his work with sine tones and standing waves.[6]

In a similar manner to Young's *Dream House* installation, Lucier used sine waves to construct his environment of sound, the parameters of which were determined by the interaction between sine tones and space. As sine waves propagate into a space they become subject to different forms of interference, which are caused by reflections from walls and other surfaces. The effects of what are termed *constructive* and *destructive* interference form stationary vibrationary patterns of standing waves as reflected sound waves interact with each other.[7] Constructive interference occurs when the two waves are in phase, creating an area of high amplitude. The opposite occurs with destructive interference, where the two waves are out of phase, causing a cancellation. This creates an area of low amplitude or silence, referred to as a node.[8] These types of interference also occur when the signal of one sine tone emitted from two different speakers meet, the time difference between the two signals determining the nature of the interaction.

A significant difference between Young's *Dream House* and *Still and Moving Lines of Silence* lies in the way each work conceptualised the effects of propagation and interference. As discussed earlier, Young had to make allowances for the effects of sound propagation within his complex scheme of composition and listening. However, in *Still and Moving Lines of Silence*, Lucier allowed the vicissitudes of the distribution of sound in space to define both the sound environment and the acts to be performed within it. Each manifestation of *Still and Moving Lines of Silence* would therefore create its own particular arrangement of standing waves, due to the effects of interference. Rather than being a means for erecting a pre-determined structure such as the *Dream House*, Lucier's use of sine tones in *Still and Moving Lines of Silence* was instead a mechanism for generating site-specific sound geographies, each with their own formations of loudness, quiet, and silence.

Expanding on the environmental character of *Still and Moving Lines of Silence*, Lucier draws an analogy between the type of acoustic phenomena at the heart of the work and the ontology of sound waves drawn from classical acoustics: "You know the first picture about the nature of sound in those acoustical books is a pebble in a pond. They show the photograph of how the surface of the pond radiates outward when you put in a pebble. And you drop another one in and those waves interfere with each other, you have exactly this sort of thing."[9] He has also described the performers as analogous to water-skimmers (small insects that travel on the surface of the water, also known as pond-skaters), in that they are invited to respond to the waves and reflections moving through their environment.[10] Insects or not, each of the performative components in the description - singers, players, dancers and unattended percussion - is representative of a different activity that would take place within the environment defined by the sine tones, in effect transcending any distinction between performance and installation. Any version of *Still and Moving Lines of Silence* might be comprised of one or more of these components individually or in combination. In each case performers establish a kind of sonic topography, locating and interacting with the high and low amplitude features of the sound environment.

While the establishment of a sonic environment of this kind might serve to distance Lucier's work from traditional musical language, *Still and Moving Lines of Silence* is the first of his mature scores that specifies traditional musical roles and resources (dancers, singers, instrumentalists) without recourse to substitutions.[11] However, their appearance here perhaps works to highlight the disjunction between the traditional musical treatment of sound and Lucier's enhancement of elided acoustic phenomena. Also, it serves to both democratise and depersonalise the role of performers in relation to the composition. Rather than holding the privileged position of being the sole producers of musical sound as they might in a traditional context, the performers are instead just one sonic component within an established environment of sound.

Lucier found that playing two sine tones of slightly different frequencies just off unison not only created a beating pattern formed by the interaction of the two tones, but that the crests and troughs of sound formed by the standing waves would begin to move around the space in elliptical patterns.[12] The speed of the rotation was determined by the difference in frequency between the two tones and the distance between the two loudspeakers. The direction of the rotation of the sounds would be towards the loudspeaker emitting the lower tone. This is not to say that the movement of sound was the result of the panning of signals from one speaker to another; rather, the movement was entirely the product of the physical encounter between two waves of sound, interacting both with each other and the acoustic properties of their environment.

Having constructed this environmental situation, Lucier developed a number of tasks that performers were to enact both within and upon the sonic terrain. As the sine waves played into the space, the effects of constructive and destructive interference produced crests and troughs of sound and silence, propagating outwards from the loudspeakers in hyperbolic curves, to form what Lucier termed "a sound maze in which dancers could move."[13] The role of the dancers then was to discover "troughs of quiet sound", following them until they either met with a louder sound, or found an intersection with another quiet zone.[14] 'Dancing' in this context was nothing more elaborate than moving slowly and carefully, in order to clearly indicate to an audience where the 'lines of silence' lay within the sonic environment. More important to Lucier than the movements of their bodies was the ability of the dancers to listen carefully in order to locate and trace the quiet nodal lines within the overall sound.

By altering the relationship between the two sine tone frequencies, and by switching off different pairs of speakers at different times, Lucier found he could progressively modify the arrangement of sounds in the room, creating pathways and impasses for his dancers to negotiate.[15] The passage of the dancers not only signified the presence of silent nodes in the standing wave patterns, but indicated the importance of location for any listener. If there were lines of silence, then the spaces between those lines was filled with sound to varying degrees, and the slow shifting passage of the dancers served to illustrate how sound arranges itself in space, inhabits space, and forms an environment within a space.

In contrast to the silence-seeking role of the dancers, the task of the vocalists and instrumental performers and players was aimed at producing specific acoustic effects, enacting a display of the physical properties of sound within the sonic environment. Singers entered into a productive relationship with the sine waves in order to help create patterns of acoustical beats (the oscillation of amplitude caused by due to the closeness of two frequencies) by singing "long pure tones" in near unison with the sine tones.[16] By placing their pitches within the intervals of sine waves, singers also generated variable rhythmic patterns with their voice beating at a different tempo against each tone.[17] Brass and wind players also produced long tones slightly off unison with the sine waves in order to create beating patterns; more importantly they were also asked to explore the relationship between their own pitches and that of the sine tones in order to spin crests and troughs of sound around the performance space.[18] Lucier described the instrumentalists as acting like oscillators, as the work required they pay careful attention to pitch. This comment could apply equally to the vocalists, once again evoking a depersonalisation of his sound sources.[19] However, a consideration of the analogy between human performers and electronics can also be extended in another direction: the acoustical effects produced by the singers and players would be minimal if they were not also able to mimic the capacity of oscillators to sustain sounds.

Where the movements of dancers were used to demonstrate the stationary, silent components of the sound environment, unattended percussion was used to show how sound moved. Snare drums on stands were set into vibration as the crests of sound produced by the sine tones spun past. The resonant response of snare drums to certain frequencies is often regarded as an annoyance in conventional musical situations, and Lucier's use of it is certainly contrary to conventional musical language. However, the effects of percussion instruments activated remotely by sound conveyed not just an impression of the spatial distribution of sound, but the spatial displacement of sound due to the effects of sound wave interaction. For Lucier this demonstration served as an important didactic tool, citing it as a method by which the audience could "clearly hear the movement" of wavefronts circling throughout the space.[20] Of course, it could also be inferred that locating a sound source aurally would lead to locating the sound source visually, becoming another means of appreciating how sounds travel.

Although it is one of the facets of *Still and Moving Lines of Silence* which most clearly shows the "spatial characteristics of sound itself," the unattended snare drums link back to the spatially distributed percussion of *Music for Solo Performer*, except now the snare drums reveal the movement of sound waves rather than the existence of brain waves. More importantly, of all the processes found in *Still and Moving Lines of Silence*, the vibrating snare drums form the strongest link back to the earlier works that explored the acoustic characteristics of natural and architectural spaces. Like the Sondol-induced echoes of *Vespers*, the sound produced by the snare drum is the response of a resonant space (the interior of the drum) activated by electronic sound (sine tones). This activation of responses, and the careful positioning of these responses as the subject of his compositions rather than the sounds which solicited them, had up until *Still and Moving Lines of Silence* been the primary method by which Lucier maintained his programme of depersonalisation. Coinciding with the shift in focus onto exploring the spatial characteristics of sound, rather than the acoustic capacity of space, would be the introduction of a new method by which this impersonality was to be realised. As this new work involved the use of new materials, in the form of sine waves and other sustained, sine-like sounds, they would be pivotal in redefining this relationship between composer, technology and the environment in which these works are performed.

From space into sound, via sine

As discussed in the previous chapter, each of the two major themes in Lucier's work provided a scheme for transforming sounds, and for depersonalising the relationship between composer and composition. The first group of compositions, which explored interactions between sound, space and environment, used synthetic or recorded sounds to elicit acoustic responses from the physical attributes of the spaces in which they were performed; the second series centred on exchanges between vocal sound and electronics. In many of the works a single class of sound (electronic clicks, speech) or batch of sound (recordings, songs) was used to interact with either a space or an electronic system. Rarely were different sounds performed simultaneously or called upon to interact with each other; nor were any resultant interactions between two sounds considered to be the subject of the work.[21] However, in this new phase of compositions, which investigated the physical properties of sound, a significant shift had occurred. With *Still and Moving Lines of Silence* it is precisely the interactions between two or more sounds within an environment that forms the subject of the work, be it between the standing waves formed by two sine tones, the beating patterns produced by the vocalists, or the moving crests of sound produced by horns, flutes and oscillators.

In its basic form, *Still and Moving Lines of Silence* used only the sound produced by sine wave oscillators, the propagation and interaction of which formed into patterns of loudness and silence. In doing so, sine waves combined both the role of physical space and the role of electronic technology identified in the earlier works. Lucier's sonic exploration of architecture had required a static, unchanging and pre-existing physical state within which the transformations of sound could be identified, whereas the alteration of voices with electronics required an engagement with the synthetic and the technical. Sine tones merged these key criteria that had activated the earlier compositions into a single resource: sine waves provided a 'found,' synthetic, static, technological sound. Sine waves also completed Lucier's gradual progression towards the use of continuous sounds, charted in the previous chapter. However, unlike the clicks of the Sondols which relied on echoes to extend their duration, or the vocal recycling of "*I am sitting in a room*", continuity was an inherent part of sine wave sound.

Although inevitably there may be elements within each of the earlier composition that defy the strictures of these distinctions, they serve to highlight a clear difference between the two eras of composition. Just as each of the earlier themes embodied a specific attitude towards either technology or environment, this change in compositional procedure marks a similar change in Lucier's relationship to both of these concepts. Of course, the effects of spaces and sound producing or recording technology would still be active in newer works; rooms would continue to reverberate and echo, and technology continue to transform sound. However, Lucier's attitude toward space and technology would now be mediated through the use of two sounds to elicit acoustic phenomena, exemplified by the interaction of sine waves.

Even in the artistic milieu of the 1970s the relationship between musicians and technology was still regarded with some suspicion. Be that as it may, it was hardly a mind-set shared by Lucier: "all this stupidity about technology being an enemy is absurd. It isn't at all; it's a tool. Technology is one tool after the other, and it's no better or no worse than any other tool."[22] The importance Lucier places on this notion of tools, rather than instruments, is significant as it has the rhetorical effect of lending an air of simplicity to what might otherwise be regarded as complex technological devices. It also refers to both the ubiquity of electronic artefacts in contemporary western life, and people's orientation towards them:

> I had to give a talk the other day about electronic music, about what I was doing, and you know most people are scared. They come into the studio and they're scared when they see an amplifier. They still think of it as hostile, and it's their tool. It's their tool more than anything else. I mean it's more natural. They use amplifiers more than they use flutes in their life, you know - the radio, the telephone. And I just explained to them that I was doing that also and that they shouldn't be afraid.[23]

Just as compositions such as *Still and Moving Lines of Silence* sought to make explicit the subtle sonic interactions other music concealed, Lucier's attitude towards electronics also made explicit the technological substrate of modern western culture. As already noted in the previous chapter, Lucier interpreted technology as a kind of landscape, and therefore the use of technological artefacts in his compositions was a response to both his era and his environment. As pre-existing, found 'tools' within an everyday environment, this perceived prevalence of electronic devices was for Lucier representative of his particular environmental situation, and therefore a means of conferring on those tools a kind of general, impersonal status.

In line with this thinking, Lucier considered that the industrial or scientific test equipment he used in performance, such as amplifiers, oscillators, Sondols and audio transducers, provided him with similarly general or neutral tools for exploring sound: "Acoustical test equipment is, by its very nature, free of content. What goes into a material or environment to be tested must be neutral so that the results are unbiased."[24] As a result, sine waves were considered by Lucier to be the exemplar form of a 'neutral' sound. Drawing on the traditional description of sine waves provided by acoustics, he valued what he described as their "purity (all fundamental, no harmonics)."[25] Lucier concluded that the use of these so-called "pure sounds" was necessary so "that what happens in and to those media is clearly perceptible. Any material with personality would blur the phenomena."[26] Such assertions expand on and render explicit what had previously been a nascent concept in Lucier's compositions - that complexity acted as a hindrance to perception. Where the overwhelming sound produced by an orchestra rendered subtle phenomena such as beating patterns, echoes or room resonance inaudible, the harmonic simplicity of the sine tone could now form an acoustic benchmark against which the effects of sonic interaction could be easily distinguished and identified.[27]

Lucier's conferring of a neutral or general status for scientific test equipment and sine tones is not altogether unproblematic. Where scientific test equipment and sine tones might be considered neutral within the context of certain forms of scientific experimentation, outside of that domain apparatus such as tone generators or vocoders are the very symbols of technological specificity. For example, an encounter with sine tones as a 'neutral' background against which the effects of acoustic phenomena could be detected is distinctly different to one's everyday experience of turning on a radio or speaking on the telephone. So while sine tones as a pre-existing, non-idiosyncratic sound conform to the general status Lucier conferred on technology, the signature role they play as acoustic markers of scientific activity does not effectively render them neutral in broader cultural contexts; Lucier's claims of purity or neutrality does not negate their ability to signify different things in different circumstances, or to different audiences. The sine tone could hardly constitute a tool or resource totally free of meaning, especially as Lucier's own designations of experimental neutrality and harmonic purity draws upon a rich series of historically and culturally situated definitions of sine tones from both science and music.

Despite Lucier's claims, the impossibility of removing what sine tones signified did not exactly inhibit his aesthetic. The association of sine tones with science and experimentation implied just the kind of testing, examining, exploratory procedures that formed Lucier's compositions, and therefore helped to clearly differentiate his intentions from those of more traditional composers. Also, a sine tone that signified would definitely constitute depersonalised material, in that the attendant set of associations indicated just how non-idiosyncratic a sound it was. So instead of an acoustic blank slate, the sine tone is present in *Still and Moving Lines of Silence* as a kind of artefact - a synthetic, technological formation derived from a specific context and placed within another. That meanings attributed to sine waves in one context (science, and more specifically, acoustics) circulate within a broader one (contemporary western society) allows the sine wave this oscillation between the general and the specific, signifying and non-signifying in equal measure. Identifying the sine tone as an artefact becomes significant when considering Lucier's programme of investigating the "spatial characteristics of sound itself" because, as earlier chapters have indicated, the sine tone is a sound complete with its own history within acoustics, and this history needs to be factored into any reading of Lucier's sine wave works.

Lucier indeed draws his basic account of sound propagation from acoustics: "Sound waves flow away from their sources roughly in three dimensional concentric spheres, the nodes and antinodes of which, under certain circumstances, can be perceived in a room as clearly as those of a vibrating string on a violin."[28] This behaviour is exemplified by sine tones, as portrayed in the loud and quiet standing wave topology of *Still and Moving Lines of Silence*. As with many descriptions of sonic phenomena derived from acoustics, verification comes through techniques of comparison and visualisation: the standing wave formed from a sine tone by analogy becomes a violin string traversing a room, while its nodal points are in turn transferred onto a stringed instrument for observation. It is unusual given Lucier's concern over the role traditional musical language plays in extinguishing subtle phenomena that a musical analogy, the violin, should intrude at such a basic level in his conceptualisation of the spatial arrangement of sound. However, this is perhaps more indicative of the pervasiveness of traditional musical aesthetics within acoustics than any attempt by Lucier to substantiate his unorthodox compositional practice within the classical concert hall. While this comparison provides a serviceable description of stationary wave phenomena, it represents only the starting point for Lucier's own realisation of sonic spatiality.

Lucier's comparison of a standing wave in a room with a vibrating violin string suggests that the manner in which sound arranges itself in space is best understood by establishing parallel relationships between different kinds of resonant spaces - the resonant room paired with the resonating body of the violin. Indeed, the vibratory pattern in one system is comparable to the pattern of the other: it provides a model for the distribution of loud and quiet (dynamics) through the effects of constructive and destructive interference. However, the example describes a static situation, and one of the most significant factors of Lucier's notion of spatial sound is motion, realised primarily in the form of acoustical beats. Therefore, identifying propagation as the agent for activating the spatial characteristics of sound means spatiality is itself understood as a relationship established between *stasis* and *movement.* Movement in turn implies dimensionality, but where the violin analogy produces a two-dimensional model of static vibration, the effects of the propagation involve sound moving through three dimensions.

It is perhaps ironic that Lucier employs this two-dimensional violin string analogy for describing standing wave phenomena, as Lucier considers his use of the three-dimensional aspects of sound as representative of his musical practice:

> Webern, Schoenberg and post-serialism are so connected with print, so connected with writing notes. And if you don't write in notes you get off the page... When you write it's in two dimensions, and sound is not two-dimensional... sound radiates everywhere all over the place. But most of the music we know is conceived on the page two-dimensionally. Now if I'm not thinking about that, if I'm not composing on a page and I really love sound, I begin to hear it as it is, which is a three-dimensional action.[29]

Petitioning against a reification of the score, where the written aspects of composition displace the importance of musical sound, Lucier considers his work as occurring "after print" in that a written account of a given work cannot provide a substitution for the acoustic phenomena which form its subject; his work requires the perception of sound in three dimensions.[30] This appeal to the three-dimensional aspects of sound therefore places the act of listening at the very core of Lucier's practice. These spatial aspects of sound are perceived by listeners through a proliferation of effects: acoustic beating, interference, diffraction, spatial distribution, and movement - all the result of the vicissitudes of propagation. This concept leads into the later works, where each one would draw on different properties or products of propagation, especially the works from the visualisation series, where a range of techniques were employed to indicate the spatial arrangements of sound.

Just as propagation is responsible for organising the sound of *Still and Moving Lines of Silence*, so Lucier is responsible for structuring the role perception plays in determining the spatial. This is initiated through attentiveness to the act of perception:

> The idea in my work is that the experience of perceiving the piece is the experience of being aware of yourself perceiving it. Not receiving a message from the piece... you are really not aware of yourself perceiving a Beethoven symphony, you're aware of what Beethoven is doing, but in this situation I hope you are aware of yourself going through the particular process of hearing.[31]

This did not make perception alone the subject of the work - something that Lucier himself considered a conceptual dead end.[32] Instead, becoming aware of the act of one's own perception is intended as a mechanism for establishing a relationship between listeners and the acoustic phenomena which is otherwise hidden in their everyday experience of listening, "stopping people in their tracks so that they can pay attention to that phenomenon which they otherwise don't pay any attention to or they miss... it's putting people in a beautiful relationship to those phenomena."[33] Lucier hoped that making listeners aware of these phenomena would in turn lead them to an appreciation of these same aspects of sound outside the concert hall. Attention was therefore directed not towards perceiving sounds 'in themselves' - a programme already well established within experimental composition due to the influence of John Cage - but towards the perception of acoustic phenomena.

Listening for the proliferation of spatial effects meant providing a situation in which this kind of listening could occur. Lucier considered it important that his works create a "timeless kind of depth," inducing the feeling of "going *into* a sound-space, rather than moving horizontally along it."[34] This spatial aspect is not dissimilar to the type of listening experience La Monte Young aimed for in his *Dream House* installations. However, where as Young conceptualised perception as an automatic procedure of comparative analysis based on duration, listening to *Still and Moving Lines of Silence* relied much more on audience attention. The immersive aspect in no way reduced the onus on audience members to listen carefully, due to the subtlety of the phenomena involved: "It is subtler than light or color I think, because sound waves don't do what you want them to do. You want them to be palpable. You can take a color and put it somewhere. It's a little bit harder to do that with sound."[35] Just as Lucier was responsible for producing the proliferation of acoustic effects to be perceived, listeners were also responsible for activating the phenomenal aspects of the work through the focusing of their attention.

Still and Moving Lines of Silence presents a clear example of how Lucier negotiated the complex series of relationships between sound, space, perception and attention. Having defined the actions of propagation as the subject matter of this composition, Lucier produced a reductive 'sound environment' where its effects could be more easily determined. In emphasising the importance of attending to acoustic phenomena rather than sounds, the constant sine tones of *Still and Moving Lines of Silence* are not simply conceived of as a 'neutral' sonic backdrop against which various sonic effects can be produced, but as the context within which a spatial, three-dimensional act of perception can occur.

Despite the new territory that *Still and Moving Lines of Silence* opened up, Lucier ultimately abandoned this first version of the work, finding the open, improvisatory form of the score unsatisfying. Ironically, the all-important beating patterns and movement of sound were too often overshadowed, appearing only as ornaments to the chordal structures formed between sine tones and performers.[36] However, many aspects of *Still and Moving Lines of Silence* would carry over into subsequent works, or in some cases go on to form whole works in themselves. The ideas and the relationships of sound to space, however, would persist.

Persons, shapes and feedback

Lucier followed *Still and Moving Lines of Silence* with two more works that continued his investigations into the spatial aspects of sound. The first of those, *Outlines of Persons and Things* (1975), used sine tones to display the "diffraction outlines of an object caused by sound."[37] The work called for loudspeakers to be arranged behind objects through which clusters of sine tones were played; for example, Lucier himself used a canoe as one of his 'things'. The relationship between the size of the object and the frequency of the sine tones was then adjusted so that audible diffraction patterns formed around and in front of the object.[38] The 'persons' then undertook one of two activities, which were performed either together or separately. The first task involved performers moving slowly in front of and away from the loudspeakers, creating what Lucier calls "moving sound shadows" as the sine tones diffracted around the shape of their bodies.[39] The second required performers with directional microphones to scan the 'things,' picking up the diffraction patterns as acoustic 'silhouettes' of the objects, conveying the signal to the audience via loudspeakers.[40]

Outlines of Persons and Things was in part influenced by the work of acoustician Winston E. Kock, whose book *Seeing Sound* provided a visual account of the effects of diffraction of sine tones striking acoustically opaque objects.[41] These images depicted what Kock referred to as the "space patterns of sounds."[42] However, where Kock's images depicted a situation in which the sound and the objects within it remain static, *Outlines of Persons and Things* aimed to make diffractive patterns more perceptible through the use of movement. As sound diffracts in three dimensions, the very idea of an 'outline' of sound (the audible or visible effects of diffraction) becomes one of perspective and location, or orientation, to the sound source. Because the effects of diffraction are more easily noticeable as they change, the two activities Lucier devised for performers presented different perspectives on the perception of diffractive patterns, realised through movement and orientation.

One of the main problems Lucier encountered in *Outlines of Persons and Things* was the difficulty of displaying the audible effects of movement and orientation to a stationary audience. Rather than move the loudspeakers or the audience, Lucier used performers to enact the shifts in orientation between sound source, object and audience. The first action involved the movement of an acoustically opaque object - a person - in front of the sound source, to create a moving, interactive situation between sound and performer in front of the loudspeakers. The second provided the investigation of a largely static situation - the flow of sound around a stationary object - using a moving microphone. Both of these actions required careful listening on the part of the performers in order to be able to first locate and then alter the sonic features of their environment.

The difficulty of realising the subtle acoustic effects of diffraction for an audience in *Outlines of Persons and Things* is another example of what Lucier's sees as a conflict between the commonality or universality of acoustic phenomena, and the opportunities for perceiving those phenomena. Although the role of the performers helped to overcome any problems caused by the stationary seating arrangement of a concert hall, Lucier's desire to make natural acoustic phenomena the subject of his work was in part problematised by the complexity of sounds and the environments in which they are to be heard: "Sounds are too complicated in everyday life: speech, sounds of automobiles, sounds of storms, things like that, are too complicated for you to perceive them bouncing around yourself or objects."[43] In order to overcome this, Lucier constructed his own environmental situation, using the simple sound of sine waves as a replacement for complex everyday sounds. This is a reductive strategy that aids the production and reception of the relevant acoustic phenomenon that forms the subject of this work - diffraction. It also allowed Lucier the ability to focus the work, and to enhance its production of one or two acoustic effects above others: "I try to find a clear technical way of presenting [the acoustic effects] by using pure sine waves coming out of loudspeakers, that I can control. I can put the loudspeakers where I want. I can tune the sound to where I want and get that beautiful diffraction as optimally as possible. It's like distilling; making pure those things that happen anyway, but that you don't perceive, because they're too complicated."[44] This shows how Lucier's compositional practice re-presents or reimagines not only the environment, but the kind of sounds that occur within it, with an aim towards the reduction of complexity as an aid to perception.

Lucier's notion of complexity encompassed not only an abundance of sounds, objects and behaviours, but the complex blend of frequencies of which everyday sounds are comprised. To overcome this, he employed harmonically simple sine tones. However, sine tones were not used as a substitute for a specific sound, but for sound in general: a sine wave of a particular frequency became a generic example of the kind of sound that would diffract around objects of a particular size. However, replacing an individual, complex sound of finite duration, such as speech, a thunderclap or the sound of a car engine, with the continuous, reductive sound of sine tones produces a very different listening situation to the everyday experience of lived sound. Rather than hearing a series of sounds which become perceptible, change over time, and fade away, the constant frequency and volume of the sine tones halt the effects of duration, presenting a static 'sample' of a sound fixed in time. Now held in place, the diffraction patterns appeared as features in a constant sine tone environment that could be explored by performers and experienced by listeners.

Bird and Person Dyning (1975) also used long, continuous sound as a tool for locating sound in space. However, for this work, Lucier used the sound of electroacoustic feedback. A pair of small microphones used for the creation of binaural recordings was worn inside the ears of the performer, the signal from which was distributed to loudspeakers and amplified to the point of feedback. An 'electronic birdcall' (actually a spherical electronic Christmas tree ornament Lucier had received as a gift) placed centrally in the space emitted "endless repetitions of a downward glissando followed by a series of repeated chirps," the sound of which combined with the two 'strands' of feedback produced by the microphones to create phantom images of the electronic bird sound.[45] By altering the orientation of the microphones to both the electronic birdcall and the loudspeakers, the performer determined the geographical locations of the phantom birdcalls.[46] As the pitch of the feedback strands became modulated by the acoustical properties of the space, interference patterns between the feedback and the birdcall shifted the phantom image up and down in pitch.[47]

The phantom images were the result of a kind of interference phenomenon called heterodyning, a term used in radio broadcasting to describe beat frequencies produced between two radio frequencies. Coined by Canadian inventor Reginald Fessenden from the Greek *heteros* ('other') - *dynamis* ('force'), it describes the interactions of a received radio-frequency wave with a stable wave of a slightly different frequency.[48] It became central to the continuous wave system for radio transmissions that Fessenden developed while working on a new system of wireless telegraphy for the US Weather Bureau in 1901.[49] However, where heterodyning in radio terms produces acoustic beats and difference tones in the radio spectrum, *Bird and Person Dyning* is another example of Lucier making the inaudible audible in its transposition of heterodyning effects into the audible spectrum, with the electronic bird acting as the varying signal which then combines with the relatively steady sound of feedback.

Lucier cites his use of feedback to the influence of Nicolas Collins (b. 1954), who studied composition under Lucier at Wesleyan in the early 1970s.[50] Collins produced a number of performance and installation works, including *Nodalings* (1973), *Feetback* (1975), *Q* (1975), and *Pea Soup* (1974-76), which explored different aspects of electroacoustic feedback as both a source of sound and a control device.[51] However, Lucier would have already been familiar with the use of feedback as a compositional tool as all of the other three members of the Sonic Arts Union had employed feedback as an integral part of their compositions at some time during the 1960s.[52] Union member Robert Ashley has actually referred to feedback as "the only sound that is intrinsic to electronic music."[53] One of the most famous, or perhaps infamous, of his feedback works was *The Wolfman* (1964), for tape, voice, and feedback. An intense and noisy work, *The Wolfman* takes place in a highly amplified situation. The breathing spaces between quietly sustained vowel sounds are filled with squalls of microphone feedback modulated by both the singer's vocal tract and the shape of the room. This was accompanied by a tape collage comprised of "a blizzard of short sounds across the whole frequency spectrum," which Ashley considered a kind of background drone, but was more like a chaotic assemblage of recorded and electronic sound.[54] David Behrman's *Wave Train* (1967) used feedback to establish an interaction between room resonance and piano resonance. Contact microphones attached to piano strings were amplified to the point of feedback. The resulting sound emanating from loudspeakers in turn excited the piano strings, forming a feedback loop of surging sound between piano and audio system.[55] *Hornpipe* (1967) by Gordon Mumma involved a combination of electroacoustic and systemic feedback. French horn sounds were modulated through the use of a self-designed "cyber-sonic console" which, through a series of filters and signal gates, could both regulate and alter resonant frequencies and feedback tones in a complex manner.[56]

However, it is one of the earliest experimental compositions using feedback, *Loud Symphony* (1958) by Fluxus artist Dick Higgins (1938-1998), that seems the most significant antecedent to *Bird and Person Dyning* in its focus on structural simplicity, movement and interference phenomena. Higgins used a series of graphic notations as movement scores in order to determine how a microphone should be moved in front of a highly amplified loudspeaker to produce feedback.[57] Higgins was able to incorporate two lines of feedback using a stereophonic tape recorder, allowing him to include the products of interference phenomena to create a wide range of effects formed by simply moving the microphone, effectively translating gesture into sound.[58]

The use of feedback in *Bird and Person Dyning* meant that orientation played a crucial role in displaying the effects of sound propagation. Rather than being an attempt, following Higgins, to register gesture as sound, Lucier's composition realises gesture as the spatialisation of sound. The shifting orientation of the performer to both the speaker and electronic bird mapped the locations in the room where phantom images could be produced. Lucier could easily have achieved a simple heterodyning effect through the use of sine tones, but feedback had the added advantage of eliciting dynamic responses from the acoustical characteristics of a space. The effects of room resonance meant that the feedback strands would not remain fixed in pitch, and would in turn alter both the pitch and the location of the phantom sound images. This uncontrolled responsiveness to resonance meant that feedback also constituted the kind of non-intentional, depersonalised material which could effectively convert Lucier's specific enactment of heterodyning and spatialisation into a general one. Also, unlike the constant sound fields of the previous compositions, the shifting feedback would produce small instances of silence, dividing the work up into a series of simple acoustic phenomena within space.

Constant sound such as sine tones and electroacoustic feedback had become Lucier's indispensable tools for indicating the spatial aspects of sound, as realised through the perception of the spatial effects of propagation. Whether they produced an uninterrupted sound environment or, as with *Bird and Person Dyning*, a succession of sonic images, Lucier used continuous sounds to provide a context for the perception of acoustic phenomena. In recommencing his series of works on 'seeing' sound, constant sounds now formed the basis of Lucier's attempts to visualise the effects of sound and vibration.

Visualising Sines

The curve of the sine wave has been one of the signal ways in which sound has been represented, and symbolises more than just a graph of frequency and amplitude information. In its ceaseless, regular undulations, the shape of the sine wave forms a nexus at which a range of wave, oscillation and vibration metaphors relating to both the harmonic and behavioural aspects of sound meet. They have been used as a graph of physical vibration, as a linear representation of modes in a vibrating string, and for describing the propagation of standing waves in a room. In the continuation of his series of works that explored techniques of sound visualisation, Lucier in effect reverses this approach to 'seeing' sound. Rather than conflating a range of acoustic phenomena into a single graphical mark, Lucier used the particular acoustic properties of the sine wave in a range of compositional schemes, playing it out into three dimensions in order to register spatially the effects of propagation and vibration.

These 'seeing' sound works had a dual purpose: not only did these works serve Lucier's dictum of 'making the inaudible audible', they attempted to make the *invisible visible*. In doing so, these compositions exploited the history of visualisation within acoustics and natural philosophy. As stated earlier, Lucier considered the tools and procedures of science provided him with neutral material with which to construct his works, while also serving to distance him from the intrusion of conventional musical language. Three of these works were, like *The Queen of the South*, either derived from, or simply staged versions of, physics experiments or demonstrations.[59] A prime example was *Tyndall Orchestrations* (1976), which recalled the sound-sensitive flames of nineteenth century natural philosopher John Tyndall (himself a great interpreter and populariser of the experiments of other acousticians). A gas flame from a Bunsen burner flickered and fluttered in response to sounds from a violin, female voice, and recorded birdcalls. Lucier described the Bunsen flame as a "nineteenth-century oscilloscope," owing to the way "a picture of the sound is outlined as the sound waves disturb the flame."[60] An additional version of the work saw glass tubes placed over the flame to produce long sine-like tones, modulated by the flow of gas and the raising and lowering of the tube over the flame. By slowly adjusting two closely tuned glass tubes, beating patterns could be formed and used to spin and move sound in elliptical patterns, as in *Still and Moving Lines of Silence*.[61]

The reconfiguring of scientific experiments as musical works effectively recasts performers as demonstrators, and vice versa. This ambiguity as to the role of those presenting the work spills over in to the general question of its aims. Rather than progressing through an experiment from beginning to end in order to achieve an outcome or conclusion, it is more important that audiences stay within the conditions of the experiment so as to perceive the acoustic phenomena that form the subject of the work. This is affected through a redirecting the focus of the experiment, from apparatus, objective and result, onto process and effect. Rather than following a narrative arc, these works produce a static situation, in which these processes can be observed or experienced. Should a goal state be reached quickly, it should be maintained or repeated (such as the flame in *Tyndall Orchestrations*) so that effects can be perceived.[62]

This shift in focus of these experimental situations, from outcome to process, is followed through in their presentation, with several of these works realised as both performance and installation. *Music on a Long Thin Wire* (1977) explored the acoustic properties of a single vibrating wire through the use of a vastly elongated version of the monochord.[63] The initial idea for the work came from demonstrations Lucier had given while teaching a course on musical acoustics at Wesleyan with physicist John Trefny.[64] A length of piano wire stretched from one side of a space to the other, and a large horseshoe magnet was placed over one end. Both ends of the wire were then connected to the amplified signal from a sine wave oscillator, causing the wire to vibrate in ways clearly observable to the eye. Microphones placed inside small bridges that support each end of the wire routed the audio signal to loudspeakers, providing the sonic analogue of the visible oscillations. Given that a single, unchanging tone was used to drive the wire at any given time, *Music on a Long Thin Wire* could function either as an installation or as a performance, where a number of different tones might be used consecutively.

In extending the wire Lucier has again confounded the aim of the 'scientific' situation - to observe the nodal points and vibratory patterns of a string as the basis of musical scale formation - and recast it as an opportunity to perceive a range of acoustic effects: simple and complex harmonic structures, rhythmic patterns, echo trains and silences.[65] These effects are produced not as the result of manipulation during performance, but through the interaction of the frequency and amplitude of the sine tone, the flux field of the magnet, and the tension of the wire. The extended monochord was found to be highly susceptible to its surroundings. However, rather than establishing the laboratory-like isolation from conditions required by experimentation, the wire was free to respond to changes in temperature, air currents and fatigue, as well as to the signal of the electrical oscillator. This responsivenes transformed the long wire from a quasi-scientific instrument into one component of an environment established for the perception of changing vibratory phenomena, both audible and visual.

This environmental aspect of the work becomes emblematic of the kind of approach to listening Lucier considered most appropriate for compositions or installations of this kind. He found that the act of listening that would best suit the situation produced by *Music on a Long Thin Wire* was compatible with the experience of listening in a natural environment:

> You listen in the same frame of mind in which you would sit beside a river. You don't demand that the river change much. You wouldn't say it's too bad there isn't an obstruction thirty feet upstream and then the ripple formations would do this and that - you're perfectly willing to take in whatever happens. That's the way I would like people to listen to this piece.[66]

For Lucier, listening to the effects of acoustic phenomena involved patient attention to the situation at hand. In *Music on a Long Thin Wire*, attending to acoustic phenomena involved a rather stationary encounter with a continuous sonic process, rather than being carried along in the flowing musical narrative of a traditional composition. Completing this encounter is its pre-existing situation or context, be it riverbank or art gallery, where one would equally have the opportunity to listen 'beside the wire' just as one would listen 'beside a river.' This environmental description serves to literalise the claim of 'three-dimensionality' Lucier uses to define his work. Further, this formulation of experiencing *Music on a Long Thin Wire* as a kind of encounter with a natural process, rather than a work of art as an expression of an artist's will, institutes Lucier's aesthetic of distanciation in the act of reception.

Just as in the earlier visualisation work *The Queen of the South*, sine waves are used in *Music on a Long Thin Wire* as a kind of engine to deliver a constant amount of energy into a system. Unlike *The Queen of the South*, only one tone is used, so it is by virtue of the interaction between the single tone and the physical properties of the wire that the visual and acoustical effects are produced, as opposed to the interference effects caused by multiple tones. However, as with *The Queen of the South*, the importance of the actual sound of the sine tone is somewhat ambiguous. Although the signal routed to the loudspeakers would inevitably be a combination of the signal of the oscillator and the sound of the vibrating string, the wire itself also produced some sound acoustically - that is, without the aid of amplification - emphasising the sound produced by the wire. Lucier has likened the set-up for *Music on a Long Thin Wire* to a "disassembled loudspeaker," where the diaphragm and the voice coil of the speaker cone become conflated in the vibrating wire.[67] This assertion is an interesting one, as it has Lucier performing another act of sonic visualisation. *Music on a Long Thin Wire* exposed those highly developed, contained and often hidden components of audio technology systems; it unravelled the speaker box, placed its insides on display and turned its functioning into a performance.

Following *Music on a Long Thin Wire* were two related works that employed sound sensitive lights to indicate the spatial location and distribution of sound. The first of those, *Directions of Sounds from the Bridge* (1978), once again used the sine wave as both an engine and a sound source. A sine tone was routed through a transducer attached to the bridge of a stringed instrument. Sound activated lights, calibrated to respond to similar frequencies, were placed either in symmetrical patterns around the instrument, or distributed at random.[68] Triggered by the sound emanating from the bridge of the stringed instrument, the lights performed a similar role to the dancers and snare drums of *Still and Moving Lines of Silence*, except that the lights showed the presence of sound in their location, rather than silence.

Directions of Sounds from the Bridge (1978) is the first of Lucier's sine wave compositions to explore the possibility of a sweeping tone - one that smoothly increases or decreases in frequency over time, transforming the static pitch of the sine tone into a glissando. However, the frequency of the sine wave was altered as slowly as possible so that the audience would not register a change in pitch, only a change in the number and location of lights illuminated.[69] The overall volume of the tone was kept low so as to reduce the possibility of standing waves and other room related phenomena and to highlight the different flow patterns created by the sweeping sine wave.[70]

The second work for sound sensitive lights, *Ghosts* (1978), reversed the procedures found in *Directions of Sounds from the Bridge* (1978). Rather than an array of lights indicating the flow of sound from a single object, one light was carried systematically from place to place to indicate the presence of sound within a space. Although not specifically stated by Lucier, these two works, like *Outlines of Persons and Things*, show the influence of Winston Kock. His photographic examples of wave propagation were made using a scanner comprised of a tiny neon lamp and a small microphone attached to a mechanical arm. Signals from the microphone fed the lamp, the brightness of the light indicating the intensity of sound a given point. As the microphone-lamp scanned the sound field, a long exposure photograph captured the fluctuations in light intensity from point to point, gradually building up an image of the propagating sound.[71] Lucier reanimated this process on a grander scale by establishing a 'sound field' within a space using one or more sine wave oscillators, and then slowly scanning the room with the sound sensitive light, capturing the performance on slow-scan video.[72]

Music for Pure Waves, Bass Drums and Acoustic Pendulums (1980) was the last of the visualisation works from this era, and like *Music on a Long, Thin Wire*, was influenced by an experiment drawn from the field of acoustics - one which Lucier discovered in a British college textbook on the physics of sound.[73] The initial experiment involved a small pith ball hung on a silk cord, which rested against a bell. When the bell was sounded with a violin bow, sonic vibrations in the bell drove the ball away.[74] Lucier's enlarged version suspended table tennis balls on fishing line in front of upright bass drums. Rather than violin bows, the bass drums were driven by sine tones played through loudspeakers placed behind them, which caused the drumhead to oscillate outwards and inwards. Once again, a sweeping sine wave was used as the sound source. As the frequency of the sine wave slowly rose in pitch, different resonant modes of the bass drums were activated, with the outward motion of the drumhead driving the balls away from the drums. As each drum responded differently to the changes in frequency, the distance that the balls travelled from the drumheads changed, and created shifting rhythmic and dynamic patterns. Drums would also silent when a frequency failed to resonate in the body of the drum. Occasionally the balls were stopped dead when they returned to the drumhead while it was moving inwards.[75]

Although not explicitly involved with the verification of scientific theory, Lucier's performance of scientific procedures has a close correlation with what Harry M. Collins describes as *experimenter's regress* - the notion that instead of being a test of a particular theory, experimentation is in fact a test of the ability of those performing the experiment to reach a previously derived outcome.[76] This concept problematises the notion, inherent in most popularisations of scientific method, that the validation of a scientific claim is achieved through replication. Instead Collins posits that experiments often serve to conform to, rather than confirm, existing theories.

This is substantially a model of how performances of Lucier's compositions relate to his intention to have specific acoustic phenomena form the subject of those works. The success or failure of a given composition in a particular space depends on how well specific acoustic phenomena are realised. For example, performances of the composition *Directions of Sounds from the Bridge* could be easily recast as a series of attempts to produce visual examples of the diffusion of sound that conform to the general theories of diffusion. In instances where the desired acoustic effects fail to arise (such as in the example of the unsatisfactory movement of sounds in *Still and Moving Lines of Silence* mentioned earlier) Lucier cites both problems with his realisation of the composition and the inability of performers to accurately produce the desired effects as mitigating factors, rather than a repudiation of the theories that underpin the work.[77] Of course, the outcome of a given performance would always be dependent upon the acoustic characteristics of theatre and gallery spaces, and how well these could be manipulated to meet the requirements of the composition. However, while Lucier is willing to accept a wide amount of variation from performance to performance, replicability plays an important part in his work.

Collins regards replicability, whether in the laboratory or in a performance space, as comparable with what sociologist Robert Merton has called the 'norm of universality' - that phenomena will continue to behave in the manner in which they have previously been perceived to behave.[78] Collins states that any ability to perceive objects and events in the physical world is dependent upon "inductive or regularising tendencies" which work to stabilise perceptions; it is this stability of perception which aids people to see things as things in order to interact with them and with other members of society through them.[79] Therefore, he considers experimental replication to be the "scientifically institutionalised counterpoint to the stability of perception" - in that repeatability provides a similar shared proof of a particular theorem.[80] This coupling of stabilised perception and scientific verification through the figure of repeatability finds many analogous expressions throughout Lucier's work, where replication is used to 'prove' to an audience the existence and effects of acoustic phenomena.

The recasting of these scientific imperatives of repeatability and verification as artistic or musical imperatives seems to coincide with Lucier's stated aesthetic of impersonality; they seem to be imposed from without, rather than from within. Along with the sounds, tools, and even many of the procedures found in these works, these motifs constitute a kind of 'depersonalised' material. However, to place Lucier solely within a landscape of neutral sounds, found technology and scientific procedures would almost leave us without an artist. Instead what is enacted through Lucier's recontextualisation of scientific demonstrations is a shift in emphasis from experimentation to exploration, and from outcome to process. This focus on process parallels the temporal nature of sound itself. To hear (or 'see') acoustic phenomena is to hear acoustic phenomena happening in time. Therefore, in Lucier's work, verification is present as an ongoing procedure, rather than a conclusion.

This highlighting of process serves to re-orientate these scientific situations towards Lucier's primary concerns - to "uncover sounds or aspects of sounds which we seldom hear because of our concern with musical language" - and connects these visualisation works to his earlier compositions. The exploration of the resonant characteristics of the drums ties *Music for Pure Waves, Bass Drums and Acoustic Pendulums* back to the articulated spaces of *Chambers* and *Music for Solo Performer*, reinforcing Lucier's ongoing concern with the effects of resonance. As with *Music on a Long Thin Wire* and *The Queen of the South*, the function of the sine wave is twofold, providing both a source of sound and a source of motion for driving vibrations. However, the shift from a static sine tone of fixed frequency to a sweeping tone in both *Music for Pure Waves, Bass Drums and Acoustic Pendulums* and *Directions of Sounds from the Bridge* signified the increasingly important role that sine and sine-like tones would go on to play in later compositions.

Even though there had been a substantial change in sound sources - from fixed tone to sweep tone - this was not accompanied by any substantial change in the focus of Lucier's compositions. As shown in *Music for Pure Waves, Bass Drums and Acoustic Pendulums*, the use of sweep tones did not produce a variety of different effects, but instead broadened the range of a single effect, showing both the manifestation and the persistence of specific acoustic phenomena across the spectrum of sound. However, the change from static to sweeping tones was not unproblematic. Lucier acknowledged that a sweeping tone had the ability to disturb the kind of static, environmental listening model he deemed best for the perception of acoustic phenomena - it suggested a hint of narrative structure in its progression from low frequency to high. He sought to overcome this effect in *Directions of Sounds from the Bridge* through the use of extremely slow changes in frequency. This perceived potential for narrative could also be overcome in the installation version of *Music for Pure Waves, Bass Drums and Acoustic Pendulums* through the use of repetition; the tone would sweep from low to high over a period of time, before beginning again at the low frequency. However, performances would inevitably retain this sense of narrative. Of course, earlier process-orientated works such as *I am sitting in a room* and *The Only Talking Machine of Its Kind in the World* also followed a similar 'narrative' trajectory without relinquishing acoustic phenomena as their subject matter.[81] Nonetheless, where in the past works such as *Music on a Long Thin Wire* had been capable of being realised as installation, performance, or an amalgam of the two, future works with sweeping tones would be more clearly defined as either one or the other. However they were conceived, new works would still have to respond to the change introduced by the use of sweeping tones.

Sweeping, spinning and seesawing

The works that follow *Music for Pure Waves, Bass Drums and Acoustic Pendulums* return to Lucier's earlier concerns with moving sound in space. Lucier acknowledges that these works explore the same principals as *Still and Moving Lines of Silence*, as in each of the works interference patterns are produced between long tones to create elliptical patterns of acoustic beats that spin in space.[82] Similarly, these new works once again involved instrumental performers, now interacting with the sine-like sweep tones. The first composition of this kind, *Crossings* (1982-84), was an orchestral piece, the result of an invitation for Lucier to produce a work for the opening concert of the New Music America festival in 1982.[83] *Crossings* used a rising tone that swept across the entire range of the orchestra, beginning below the low C at 32 Hz and rising to slightly above a high C at 4186 Hz.[84] Members of the orchestra alternated in playing each of the chromatic notes in ascending order through seven octaves, introducing each pitch slightly ahead of the rising sine tone and sustaining it for sixteen seconds.[85] The interference pattern between the instrumental sound and sweeping tone produced acoustic beats, which would begin to slow in speed as the two tones reach unison, before accelerating as the pitch 'crosses' the rising tone, the resulting patterns of deceleration-stasis-acceleration forming the basic gestures of the work.[86] As the pitch of the tone rose, each beating pattern started faster, slowed quicker and accelerated quicker due to the multiplication of frequencies.[87]

Conventional western instrumentation had by 1982 become a feature of Lucier's work. The two previous compositions that used sweeping tones had also featured instruments such as violins and bass drums, but these were used simply as resonating bodies, much in the manner of the unattended snare drums of *Still and Moving Lines of Silence* and the alpha wave driven percussion of *Music for Solo Performer*.[88] For *Crossings*, instrumentalists would once again be required, but with the constant, fixed frequency of the sine tone replaced with a sweeping tone, their role would be the reverse of that of the horn players and vocalists in *Still and Moving Lines of Silence*. Earlier compositions such as *Still and Moving Lines of Silence* and *Outline of Persons and Things* had relied on static sine tones as both a means for producing acoustic effects, and for providing a continuous, environmental context for listening to those effects. With the introduction of the sweep tone into a performance situation, stability of tone would now be the domain of the performers, with each instrument generating one of a succession of static pitches against which the rising pitch of the sweep tone would form interference patterns. Once again, instrumentalists would be called upon to act as oscillators, in that they were required to produce unwavering tones of fixed frequency (albeit at a range of different frequencies over a given performance); however, in this instance, it would be against a shifting environment of sound.

Despite the perceived narrative element that the introduction of a sweeping tone might imply, Lucier considered it capable of fulfilling much the same function as a static sine tone. However, just as sine tones had to maintain their stability of frequency, so to the sweeping tone had to be kept free of manipulation if it was to permit acoustic phenomena to be perceived without interference: "It has to be that way so that when the instruments cross the pure wave you hear the differences. If you screw up the wave then it becomes expressive, it's like a theremin or something. I'm always cutting things down to their simplest form so that the phenomena is exposed. The minute your hand goes in there, you alter."[89] This kind of distanciation is even more evident with *In Memoriam Jon Higgins* (1984), a companion piece to *Crossings*, where the orchestra was replaced with a clarinet. Similar to *Crossings*, the sweep tone covered the full range of the instrument, rising at the rate of approximately one semitone every thirty seconds. The clarinet progressively played and held each tone for a full minute, beginning above the pitch of the rising wave, before 'crossing' the rising pitch at the point of unity, and effectively falling below it in pitch as the sweep tone continued to rise. The reduction in the number of instruments and instrumental timbres allowed beating patterns to appear more vividly, which stressed Lucier's use of acoustical beats as structural rather than ornamental.[90] It also allowed listeners to more clearly perceive the rotating ellipses of sound, such as those first found in *Still and Moving Lines of Silence*, and helped the beating patterns to be experienced not just rhythmically but spatially.

The perception of acoustic beating as a spatial phenomenon becomes even more apparent in the installation *Seesaw* (1983). Unlike the other sweep tone works it is fully electronic, employing one fixed sine wave and one sweeping wave. However, rather than perceiving the movement of sound against the orchestra-wide electronic sweep tone of *Crossings*, *Seesaw* used an almost imperceptible wavering in frequency to spin sound in space. *Seesaw* is probably Lucier's most stark and reductive work, and involved only two loudspeakers facing each other across an acoustically deadened room. One loudspeaker emitted a steady sine tone of 256 Hz, the second a tone sweeping between 255.8 Hz and 256.2 Hz - from just slightly below to slightly above the fixed frequency.[91] The sweeping tone was set to cover a full cycle (starting at unison, increasing in frequency to its highest point before dropping in pitch until reaching the lower frequency and returning to unison) in approximately three minutes. Beating patterns were formed between the two tones as they drew apart in frequency. The acoustic interference between the standing waves produced by the two tones also caused the beats to spin in elliptical patterns. As discussed earlier, the direction of this rotation is determined by the source of the lower of the two sounds. As one tone remained at a fixed frequency while the other oscillated above and below it, each loudspeaker successively became the source for the lower sound, alternating the movement of sound first towards one loudspeaker, then the other.[92] As the range of the sweep was very small (only 0.4 Hz, a fraction of a semitone) and executed so gradually, any shift in pitch was significantly less noticeable than the acoustic effects it produced.

Seesaw is a clear offshoot of the 'sonic environment' of *Still and Moving Lines of Silence*, as is its companion piece *Spinner* (1984), a sound installation for six closely tuned oscillators of fixed frequency.[93] Two loudspeakers play three sine tones each, tuned to produce slowly shifting patterns of moving beats and standing waves.[94] Both retain elements of the same static, environmental listening situation found in *Still and Moving Lines of Silence* and *Music on a long Thin Wire* (amongst others), not just in their use of a fixed reference tone, but in the case of *Seesaw*, through the continuous oscillation of the sweeping tone from high to low frequency. This repetition in the form of oscillation also overcame any potential sense of narrative that the glissando-like sweep tone had introduced to both *Crossings* and *In Memoriam Jon Higgins*. However, where the effects of narrative seemed to problematise an environmental reading of the listening situation, they had not only broadened the range of a single effect, but presented a new condition for the perception of acoustic effects. Each clarinet note of *In Memoriam Jon Higgins* represents half an oscillation of the process found in *Seesaw* shifted into a different frequency register. Therefore the glissando sweep of *In Memoriam Jon Higgins* or *Crossings* does not present the listener with the experience of perceiving a single sonic environment or sonic context defined by static frequencies - as in *Still and Moving Lines of Silence*. Instead, its sweeping tone represents the scanning of a range of potential single or multiple frequency sound environments such as *Seesaw* or *Spinner*, each capable of producing a specific effect, exemplified through the interaction between the rising tone and the sustained note of the instrument.

This proliferation of fixed sine tone 'environments' was realised in Lucier's new version of *Still and Moving Lines of Silence in Families of Hyperbolas* in 1984. Rather than constructing one sonic environment in which a number of events took place, the work was now comprised of twelve short pieces, eleven solos and a duet, for instruments and sine tones. In the pieces for instruments capable of sustaining pitches (clarinet, female voice, flute, horn, viola, violin duet, cello, and violin), the performer played sixteen long tones, separated by silences, against one or two fixed sine tones. As in the original version of the work, with each note the musicians slightly raised and lowered their pitch to produce audible beats with the sine wave.[95] The interference between the two sounds once again produced crests and troughs of loud and quiet sound that would rotate in space. The pieces for percussion instruments (marimba, xylophone, glockenspiel and vibraphone) required the performer to play a series of repeated even strokes on one note, again separated by silences, accompanied by a sine tone which had been tuned to produce a simple beating pattern. As the percussion instruments were all fixed in pitch, different beating effects were produced through playing faster or slower strokes. Each change in tempo created a different interference pattern with the standing wave produced by the sine tone. The short decay times of the percussion instruments meant that rather than affecting a smooth spinning of sound like the sustaining instruments, sounds become localised at different points in space.[96] As a whole, this new version of *Still and Moving Lines of Silence* presented a catalogue of beating-related interference phenomena across a broad range of instruments, with each piece emphasising a particular facet of the relationship between two sounds in space.

While each of these twelve pieces sees the return of the kind of listening situation Lucier valued for the perception of acoustic phenomena, at the same time they also reformulated the more open-form environment of the original work into a far more conventionally presented suite of pieces - a series of variations on a theme. Lucier has continued with conventional instruments in his explorations of acoustic phenomena, and although sine tones and sweeping tones have played a major role in subsequent compositions, he has increasingly shied away from the use of electronics in favour of solely acoustic works. However, the centrality of listening in Lucier's practice, demonstrated concretely and conceptually through his use of sine tones, remains.

[1] Alvin Lucier, "The Tools of My Trade," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 446.
[2] Of the 27 compositions in the period 1973-1984 (including *The Re-orchestration of the Opera "Benvenuto Cellini" by Hector Berlioz* and both versions of *Still and Moving Lines of Silence in Families of Hyperbolas*), at least 14 use sine or sine-like tones in some capacity.
[3] Douglas Simon, "Interviews with Douglas Simon," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 152.
[4] James Tenney, "Interview with James Tenney," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 214.
[5] Thomas Moore, *Alvin Lucier in Conversation* [web site] (1983 [cited April 25 2007]); available from http://research.umbc.edu/~tmoore/interview_frame.html?/~tmoore/lucier.html.
[6] Alvin Lucier, "Origins of a Form: Acoustical Exploration, Science and Incessancy," *Leonardo Music Journal* 8 (1998): 8.
[7] Thomas D. Rossing, *The Science of Sound*, 2nd ed. (Reading: Addison-Wesley Publishing Co., 1990), 38.
[8] ibid., 39.
[9] Robert Ashley, "Landscape with Alvin Lucier," in *Music with Roots in the Aether: Interviews with and Essays About Seven American Composers*, ed. Gisela Gronemeyer & Reinhard Oehlschlägel (Köln: MusikTexte, 2000), 86.
[10] Simon, "Interviews with Douglas Simon," 170. Lucier has also referred to a performance of the work using electric guitars and oscillators as forming an "electric pond." ibid., 160.
[11] Lucier, "The Tools of My Trade," 448.
[12] Simon, "Interviews with Douglas Simon," 158.
[13] ibid., 154.
[14] Alvin Lucier, *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 358.
[15] Simon, "Interviews with Douglas Simon," 166.
[16] Lucier, *Reflections*, 358.
[17] ibid.
[18] ibid., 360.
[19] Simon, "Interviews with Douglas Simon," 158.
[20] ibid.
[21] The whistling tones of *Quasimodo the Great Lover* are a clear exception.
[22] Ashley, "Landscape with Alvin Lucier," 80.
[23] ibid., 85. The transcribed interview "Landscape with Alvin Lucier" is drawn from Robert Ashley's video series *Music with Roots in the Aether*. Having revisited the original video, it seems the phrase "the radio, the telephone" has been incorrectly transcribed as "to regulate the telephone," and has therefore been corrected here.
[24] Lucier, "The Tools of My Trade," 456.
[25] ibid., 458.
[26] ibid.
[27] Lucier's conception of the relationship between technological artefacts and his environment finds some resonance in Martin Heidegger's discussion of the nature of tools and equipment. Heidegger considered context as the prime factor in determining the relationship between human subjects and how they understood the objects they encountered in the world, positing that things are not simply present in the world but are were instead made present through the context. In this regard, tools are experienced as belonging to an *equipmental context*, or ensemble of tools, that specifies the use of any tool and in which that tool plays its various roles. Within this equipment context, the nature of tool is further defined by its *assignment* - the job for which it is designed. The condition under which a given tool is most truly "the thing that it is" is when the tool is used according to its assignment within its equipmental context. Following Heidegger's model, the impersonal aspects Lucier locates in electronic technology are in part the result of his associating these artefacts with a specific equipmental context and assignment - that is, one of science and testing - rather than with the particular aesthetic context in which he

would employ them. See Robert P. Crease, *The Play of Nature: Experimentation as Performance* (Bloomington: Indiana University Press, 1993), 61-63.
[28] Alvin Lucier, "The Propagation of Sound in Space," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 430.
[29] Ashley, "Landscape with Alvin Lucier," 82.
[30] ibid.
[31] Michael Parsons, *Beats That Can Push Sugar* [web site] (LMC, 1995 [cited October 21 2005]); available from http://www.l-m-c.org.uk/texts/lucier.html.
[32] Ashley, "Landscape with Alvin Lucier," 81.
[33] ibid.
[34] Arthur Margolin, "Conversation with Alvin Lucier," *Perspectives of New Music* 20, no. 1 & 2, Spring-Summer (1981): 56.
[35] Parsons, *Beats That Can Push Sugar*.
[36] Tenney, "Interview with James Tenney," 214.
[37] Simon, "Interviews with Douglas Simon," 172.
[38] Lucier, *Reflections*, 370.
[39] ibid.
[40] Lucier, "The Propagation of Sound in Space," 436.
[41] Lucier, "The Tools of My Trade," 462.
[42] Winston E. Kock, *Seeing Sound* (New York: Wiley-Interscience, 1971), 34.
[43] Ashley, "Landscape with Alvin Lucier," 81.
[44] ibid.
[45] Alvin Lucier, "My Affairs with Feedback," *Resonance* 9, no. 2 (2002): 24. Douglas Kahn, the artist and writer who sent Lucier the 'singing bird ball', recalls that it was made out of "the finest cheapest plastic, had an electric cord coming out of it, and generated a very electronic bird singing sound. As I remember, the song grew longer between pauses as the electronics grew warmer and warmer." Personal correspondence, 13th July 2007.
[46] ibid., 25.
[47] Parsons, *Beats That Can Push Sugar*.
[48] Walter Malcolm Dalton, *The Story of Radio*, 3 vols., vol. 1: How Radio Began (London: Adam Hilger, 1975), 108-09. Fessenden submitted a patent application for his 'wireless signalling' system in 1901, but it was not granted until August the following year. His continuous wave system was the first of its kind, the antecedent of amplitude modulation (AM) radio broadcasting.
[49] Susan J. Douglas, *Inventing American Broadcasting 1899-1922* (Baltimore: Johns Hopkins University Press, 1987), 45.
[50] Simon, "Interviews with Douglas Simon," 174.
[51] Nicolas Collins, "All This and Brains Too: Thirty Years of Howling Round," *Resonance* 9, no. 2 (2002): 7-8.
[52] Feedback also has a long history in rock'n'roll music, especially since being popularised in the 1960s by artists such as Jimi Hendrix, The Velvet Underground and Pete Townsend of The Who, to name just a few.
[53] Thom Holmes, *Electronic and Experimental Music: Pioneers in Technology and Composition*, Second ed. (New York: Routledge, 2002), 27.
[54] Robert Ashley, Liner notes, *The Wolfman* compact disc (Alga Marghen plana-A 20NMN.048, 2003).
[55] David Behrman, Liner notes, *Wave Train* compact disc (Alga Marghen plana-B 5NMN.020, 1998).
[56] Maggie Payne, "The System Is the Composition Itself," in *Music with Roots in the Aether: Interviews with and Essays About Seven American Composers*, ed. Gisela Gronemeyer & Reinhard Oehlschlägel (Köln: MusikTexte, 2000), 111. Other works, such as *Pendulum Music* (1968) by Steve Reich, produced pulses of feedback from microphones swinging in front of speakers, the tone and phase relationships of the feedback sounds determined by their slowing motion. Percussionist Max Neuhaus also employed feedback in his performances of John Cage's *Fontana Mix* (1965) by amplifying tympani with microphones, producing tones influenced by the

resonating drum skins and hollow bodies. Michael Nyman, *Experimental Music: Cage and Beyond* (New York: Schirmer, 1974), 100.
[57] Douglas Kahn, *Noise Water Meat: A History of Sound in the Arts* (Cambridge: MIT Press, 1999), 227.
[58] ibid., 413.
[59] Lucier, "The Tools of My Trade," 462.
[60] Lucier, "Origins of a Form," 9.
[61] Lucier, *Reflections*, 356.
[62] ibid.
[63] ibid., 374.
[64] Liner notes, Alvin Lucier, *Music on a Long, Thin Wire* compact disc (Lovely Music LCD 1011, 1992)
[65] Lucier, *Reflections*, 374.
[66] Margolin, "Conversation with Alvin Lucier," 53.
[67] Simon, "Interviews with Douglas Simon," 190.
[68] Lucier, *Reflections*, 378.
[69] Simon, "Interviews with Douglas Simon," 202.
[70] Lucier himself has used a cello for realisations of this work, tuning the sine wave initially to the low C, then slowly sweeping up to the top of the cello's range: William Duckworth, "Interview with William Duckworth," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 38.
[71] Kock, *Seeing Sound*, 7-11.
[72] Lucier, *Reflections*, 380. Lucier's score also allows for the use of time-lapse photography and other "visual storage systems."
[73] The book in question: Edmund Catchpole & John Satterly, *Textbook of Sound*, 7th ed. revised by H.N.V. Temperley (London: University Press, 1949), Lucier, "Origins of a Form," 8. A similar experiment using a tuning fork instead of bell appears in Dayton Clarence Miller, *The Science of Musical Sounds* (New York: Macmillan, 1916), 3.
[74] ibid.
[75] ibid., 10.
[76] Harry M. Collins, *Changing Order: Replication and Induction in Scientific Practice* (London: Sage, 1985), 2, 130.
[77] Sometimes there were other unexpected mitigating factors. In a performance of a work for contrabass clarinet and sine wave, Anthony Braxton's ability to maintain accurate pitch meant that the acoustic beating produced by the interaction of the clarinet tone and the sine tone remained regular throughout the duration of the work, instead of the expected variations in rhythm a less competent performer would have produced (although in this context, it could be said that Braxton 'incompetently' produced the minute fluctuations in intonation that the work required). Lucier, *Reflections*, 284.
[78] See "Paradigm for the Sociology of Knowledge" (8-40) and "The Normative Structure of Science" (267-278) in Robert K. Merton, *The Sociology of Science: Theoretical and Empirical Investigations* (Chicago: University of Chicago Press, 1973).
[79] Collins, *Changing Order*, 9.
[80] ibid., 19.
[81] In regards to *Music for Pure Waves, Bass Drums and Acoustic Pendulums*, and indeed any of the works which use sweeping tones, the notion of a trajectory should not be equated with Michel Chion's term 'vectorisation', which he uses to describe a kind of imperative found in the attack-decay-resonance scheme of a given sound, giving it a beginning, middle and end. The sweeping tone in *Music for Pure Waves, Bass Drums and Acoustic Pendulums* could just as easily sweep from high to low frequency and still elicit the same acoustic phenomena which are the subject of the composition. Any sense of narrative found in the work was due only to the change in frequency, not to the dynamic shape of the envelope. See Michel Chion, *Audio-Vision*, trans. Claudia Gorbman (New York: Columbia University Press, 1994), 18-20.
[82] Moore, *Alvin Lucier in Conversation.*

[83] Daniel Wolf, "Interviews with Daniel Wolf," in *Reflections: Interviews, Scores, Writings* (Köln: MusikTexte, 1995), 244.
[84] Liner notes, Alvin Lucier, *Crossings* compact disc (Lovely Music LCD 1018, 1990).
[85] ibid. The piece is scored for an orchestra of sixteen players: two flutes with piccolos; two oboes, one with english horn; two clarinets in Bb, with bass clarinets in Bb; bassoon; trumpet in C; two horns in F; tuba; two violins; viola; cello; and double bass.
[86] ibid.
[87] Tenney, "Interview with James Tenney," 212.
[88] Lucier at this time updated the combination of brainwaves and percussion found in *Music for Solo Performer* with a new work *Music for Alpha Waves, Assorted Percussion, and Automated Coded Relays* (1982).
[89] Tenney, "Interview with James Tenney," 234.
[90] Wolf, "Interviews with Daniel Wolf," 280.
[91] Alvin Lucier, "Seesaw: A Sound Installation," in *Words and Spaces: An Anthology of Twentieth Century Experiments in Language and Sonic Environments*, ed. Stuart Saunders Smith and Thomas Delio (Lanham: University Press of America, 1989), 225.
[92] ibid., 224.
[93] In the liner notes to the compact disc recording of *Still and Moving Lines of Silence*, Lucier refers to the work as having four parts, the first of which is a sound installation comprised of a fixed and a sweeping tone in the same manner as *Seesaw*. See Alvin Lucier, Liner notes, *Still and Moving Lines of Silence in Families of Hyperbolas* double compact disc (Lovely Music LCD 1015, 2002)
[94] Tenney, "Interview with James Tenney," 210.
[95] Lucier, Liner notes, *Still and Moving Lines of Silence in Families of Hyperbolas*.
[96] ibid.

Conclusion: Not-so-simple acoustic phenomena?

> I'm going in this direction because of my own natural tendencies. There still is considerable variation in the piece, because variation is such an unavoidable factor of life that nothing exists without it. No matter how exact you try to be, no matter how many times you try to draw the line exactly the same, things will always be different. This is one of the inherent characteristics of my work. - La Monte Young[1]

Historically, the fields of music and acoustics were seen to be wholly contiguous, with every aspect of the study of sound finding a place within aesthetic concerns. However, over time, music and acoustics have diverged, with dissimilar and sometime incompatible interests and objectives, operating in different spaces. The exploration of points of connection between these two fields has served as an heuristic frame for discussing the manner in which artists have transcended the traditional reference points of music in order to encompass a broader understanding of sound. The approach of this thesis has, in part, involved using the science of acoustics in order to generate theoretical responses to experimental music - specifically the kind of music that musicology has struggled to provide an account of. Conversely, this thesis has not only attempted to examine some of the roles of acoustics in relation to aesthetics, but to reflect on several pronouncements of acoustics, in order to question the representations of sound they have produced.

In line with the above statement from La Monte Young, the concept of vicissitude has been an important part of this thesis. One facet of this work has been identifying where the changeability of conditions (including objects and systems) in the physical world has influenced both the formulation of aesthetic choices and the possibility of their execution. In doing so this thesis has traced a range of approaches utilised by both Young and Lucier for either reducing the effects of variation, or for incorporating variables into their work. In surveying the use of reductive procedures (by both natural philosophers and artists), this thesis has examined the ways in which variation has proved to be a factor that is difficult, if not impossible, to diminish or remove. This variability is not simply the 'noise' produced as a result of collisions between abstract, intellectual gestures and the 'real' world in which these gestures must take place. It is due to the fact that the work of Young and Lucier is situated at the point where the *reductive* becomes *generative*: where the pared-back nature of their method produces a proliferation of outcomes that might be otherwise occluded or unperceivable in a more complex context or situation. Their approach exposes not single or unitary phenomena - a sine wave, an acoustic beat, a difference tone - but many simple phenomena, occurring simultaneously. Stripping away the traditional components of musical language - melody, harmony, counterpoint, conventional compositional structure - has allowed their work to reveal the underlying armature of sound per se.

Compositional strategies that remove these traditional components of musical language -while simultaneously avoiding traditional sources of musical sound, incorporating silence, or reconfiguring and distending musical structure - may be understood as creating a reductive context within music. They do not, of course, somehow produce a reduction in the physical attributes of sound. What these compositions and installations do, however, is produce a very different kind of auditory experience - one where the reductive context serves to exaggerate specific characteristics of the soundscape. In the case of Lucier and Young, reduction is perhaps better understood as a radical form of *emphasis*, exercised through a focussing of attention onto the smallest details of sound - onto minute interactions, the placement of sounds, and their movement in space.[2] Therefore, any perceived 'loss' of complexity or musicality as a result of their employment of reductive procedures has the potential to be recouped through the perception of the multifaceted behaviour of sound, realised through an emphasis on listening.

In the analyses of preceding chapters there have been a significant number of claims made about the sine wave - its origin, structure, import, function, and usefulness. When the sine wave is regarded as the exemplary form of simple harmonic motion, or of simple musical sound, of 'sonic purity', it becomes a prime example of reduction as a radical form of emphasis, as it conflates these three sonic concerns into a single wave. Michel Serres has questioned the manner in which ostensibly 'pure and simple' forms can limit and conceal multiple interpretations.[3] Serres finds that this kind of conceptualisation works against notions of multiplicity, as it presents 'simple' forms as complete, theoretical knowns - singular and without residue. Throughout this thesis, importance has been placed on identifying the residual meanings excluded from the formulation of sine waves in both science and musicology order to expand upon the accounts of sound provided by those fields. For example, in the study of musical sound, research that identified the composite structure of overtones overturned any suggestion that the harmonic could be considered a sine tone with only one frequency component. Similarly, the demonstration of the impossibility of actual infinites problematises a putative identification of sine-like sound as being an exact realisation of a mathematical abstraction. These residues, mostly empirical in nature, destabilise conceptions of the sine wave as a simplex - as an exemplar of artistic, acoustic or even metaphysical purity.

Residues of the sine wave are by no means limited to the domain of science. Despite Lucier's designation of the sine wave as 'neutral' or 'found material', the sine tone could not escape its role as an aural signifier of scientific experimentation, even when transplanted to the concert stage. Instead, it worked to provide an echo of an investigative context, one that no doubt highlighted the difference in the musical concerns of Lucier as a composer and the traditional musical language from which he wished to distinguish himself. The sine waves that travelled through the air and the human auditory system introduced a level of ambiguity into aspects of Young's perceptual theory, which he deemed essential for the reception of his work *Map of 49's Dream*. The interaction between the notional purity of a sine-like sound and the physical resistance of the air produced residual frequencies, thickening the plot, even before physiological and psychoacoustical factors provided their own resistances to sinusoidal incessancy. Yet this disparity can be seen as having produced its own effects. The identification of residues does not therefore stand as an indictment or condemnation of aesthetic or scientific practices, but is instead a means of enlivening and augmenting accounts of these practices through a reintroduction of that which has been reduced.

Sine waves were but one part of a substantial shift in acoustics in the late nineteenth century that altered the way in which sound was understood and investigated. Prior to the introduction of Fourier analysis, findings drawn from the empirical audition of sounds were backed up by observation, where mechanical vibration in a variety of media was monitored over time. Sustained attention therefore played a crucial role in any measurement of sound. Of course, some earlier experimental techniques for visualising vibration, such as Chladni plates and Lissajous figures, produced images of sound that were not simply a graph of vibration over time - such as the image produced by the phonautograph - but the static images they provided did not lend themselves to mensuration. The application of Fourier analysis, however, allowed for the interpretation of sound on the basis of its harmonic structure; it heralded the progressive shift in modern acoustics from observing sound in the time domain to the analysis of sound in the frequency domain.[4] Like Chladni plates, Fourier analysis depicted an instance of sound. It effectively halted a transient phenomenon, and allowed for an analytical focus upon the material aspects of sound (that of a musical sound comprised of a related series of simple sounds) and on the spatial distribution of its components. Of course, the model of sound that Fourier analysis produced portrayed musical sound as a series of vertically arranged sine and cosine functions on a two dimensional grid. Musical sound was thereby rendered not merely static, but depthless.

Despite its restrictions, this model of the physical shape of sound contained sufficient space to accommodate artists of the avant-garde in the first half of the twentieth century looking to formulate new definitions of musical sound. For some, like Busoni, the classification of sound by frequency implied a continuum of musical tones, filling the audible spectrum (and beyond it). For others, such as Russolo and Cage, this model was more contentious, given the role it played within acoustics for delimiting musical sound from noise. These findings were, however, part of a creative reconceptualisation of musical sound, and were therefore necessarily context-specific. As the example of Cowell's tone-clusters as transposition of higher harmonies demonstrates, the overtone series could be used to pass judgement either for or against the use of extra-musical sounds in composition. The obvious exception would be Cage, who while a progenitor of this kind of discourse, had rejected harmony as the primary musical structure in favour of an encompassing aesthetic of *all-sound.* What seems most significant, especially with regard to more orchestral composers such as Varèse, was the way in which concepts drawn from acoustics - such as the overtone series or frequency ratios - allowed artists to participate in a discourse of sound that did not have the traditional concerns of music, such as melody or compositional structure, at its core. Despite his somewhat ambivalent relationship with formal acoustics, it would be Cage who would ultimately incorporate sine tones into his *Imaginary Landscape No. 1* as an extra-musical sound drawn from the world of radio.

Many of these experimental and artistic concepts - such as the representation of sound by frequency, and attention to the physical and spatial character of sound - find resonances in the aesthetic of both Young and Lucier. This is not to imply that their individual artistic approaches and conceptualisations are in any way indistinguishable; but nor are they incommensurable. On the surface, the work of these two artists seems capable of being slotted into one of two aesthetic categories: Young's work, with its mathematically described sine tone structure, is engaged in formalism; Lucier strives to produce natural acoustic phenomena, and is therefore 'naturalistic'. Yet this type of categorisation is problematic, especially as both artists maintain a flexible and somewhat idiosyncratic approach to the distinction between nature and artifice. For example: Young's numerical intervals are derived from the overtone series, which he defined as natural; he also has cited his use of long tones stems from his childhood experience of a range of sustained sounds, both naturally occurring and man-made. For Lucier, synthetic artefacts such as electronic devices are considered to form part of the landscape, and are, to a degree, on par with natural features such as trees or animals. Further, works such as *Seesaw* (which uses one sine tone, one sweeping tone and two speakers) and *Music on a Long Thin Wire* are decidedly formal in their aims and execution. Both Lucier and Young deal in formalism and naturalism in their own way.

Young and Lucier have each made claims for the aesthetic significance of their practice on the basis that their works constructed or constituted environments, and that the perception or experience of those artworks was in some ways analogous to the perceptions and experiences one might have of natural environments. For both artists, constancy became a hallmark of an environmental sound work, and one of the main features of an electrically generated sine wave is its ability to be a source of continuous (or indefinitely sustained) sound. It provided the continuum between one event and the next, and was the basis against which acoustic effects could be produced and compared, the latter appearing as features in the soundscape.[5] As such, sine waves can be considered as performing a dual function, insofar as they were a feature of an experimental or investigative procedure, while at the same time being the *control* for that same procedure; they were both figure and ground. With no attack or decay, the absence of change effected a perpetual suspension of the passing of time, marking a work such as *Dream House* or *Still and Moving Lines of Silence* as functioning as if they were a captured moment - analogous to the kind of 'time stopping' produced by Fourier analysis, except this time rendered in three dimensions.

For both artists, substantial groundwork for their use of continuous sine waves was laid in those earlier compositions that employed sounds that were neither pitched nor tuned - a clear debt to the use of extra-musical sound by Cage. Although Young had used long musical tones in his *Trio for Strings*, it was the sustained friction sounds of *2 sounds* that were pivotal in informing his experience of listening 'inside a sound'. Following that, the raucous repetitions of *X for Henry Flynt* displayed how one sound could provide enough sonic resources for a similar listening experience to take place; that one complex sound could itself be the source of a range of simpler sounds was also pivotal for Young's later work with whole number ratios. Equally, after he returned to America in the early 1960s, Lucier worked his way through rattling percussion, the echoing and reverberating sounds of whistles and electronic clicks, re-recorded voices and resonating seashells, before he commenced working with sine tones and pitched instruments. His increased use of continuous sound in the form of sine waves followed on from the gradual prolongation of sound that had its origins in earlier works that explored the transformative possibilities of acoustic resonance and of electronic sound production technology - such as the echoes of *Vespers*, the room tone of *"I am sitting in a room"*, or their combined effect in *Quasimodo the Great Lover*.

However, as earlier chapters have illustrated, the gradual shift in the work of Young from the sustained friction sounds of *2 sounds* to the continuous sines tones in *Map of 49's Dream* demonstrates a progressive reduction in the complexity of his musical materials: from broad-spectrum noise sounds, to sustained instrumental and vocal drones, and finally single frequency sounds. This was accompanied by a reconceptualisation by Young of the role of sound in music and its relationship to the listener, and produced a strict delimitation of the role of listening inside his *Dream House* installations. For Lucier, the use of the simple sound of sine waves was a reflection of his concern that complexity acted a hindrance to perception - that the density and volume of everyday sounds in the modern soundscape obscured the simple acoustic phenomena that he had made the subject of his work. Although earlier pieces had used complex sounds such as the human voice, these sounds were used primarily to elicit effects from architectural structures or technological systems. When sound itself was to provide the environmental context against which transformation would be compared or effects would be produced - such as the sine tone of *Still and Moving Lines of Silence* - it would be as a substitute for a 'noisier' milieu. Lucier's use of sine waves was also aligned with his programme of distanciation or impersonality, as he considered it provided him with a kind of neutral sonic material which would help direct listener's attention away from traditional musical concerns and notions of compositional intent, and towards the natural acoustic phenomena that were the real subject of his oeuvre.[6]

By mediating artistically at the juncture between sound and environment, the work of Lucier and Young had significant implications for the way in which listeners were positioned in relation to the sounds of their compositions and installations, and consequently in configuring the perceptual acts and experiences that were to take place within them. As this thesis has contended, the acts of listening that were deemed to take place in the sine wave works of Lucier and Young involved attending to simple acoustic phenomena, be that standing waves, acoustic beats, sum and difference tones or diffraction effects. Nevertheless, the manner in which each artist positioned the listener in relation to their work was substantially different.

Whereas the account of listening Young gave in "Lecture 1960" described a process of 'getting inside' the physical and experiential space of 'long sounds', by the time of his Dream House installations he was more interested in how sound acted *inside the listener*. This shift in objective paralleled the progressive reduction in the complexity of the sounds he used to realise his compositions - from noise sounds to sine tones. Young's switch to sine tones allowed him to construe all the elements within his listening scheme in terms of frequency, irrespective of whether they were sonic phenomena, nerve impulses or brain waves. The change in importance from the 'listener within the work' to the 'work within the listener' not only produced an internalised sense of listening - it also modelled an internalisation of acoustic phenomena: in Young's theory of perception, intervals of whole number ratios produced patterns in the brain, just as they produced patterns in the air. Sum and difference tones would form their own exact brain pattern correlates. Listening for Young became synonymous with a psychophysical process that yielded specific psychological effects. The role attention played in this scheme was one of submission, in that it involved restricting or controlling the physical needs of the body in order that the prescribed processes of perception would be able to take place. Listeners still needed to inhabit the sound environment, but only so that a similar sine tone structure could be established inside them.

For Lucier, the environmental factors in his work reflected those aspects of his compositional practice that were directed at the behaviour of sound itself. For example, a work such as *Outlines of Persons and Things* provided a demonstration of the effects produced by the propagation of sound in three dimensions. Dimensionality therefore played an important part in determining the relationship of sound to listener. If sound events took place in three dimensions, then listening also needed to take place in that same three-dimensional space. Therefore it was crucial that listeners' share the space with the work. However, unlike listeners in Young's *Dream House*, they must to some degree remain separate and distinct from the sounds and effects that were realised within the context of the work in order to perceive them as natural acoustic phenomena. Listeners, therefore, became a feature of the environment, just as the sine waves and simple acoustic phenomena were features. Of course, any of Lucier's compositions involved a proliferation of acoustic phenomena, not just the one or two specified as the subjects of a particular work. As a result, the highlighting of one phenomenon over any others involved the careful focussing of attention onto the perception of one sonic event amongst many.

Whether sound was to be experienced as an environmental feature (as in the work of Lucier) or as a psychological effect (as in Young's *Dream House*), what remains central in the work of Young and Lucier is the act of listening - an act considered to be as important for the artist as it is for the audience. Although their works would be subject to the vicissitudes of audience attention and the complexity of the physical world, they succeeded in revealing simple acoustic phenomena as a consequence of sound interacting with itself and with the environment. Although this 'revelatory' aspect of acoustic phenomena finds a different expression with each artist, it is nonetheless an important operation of their artworks, which have undeniably expanded the role of sound in music. It could be said that defining simple acoustic phenomena as the subject for musical compositions is itself a means for identifying the residues that have resulted from the traditional formulation of western art music. In doing so, both Lucier and Young have expanded the use of sound in art to include the discrete and natural phenomena that occur when a sound interacts with its environment, and also with other sounds, through a renegotiation of the contract between notions of musical sound and listening.

[1] Richard Kostelanetz, "Conversation with La Monte Young," in *Selected Writings* (Munich: Heiner Freidrich, 1969), 62.
[2] I would like to acknowledge Joyce Hinterding for a crucial discussion that produced this argument.
[3] Michel Serres, *Hermes: Literature, Science, Philosophy*, trans. Ilya Prirogine and Isabelle Stengers (Baltimore: Johns Hopkins University, 1982), 97.
[4] Harry B. Miller, "Acoustical Measurement and Instrumentation," *Journal of the Acoustical Society of America* 61, no. 2 (1977): 274.
[5] This is not to say that constancy necessarily produced constant *sounds*, or even a constant *pitch*: for example, the sine wave signal that powered *Music on a Long Thin Wire* produced a range of pulses, rhythms and harmonics from the wire. It also produced moments of silence. It was, however, a constant signal.
[6] The irony is that thirty six years after his first use of sine waves in *The Queen of the South*, Lucier is now irrevocably associated with the use of sine waves in experimental composition.

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