Synthesizing Sound:

Metaphor in Audio-Technical Discourse and Synthesis History

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ABSTRACT

Synthesized sound is ubiquitous in contemporary music and aural environments around the world. Yet, relatively little has been written on its cultural origins and meanings. This dissertation constructs a long history of synthesized sound that examines the century before synthesizers were mass-produced in the 1970s, and attends to ancient and mythic themes that circulate in contemporary audio-technical discourse. Research draws upon archival materials including late-nineteenth and early-twentieth century acoustics texts, and inventors' publications, correspondence, and synthesizer product manuals from the 1940s through the 1970s.

As a feminist history of synthesized sound, this project investigates how metaphors in audio-technical discourse are invested with notions of identity and difference. Through analyses of key concepts in the history of synthesized sound, I argue that audio-technical language and representation, which typically stands as neutral, in fact privileges the perspective of an archetypal Western, white, and male subject. I identify two primary metaphors for conceiving electronic sounds that were in use by the early-twentieth century and continue to inform sonic epistemologies: *electronic sounds as waves*, and *electronic sounds as individuals*. The wave metaphor, in circulation since ancient times, produces an affective orientation to audio technologies based on a masculinist and colonizing subject position, whereby the generation and control of electronic sound entails the pleasure and danger of navigating and taming unruly waves. The second metaphor

took shape over the nineteenth century as sounds, like modern bodies and subjects, came to be understood as individual entities with varying properties to be analyzed and controlled. Notions of sonic individuation and variability emerged in the contexts of Darwinian thought and a cultural fascination with electricity as a kind of animating force. Practices of classifying sounds as individuals, sorted by desirable and undesirable aesthetic variations, were deeply entwined with epistemologies of gender and racial difference in Western philosophy and modern science. Synthesized sound also inherits other histories, including applications of the terms synthesis and synthetic in diverse cultural fields; designs of earlier mechanical and electronic devices; and developments in musical modernism and electronics hobbyist cultures. The long-term and broad perspective on synthesis history adopted in this study aims to challenge received truths in audio-technical discourse and resist the linear and coherent progress narratives often found in histories of technology and new media.

This dissertation aims to make important contributions to fields of sound and media studies, which can benefit from feminist contributions generally and elaboration on forms and meanings of synthesis technologies specifically. Also, feminist scholars have extensively theorized visual cultures and technologies, with few extended investigations of sound and audio technologies. This project also aims to open up new directions in a field of feminist sound studies by historicizing notions of identity and difference in audio-technical discourse, and claiming the usefulness of sound to feminist thought.

RÉSUMÉ

Le son synthétique est omniprésent dans la musique contemporaine et dans l'environnement sonore à l'échelle mondiale. Cependant, on a relativement peu écrit sur sa signification ou sur ses origines culturelles. Cette thèse construit une longue histoire du son synthétique au cours du siècle avant que ne soit massivement introduit le synthétiseur dans les années 1970; et s'attache aux thèmes anciens et mythiques qui émanent dans le discours contemporain de la technique audio. Cette recherche s'appuie sur des documents d'archives, y compris ceux de la fin du XIXe siècle et du début du XXe siècle, comprenant des textes acoustiques, des publications d'inventeurs, de la correspondance ou des manuels d'utilisation des synthétiseurs à partir des années 1940 jusqu'aux années 1970.

En tant que récit féministe du son synthétique, ce projet étudie comment les métaphores dans le discours de la technique audio sont porteuses de notions d'identité et de différence. À travers l'analyse de concepts clés de l'histoire du son synthétique, j'affirme que le langage de la technique audio et sa représentation, qui passe habituellement pour neutre, privilégie en fait la perspective masculine, archétypale du sujet blanc occidental. J'identifie deux métaphores primaires pour la conception des sons électroniques qui ont été utilisés à l'aube du XXe siècle et qui contribuent sans cesse à une épistémologie du son: des sons électroniques comme des vagues et les sons électroniques en tant qu'individus. La métaphore des vagues, en circulation depuis l'aube des temps, est productrice d'un affect aux technologies audio, typiquement basé sur un point de vue masculin et colonisateur; où la création et le contrôle du son électronique entraîne le plaisir et le danger propre à la navigation sur une mer houleuse. La seconde métaphore a pris forme au cours du XIXe siècle au moment où les sons,

comme des organismes vivants modernes, sujets, se sont vus interprétés comme de véritables entités individuelles aux propriétés variables pouvant faire l'objet d'analyse et de contrôle. Les notions d'individuation et de variabilité sonore émergèrent dans le contexte d'une pensée Darwinienne, alors qu'une fascination culturelle pour l'électricité vue comme une sorte de puissance immuable, se forgeait. Les méthodes de classification des sons en tant qu'individus, triés en fonction de variations esthétiques désirables ou indésirables, ont été intimement liées aux épistémologies du sexe et de la différence raciale dans la philosophie occidentale et dans les sciences modernes. Le son électronique est aussi l'héritier d'autres histoires, incluant les usages de notions telles que *synthèse* ou *synthétique* dans divers champs culturels; le design des premiers dispositifs mécaniques et électroniques, ou encore l'évolution de la modernité musicale et le développement d'un public amateur de culture électronique. La perspective à long terme et le large spectre sur l'histoire de la synthèse musicale adoptée dans cette étude vise à contester les vérités reçues dans le discours ambiant de la technique audio et à résister à la progression d'histoires linéaires et cohérentes qu'on trouve encore trop souvent dans l'histoire de la technologie et des nouveaux médias.

Cette thèse contribue d'une façon importante au domaine des études en son et médias, qui pourraient à leur tour bénéficier d'un apport féministe en général et plus spécifiquement de l'élaboration des formes et des significations des technologies de la synthèse musicale. En outre, si les universitaires féministes ont largement théorisé les nouvelles cultures technologiques ou visuelles, peu d'entre elles ont exploré le son et les techniques audio. Ce projet veut ouvrir de nouvelles voies dans un domaine d'études féministes du son dans une perspective historienne avec des notions d'identité et de différence dans le discours de la technique audio, tout en clamant l'utilité du son à une pensée féministe.

We have also sound-houses,
where we practise and demonstrate
all sounds and their generation...
We represent small sounds as great and deep;
likewise great sounds, extentuate and sharp;
we make divers tremblings and warblings of sounds...
We represent and imitate all articulate sounds and letters,
and the voices and notes of beasts and birds.
– Francis Bacon, *New Atlantis*, 1626

Where did they come from, those dim, slow, vast tides?...
We could not understand that; we could only feel their touch against us,
but in straining our sense to guess their origin and end, we became aware of...
something out there in the darkness of the great currents: sounds...
Sound is a fragile thing, a tremor, as delicate as life itself.
– Ursula Le Guin, *The New Atlantis*, 1975

INTRODUCTION: SOME FUNDAMENTAL PARAMETERS

> Figurations can be condensed maps of contestable worlds... think of a small set of objects into which lives and worlds are built—chip, gene, seed, fetus, database, bomb, race, brain, ecosystem... dense nodes that explode into entire worlds of practice... We inhabit and are inhabited by such figures that map universes of knowledge, practice and power.
> – Donna Haraway, "Syntactics: The Grammar of Feminism and Technoscience" (1997, 11)

> The MICROMOOG is a world of sound in a nutshell.
> – Moog synthesizer specification sheet (1975)

Synthesized sound is ubiquitous in contemporary music and aural environments around the world (Davies 2002, 43-44; Greene 2005, 2). It is generated electronically through techniques of analysis and recombination of a sound's constituent elements. It emanates from a proliferation of hardware and software synthesizers (Synthtopia 2010), and synthesis techniques also structure many of the sounds emitted by mobile phones and other electronic devices (Gleick 1998; Heffernan 2010). Synthesized sound circulates in a "global circuit" of electronics manufacturing and musical instrument production and use. As quickly as musicians develop new sounds, often working with synthesizers that are designed and built in factories far away, sounds of local cultures are incorporated into the next generation of electronic musical instruments and redistributed globally by multinational corporations (Greene 2005, 5-6; see also Théberge 2004; Reiffenstein 2006).

Despite its prevalence and wide-ranging travels—or perhaps *because* it is such a common element in contemporary soundscapes—relatively little has been written from critical perspectives about how synthesized sound is produced, and on its cultural roots and meanings. (Compare a broad range of literature on technologies of sound recording and reproduction: see Chanan 1995; Morton 2000, 2006; Sterne 2003; Katz 2004; Millard 2005; Weheliye 2005; Gitelman 2006; Wurtzler 2007.) Scholars and documentary filmmakers interested in synthesized sound have explored such noteworthy phenomena as the mass appeal of Wendy Carlos's album *Switched-On Bach* and the marketing of Moog and other analog synthesizers made by small companies in the 1970s (Pinch and Trocco 2002a; Fjellestad 2004); the production of digital synthesizers by multinational corporations beginning in the early 1980s, exemplified by Yamaha's popular DX-7 model (Théberge 1997, 73-74); and the contributions of the Roland TB-303 bass-line synthesizer to the characteristic sound of acid house and other musical genres (Gilbert and Pearson 1999, 124-25; Harrison 2005). Such distinctive sounds and events of the last few decades contribute to a popular assumption that the history of synthesized sound extends *all the way back to the 1960s*.

This project reperiodizes the history of synthesized sound by examining ideas and machines of synthesis that manifested in acoustics texts and other technical writings throughout the century before synthesizers were popularized and mass-produced. It also takes seriously the citations of ancient and mythic themes in these texts as partly constitutive of the long history of audio technologies and cultures in the present. It addresses a set of questions: How did synthesized sound come to be known as a technological means for the generation and control of waves? How did sounds more generally become conceived as individual entities, with varying properties of loudness, duration, and color that could be electronically synthesized? How was the idea of synthesized sound influenced by circulations of the term synthesis in other fields, such as life sciences and philosophy, and by cultural notions of the natural and synthetic?

I use metaphor as a way into these questions. Metaphor marks the articulation of descriptive concepts, visual representations, and narrative strategies to physical phenomena and subjective experiences of sound: the meeting of the figurative and material through audio-technical discourse. In the late-nineteenth and early-twentieth centuries, as sounds became electronically produced and reproduced as signals and modern listening techniques were cultivated to interpret them, there were stakes in the representational conventions established in audio-technical discourse. It is my contention that a world of others—other to the white and male subjects of science and history—inhabit the metaphors that constitute knowledge about sound.

This project forms part of my ongoing work to combine feminist historiographic methods with the study of electronic music and sound. Over the last decade, as editor of the Pinknoises.com website and a related book, I conducted interviews with women who make electronic music. *Pink Noises* introduced a greater range of perspectives on electronic music history and culture through ethnographic research with women who are cultural producers (Rodgers

2010). It constituted a critical intervention in existing historiography, which has focused on the cultural contributions of a limited group of white men who are composers and inventors (McCartney and Waterman 2006, 4; Oliveros 1984, 47-51). The dissertation takes this work in a new direction by using methods of feminist science and technology studies to expose how sonic epistemologies are inflected with perspectives of an archetypal Western, white, male subject. It examines representation as a site from which histories of audio technologies can be told differently.

Analog Signification: Visual Cultures and Sonic Meanings

Histories and media accounts of electronic and experimental music have routinely marginalized or exoticized women and racial minorities as cultural producers while touting a “universal” experience of electronic sound (Rodgers 2010, 14, 91-93; see also Lee 1998). My research in this dissertation suggests that these omissions and objectifications in historical accounts have been accompanied by signifying practices within the formal structures and aesthetics of electronic sound that normalize white men as the subjects of audio-technical discourse, as proper creators and navigators of synthetic sound waves. I use the phrase *analog signifying practices* to refer to the ways that audio-technical discourse and audio technologies materialize and circulate analogies, which mark notions of identity and difference and relations of power in representations of electronic sound.

I expand this concept out of Lisa Nakamura’s work, which has foregrounded the materiality of embodiment—especially raced and gendered embodiment—"that underlies... the possibilities of technologically enabled body and identity transformations" in digital cultures (Nakamura 2008, 13; see also Foster 2005 and Weheliye 2002). Nakamura has shown that a neoliberal rhetoric of nondiscrimination characterized discourses of internet use at the turn of the twenty-first century. The internet has been constructed as a technologically-enabled "even playing field" regardless of significant variations in access according to socioeconomic differences of race, gender, class, and education. But despite such promises of its democratizing potential, the internet has been a crucial site for representations of social difference through "digital signifying practices" that render aspects of identity and difference visible in particular ways (Nakamura 2008, 5). For Nakamura, a theory of "[d]igital racial formation can trace the ways that race is formed online using visual images as part of the currency of communication and dialogues between users" (Nakamura 2008, 11).

Such interventions remain necessary and relevant to *analog technocultures* as well—the constellation of concepts, designs, and uses of analog technologies which are antecedents of digital cultures. The representational "space" of electronic sound was established over the course of nineteenth-century scientific research and the consolidation of acoustics as a professional field in the early-twentieth century. It provided an imagined world for the expression of identity and social stratification much as the internet and other digital media do today. The idea that electronic sounds were part of a flux of waves or "ocean of air" was informed by maritime themes and modernist sensibilities in nineteenth-century

European and American cultures (Hunt 1978, 1; Beer 1996, 298). At that time, naval strategies were central to colonialist expansion, and investigators plumbed the depths of the ocean for the first time and instituted oceanography as scientific discipline (Helmreich 2009, 15, 34-35; Rozwadowski 1996; Headrick 1979). Also, as political, economic, and scientific discourses over the nineteenth century increasingly centered on the individual as a fundamental unit of society and the organism as a fundamental unit in biology (Foucault 1990, 139-43; Haraway 1991, 45), sounds came into focus as discrete individuals with varying properties, in tandem with the emergence of new possibilities for their electronic generation and control. These practices of imagining sound waves as unruly fluids to be technologically controlled, and of classifying sounds as individuals to be sorted by desirable and undesirable aesthetic variations, are deeply entwined with epistemologies of gender and racial difference in Western philosophy and modern science (Irigaray 1985a, 106-07, 111, 116; Young 2005, 81; Wiegman 1995, 31-33). Analog signifying practices expressed notions of social difference in formalized representations of electronic sound, such as the shapes of waveforms and the terms used to describe them.

Analog signification has roots in graphical methods, by which scientific instruments render physical motions and vibrations as lines or curves. Scientists discern meanings of these representations and use them as a foundation for their communications within and across fields (Brain 2002). Graphical methods articulate sonic representations to techniques and cultures of visualization. Recent scholarship in sound studies has demonstrated that in Western philosophy and cultures:

> sound itself [is] constantly subjugated to the primacy of the visual, associated with emotion and subjectivity as against the objectivity and rationality of vision, seen as somehow more 'natural' and less constructed as a mode of communication—in essence, fundamentally secondary to our relationship to the world and to dominant ways of understanding it (Hilmes 2005, 249; see also Pinch and Bijsterveld 2004, 636; Sterne 2003; Thompson 2002).

In studying sound, "it is nearly impossible to escape the visual. Visual metaphors dominate our language" (Pinch and Bijsterveld 2004, 637). Scientific techniques of visualizing sound, especially graphical methods used from the mid-nineteenth century forward, have played a central role in constituting audio-technical knowledge (Sterne 2003, 45). And the visual experience of seeing sound produced in musical performance has been integral to the ways that performers and audiences alike determine the meanings of sound in society and culture: "For much of Western history, at the most fundamental levels of perception, the sound *is* the sight, and the sight *is* the sound" (Leppert 1993, xx). This dissertation explores some of the ways that sound, as an imagined domain of unruly "nature" that is both feminized and racialized in audio-technical discourse, has been tamed into prevailing systems of scientific objectivity through visual tropes.

Sound must not be ceded entirely to the realm of the visual, for it carries its own cultural associations as well as interconnections to multiple modes of sensory experience (Sterne 2003, 14-19). For example, the senses of hearing and touch are profoundly interconnected, especially in experiences of lower frequencies when audible sound is felt throughout the body as tactile vibration (McCartney 2004, 179). Yet, given the strong attachments of vision and objectivity to systems of knowledge and power in the West (Haraway 1988, 581), it remains necessary to account for ways in which techniques and cultures of visualization are historically and epistemologically inseparable from the construction of sonic meanings.

Synthesis, From the Beginning of Time to the Present

Audio technologies also leave a vast paper trail of visual materials, from inventors' notes and drawings to product manuals and advertisements. I began this project by sifting through archives on mid-twentieth century synthesizer instruments designed by Harry F. Olson at RCA (the Radio Corporation of America) and the Canadian inventor Hugh Le Caine. I approached this material in earnest as representative of the "early" history of synthesized sound, relative to the Moog-and-after emphasis of other histories (Pinch and Trocco 2002a; Théberge 1997). I followed historical materials and ideas within them further and further back in time, motivated by inventors' own sense of the long history of their field, as well as by numerous references in nineteenth- and twentieth-century audio-technical discourse to ancient and early modern texts. I encountered the phenomenon that Lisa Gitelman has described as "the oddly perennial newness of... new media." Media, "somewhat like... 'mankind,' tend unthinkingly to be regarded as heading... along an inevitable path, a History, toward a specific and not-so-distant end" (Gitelman 2006, 3). Observers in any era tend to regard "new" media as the culmination of a predominantly coherent and linear historical path; media are always-already new. The rather unwieldy time period that this dissertation touches upon—which I referred to first jokingly, and then with encroaching seriousness, as the beginning of time to the present—affords a perspective on multiple and overlapping prehistories that inform cultural arrangements in the present (Born 2009, 104). This long-term perspective on the history of synthesized sound resists the linear and coherent progress narratives that characterize many histories of technology and new media.

For the inventors and composers who contribute to audio-technical discourse, part of the process of defining their technologies as new entails positioning them as a culmination of historical developments; their writings often bear the mark of an "overdetermined sense of reaching the end of media history" (Gitelman 2006, 3). For example, Benjamin Meissner, an inventor based in New Jersey, published a history of electronic music and instruments in the *Proceedings of the Institute of Radio Engineers* in 1936, in which he concluded: "Electronic music and instruments, with an incubation period of about forty years since their early beginnings, are now rapidly growing into a final commercial stage. During 1935 retail sales of these new musical instruments exceeded two million dollars in the United States alone" (Meissner 1936, 1427). Meissner defines electronic musical instruments as devices "for creating music, wherein periodic electric currents are either selectively generated, or selectively controlled by a player, and translated into sound," and his lineage includes instruments such as the Telharmonium, the Theremin, the Hammond and other electronic organs, photoelectric devices, and other lesser-known instruments (Meissner 1936, 1429). He charts the "growth of the art as represented by patents, technical literature, popular articles, and commercial projects," documenting thousands of items (Meissner 1936, 1441; Fig. 1). Meissner's findings underscore the importance of textual materials in the constitution of audio-technical knowledge and technological designs, effectively supporting the relevance of my focus on audio-technical discourse in this study. But his article is especially significant as evidence that inventors in the 1930s saw the commercial appeal of electronic musical instruments as reaching their peak, decades before Moog's synthesizers were introduced.

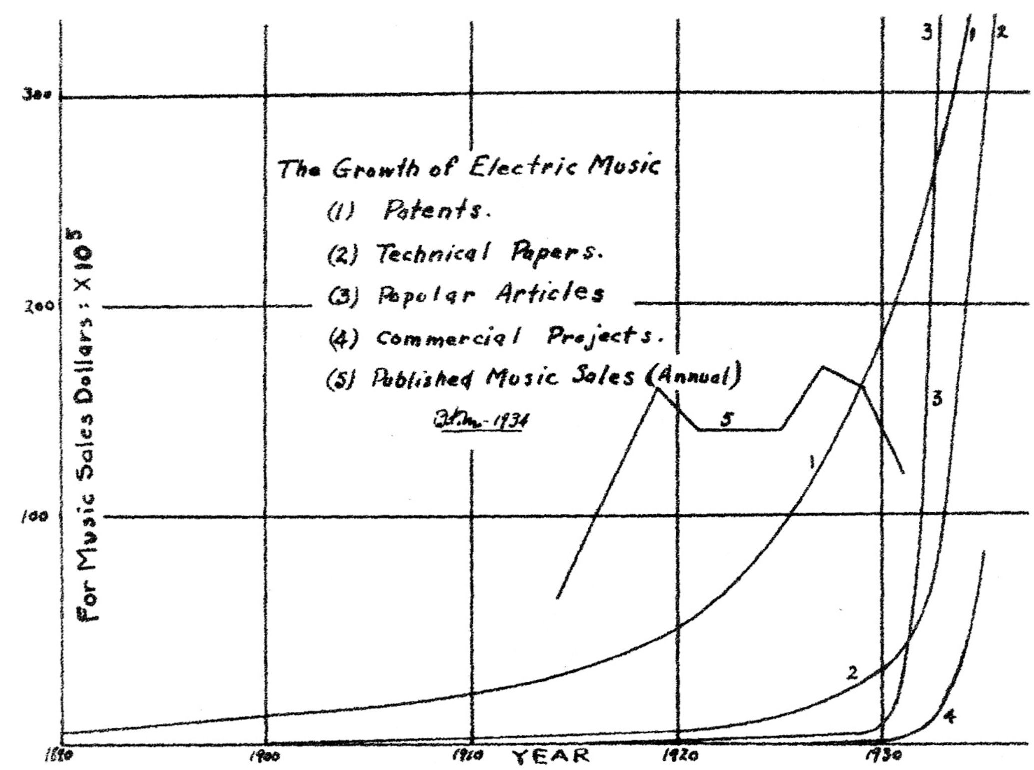

Fig. 1. "The Growth of Electric Music" (Meissner 1936, 1441).

The ongoing construction of history in audio-technical discourse dispels any lingering popular assumptions that any one inventor's contributions are singularly transformative, or that the history of synthesized sound has origins in the 1960s. Electronic musical instrument inventors in all eras communicate a strong historical sensibility; historiography is an integral aspect of audio-technical writing, as inventors imagine and write the history of their field in patents and other publications and lectures. Thaddeus Cahill, in his 1897 patent for the Telharmonium (which some call the "first synthesizer"; see Deutsch 1976, 13), drew on Helmholtz's ideas from a quarter-century earlier, acknowledging that "It is a fact well known to physicists that the quality of a tone depends upon the particular tone partials... and their strengths with relation to each other" (Cahill 1897, 2). In a late-1950s report to the Rockefeller Foundation to secure funding for purchasing an RCA synthesizer, composers at Columbia University described the previous decade as "a climax to some fifty years of serious attempts to synthesize musical sounds by electrical means" (*Preliminary Report* 1957, n.d., 1). In his influential 1964 paper delivered at the Audio Engineering Society annual meeting on techniques of voltage control, Moog reviewed the cultural contributions of earlier instruments like the Theremin, Ondes Martenot, and Trautonium, carefully noting that "The development of 'electronic musical instruments' is certainly not a new field" (Moog 1964, 2). Daphne Oram, a composer and instrument designer at the BBC, located roots of electronic music well before World War II and commented on the gendering of most inventors in historical accounts: "New developments are rarely, if ever, the complete and singular achievement of one mind... I wonder why we want so much to see one man as the hero of the occasion" (Oram 1972, 111). Hugh Le Caine adopted a most ambitious historical purview, recognizing ancient mechanical musical instruments as part of the long history of synthesized sound. In a 1955 paper, he remarked that the synthesizer designers at RCA were "several thousand years too late to say the first word on synthetic music" (Le Caine 1955a, 1-2).

Indeed, in audio-technical discourse, technological progress tends to be situated within a grand narrative of Western history, where modern science fulfills a lineage of ancient Judeo-Christian and early modern scientific texts, and is cast against racialized constructions of "primitive" music technologies and cultures (Meissner 1936, 1427; Chavez 1937, 20, 23-24). Epigraphs are often used to position contemporary technologies and technical knowledge within a long-term historical time frame (a practice I adopt in this dissertation). As I discuss in chapter 3, a passage on sound from Francis Bacon's seventeenth-century utopian travel narrative *New Atlantis* appears in numerous electronic music histories and acoustics texts (see Chadabe 1997, 3; Jenkins and Smith 1975, 146; Deutsch 1976, v). This passage situates modern sound studios as a fulfillment and extension of those experimental "sound-houses" imagined by a prescient Bacon, the "father of modern science" (Merchant 1980, 164). Another representative epigraph frames the opening chapter of Robert T. Beyer's acclaimed history of acoustics, *Sounds of Our Times*:

> The soughing of the wind,
> the tuneful noise of birds in the spreading branches,
> the measured beat of water in its powerful course,
> the harsh din of the rocky avalanches,
> the invisible swift course of bounding animals,
> the roaring of the savage wild beasts,
> the echoes rebounding from the cleft in the mountains
> (Beyer 1999, 1).

Excerpted from the Book of Wisdom in the bible and positioned at the outset of a history of acoustics research from 1800 on, this passage claims an ancient world of sounds in nature (to be read as timeless) as the proper domain of inquiry for modern acoustics. But Beyer left out the last and unsettling line that follows this litany of sounds in the biblical passage: "all held them paralyzed with fear" (Wisdom – chapter 17). This is a telling omission, one that reveals a dominant perspective in audio-technical discourse that is about the fantasies and desires for a world of sonic beauty, the technological possibilities for its creation and control, and the suppression *through* technological control of any fears of uncontrollable "nature." The litany of sounds from the Book of Wisdom, re-presented in Beyer's history of acoustics, is a figurative map that both contains a world and "explode[s] into entire worlds of practice" (Haraway 1997, 11). As a modern, material fulfillment of the same mythic and imaginary soundscape, stock presets in commercial synthesizers after 1970 include the electronic noises of wind, water, and animals, as well as echo and reverberation effects (ARP 1976, 1981). The genesis of the sounds of all creation is within reach of an archetypal god and man; the promise of its fulfillment is perpetually expressed in audio-technical discourse by a desire to use electronic synthesis to "produce every known or conceivable sound" (Meissner 1936, 1439), "any kind of sound that can be imagined" (Olson and Belar 1955, 610), "with a multiplicity of sound parameters under his control [to] produce the desired results" (Moog 1964, 1; see also Théberge 1997).

As Donna Haraway has explained: "U.S. scientific culture is replete with figures and stories that can only be called Christian... technoscience is a millenniarian discourse about beginnings and ends, first and last things, suffering and progress, figure and fulfillment" (Haraway 1997, 9-10). Figural realism, which is central to Christian traditions and manifests most significantly in the reading of the historical figure of Christ into Jewish scripture, connects two events or persons in a way that the first signifies the second, and the second fulfills the first: "They are both contained in the flowing stream that is historical life" (Auerbach 1953, 64; cited in Haraway 1997, 10). "Our times," as encompassed by Beyer's title *Sounds of Our Times*, are thus the deep historical time of technoscience. The biblical taming of waves and parting of seas, the sound-houses in Francis Bacon's *New Atlantis,* and the electronic sounds of wind and rain available to users of 1970s synthesizers are all figurations and fulfillments of one another, representing the "barely secularized" promises of progress, salvation, and prolongation of life for the faithful subjects of technoscience (Haraway 1997, 10). These transhistorical connections are not coincidental juxtapositions, but articulations that are actively produced and reproduced in epigraphs, charts, and other metaphoric representations in audio-technical discourse.

Fundamental Parameters?

The long-term time frame adopted in this study is a strategy for exposing the contingencies of received truths in audio-technical discourse. I follow a genealogical practice that Michel Foucault calls *eventalization*: "rediscovering the connections, encounters, supports, blockages, plays of forces, strategies, and so on, that at a given moment establish what subsequently counts as being self-evident, universal, and necessary" (Foucault 2000, 226-27). For example, what are the fundamental parameters that enable sound to be electronically synthesized, and why are they "fundamental"? Jessica Rylan, who designs synthesizers for herself and her small company Flower Electronics, described in a 2006 interview how so-called "fundamental parameters of sound" have played a defining role in synthesizer designs and techniques. Conventional synthesis, she explained, is characterized by "this very scientific approach to sound, like, What are the fundamental parameters of sound? Volume, pitch, and timbre." She continued: "What a joke that is! It has nothing to do with anything. [Laughs] How do you manipulate volume and pitch? And timbre they couldn't really figure out" (Rodgers 2010, 147).

The three "fundamental parameters" do have to do with something: their establishment in scientific and technological practice was contingent upon

Helmholtz's analogies of eyes and ears, and light and sound waves. In the 1860s, Helmholtz theorized that loudness, pitch, and timbre corresponded to the primary properties of color: brightness, hue, and saturation (Lenoir 1994, 198-99; Helmholtz 1954, 18-19). His resolution of sound into these basic elements**,** in connection with a logic of resolving complex waveforms into simpler sine waves, laid an epistemological foundation for synthesis techniques. Any sound could be analyzed to its fundamental parameters and, at least in theory, synthesized from that information (Peters 2004, 183). Friedrich Nietzsche, writing on the illusions of metaphor in the early-1870s as Helmholtz's theories spread, critiqued such analogies of eye and ear: "A nerve-stimulus, first transcribed into an image! First metaphor! The image again copied to a sound! Second metaphor! And each time he [the creator of language] leaps completely out of one sphere right into the midst of an entirely different one" (Nietzsche 1909, 180; see also Spivak 1997, xxii). Yet, like many metaphoric leaps with persuasive power, Helmholtz's ideas influenced subsequent generations of acousticians, synthesizer designers, and composers who continued to make sense of sound this way and adopt these fundamental properties as standard.

Rylan's bold and rather agnostic suggestion that the fundamental parameters of sound may have "nothing to do with anything" invites us to reconsider concepts in audio-technical discourse that are usually taken as self-evident and universal. (The title of this introduction, then, may be inflected like one of Nietzsche's exclamations: "Some fundamental parameters!") Rylan herself sometimes analyzes sound not according to the conventional parameters of loudness, pitch, and timbre, but in comparison to other things that she admires and is affected by, like the size and temporal regularity of raindrops: “big, fat raindrops that don’t come as often... really fine mist and it’s smooth and constant... a mix between the constant *chhhh* with quieter, little drops that are steady, and big drops once in awhile” (Rodgers 2010, 149). She designs her instruments to create a range of possibilities from which performers can synthesize these ever-changing sonic patterns, like those of wind and rain. To imagine synthesized sound outside of the analytic framework of loudness, pitch, and timbre, as Rylan does in this example, is to circumvent the “familiar landmarks of... our thought,” like Jorges Luis Borges’ story in which animals are not classified according to the conventional taxonomies of Western science, but placed in categories such as “‘fabulous... frenzied... innumerable... having just broken the water pitcher... that from a long way off look like flies’” (cited in Foucault 1994, xv). As Foucault notes in his interpretation of Borges’s story, it is through such encounters with alternative systems of thought that we come to grasp the limitations of those we inherit, and recognize “the stark impossibility of thinking *that*” (Foucault 1994, xv). This project endeavors to open up such impossibilities in thinking synthesized sound other-wise, by locating “elsewheres” within audio-technical discourse: those spaces of discourse “not represented yet implied... in them” from which cultural and historical narratives may be re-imagined (de Lauretis 1987, 25-26).

Notes on Terminology

Electronic and synthesized sound technologies are considered by designers and users to have a communicative capacity, and to mediate and extend human expression. As such, they fall within Lisa Gitelman's definition of media as "socially realized structures of communication" (Gitelman 2006, 7). While this definition of media encompasses technological forms and their social formation, I tend to apply distinct terms in context, such as *audio technologies* and *audio-technical discourse*. These terms are meant to imply technologies of communication and their ongoing formations in material, social and imaginary realms. *Audio technologies* (of which synthesized sound technologies such as keyboard instruments and software are a subset) are devices for the production and reproduction of sound. *Discourse* (as applied in the phrase audio-technical discourse) refers to "a way of knowledge, a background of assumptions and agreements about how reality is to be interpreted and expressed, supported by paradigmatic metaphors, techniques, and technologies" (Edwards 1996, 34). The modifier *audio-technical* encompasses a range of social actors and institutions invested in the technologically-mediated production of knowledge about sound, distributed across such fields as music-making and consumption, acoustics research, engineering, and electronics hobbyist cultures.

In tracing the evolution of synthesized sound I necessarily move between the terms *sounds*, *electronic sounds*, and *synthesized sounds*. These categories have increasing degrees of specificity: *sounds* are all audible vibrations within the range of human hearing; *electronic sounds* refer to audio signals produced by electronic oscillators; *synthesized sounds* are produced electronically through techniques of analysis and synthesis of a sound's constituent elements, like frequency (pitch) and amplitude (volume). Synthesized sound technologies inherit some concepts and practices developed for the broader categories of sound and electronic sound. But knowledge also moves in the other direction, from the specific category back to the general: ideas of synthesis, in combination with electronic technologies, have made all sounds potentially synthesizable.

This dissertation primarily addresses the logics of additive and subtractive synthesis that informed the design of most electronic musical instruments and synthesizers through the 1970s. Additive synthesis is based on the concept that a complex waveform can be approximated by the sum of many simple waveforms; it informs the design of instruments from pipe organs, to Cahill's Telharmonium at the turn of the twentieth century, to the Hammond electronic organs popular in the mid-twentieth century. Subtractive synthesis techniques, which were popularized by Homer Dudley's vocoder system for synthesizing speech at the 1936 World's Fair and continue to inform the designs of many analog synthesizers through the 1970s and beyond, are based on a premise that a wide range of timbral variations can be achieved by the controlled removal or attenuation of harmonic frequencies from a basic waveform. A classic technique of subtractive synthesis involves the independent regulation of the pitch, volume, and timbre of waveform, as controlled respectively by an oscillator, amplifier, and filter (Roads

1996, 134, 197-98). Many other techniques for synthesizing sound have emerged in recent decades, including physical modeling, granular synthesis, and wave terrain synthesis, a technique based on mathematical models of three-dimensional surfaces (Roads 1996, 163-65, 168-69, 265-67). These represent rich areas for further research on the role of metaphors in sonic epistemologies at the turn of the twenty-first century, beyond what I undertake in this study.

Chapter Outline

The next chapter elaborates on my method of using metaphor to organize a feminist history of technology. Metaphors in audio-technical discourse are a mode of communication by which humans define themselves in relation to nature, machines, the body, and each other. They reveal technologies as deeply and broadly historical. Some metaphors and analogies that link electronic sound to such themes as water, color, and life have persisted over decades, and even centuries. This suggests that the history of electronic sound can be characterized by broad concepts that are largely *un*changing, as much as by more circumscribed changes to design that are typically seen as innovative. Metaphor also connects audio-technical terms and concepts to discourses in numerous cultural fields, such as life sciences and philosophy. Because audio-technical discourse relies on a broad cultural consensus of meanings embodied by metaphor, one could argue that it is, in some ways, not very technical at all—unless the technical is understood to be at once modern and mythic, scientific and science fictional.

I identify two primary metaphors for conceiving electronic sound which were in use by the early-twentieth century and continue to inform sonic epistemologies: *electronic sounds as waves*, and *electronic sounds as individuals*. These metaphors were consistent with theories of wave-particle duality, a central idea in quantum mechanics that coalesced around the same time. Electrodynamic theories had treated electricity as a fluid for many years, but these were challenged at the end of the nineteenth century by advances in atomic theory. After J. J. Thomson's experiments that led to the discovery of the electron at the turn of the twentieth century (with a corresponding shift in everyday language from the term *electric* to *electronic*), the notion of wave-particle duality resolved centuries-old debates with a scientific consensus that all energy and matter exhibited properties of *both* waves and particles (Ponomarev 1993, 31-32, 111). In epistemologies of electronic sound, the wave metaphor maintained connections to the fluid connotations of electricity, while the individual metaphor constructed electronic sounds as unique entities with variable component parts. Through this dualism, electronic sounds manifested as at once mythic/organic (through the figure of the wave) and thoroughly modern/technological (through the figure of the individual). As I discuss in chapter 3, this dualism was also expressed in audio-technical discourse in gendered terms, with particles as male subjects and waves as a feminized background.

Chapter 3, "'An Uneasy Ocean of Air': Waves and Maritime Voyage in Epistemologies of Electronic Sound," surveys audio-technical discourse in late-nineteenth and early-twentieth century texts that were foundational to the fields of acoustics and electroacoustics, and to ideas and machines of sound synthesis. These texts defined sound as fluid disturbances that initiate sensory pleasures and affects; sound was also figured as a journey of vibrating particles that voyage back and forth, outward and home again. Themes of sound as fluid disturbance and maritime journey were not only imagined in the exterior world (the "ocean of air") but also transposed onto the interior structures of the inner ear, itself a kind of seascape of canals, sinus curves, and other fluid passageways to be traversed by scientific exploration. I use Luce Irigaray's work on fluids and female corporealities, and postcolonial writings on maritime voyage, to interpret these representations. I argue that the wave metaphor functions in audio-technical discourse to produce an affective orientation to audio technologies based on a masculinist and colonizing subject position, whereby the generation and control of electronic sound entails the pleasure and danger of navigating and taming unruly waves. I suggest alternate ways of theorizing sound waves through a reading of science fiction writer Ursula Le Guin's short story *The New Atlantis* (1975).

The wave metaphor continues the analogies of sound and water waves that have circulated since ancient times. Chapter 4, "The Growth and Decay of Waveforms: Electronic Sounds as Forms of Life," examines the convergence of the wave metaphor with a modern metaphor of electronic sounds as individuals, in the figure of the waveform. I use Ludwig Wittgenstein's notion of "forms of life," along with Langdon Winner's reworking of this concept, to theorize how relationships of electricity, sounds, and life are articulated by language in worldly context. Over the course of the nineteenth century, like modern bodies and subjects, sounds came to be understood as complex wholes characterized by individually distinctive variations, and comprised of component parts which could be analyzed and controlled by specialized technologies and techniques. The waveform, and the related technology of the amplitude envelope, symbolized a convergence of wave and individual metaphors by representing the technological possibility of isolating an individual sound amidst an otherwise formless flux of waves.

Sounds and diverse organic processes were expressed similarly as waveforms through the use of graphical inscription instruments, which were employed extensively in acoustics and physiology research in the mid-nineteenth century. Alongside respiration, muscle movements, and other bodily processes, sounds were described in terms of extension into space (amplitude) and variation over time (duration and character). As scientists identified the presence of electrical activity among diverse forms of life, the liveliness of electronic and synthesized sounds was naturalized. Electronic sounds became more prevalent toward the end of the nineteenth century and concepts associated with life-cycles, like duration and decay, were used to describe their formal structure. Notions of sonic individuation and variability also resonated with Darwinian theories of evolution; indeed, Helmholtz actively situated his research in the context of concerns with form that manifested across writings by scientific and cultural commentators like Goethe and Darwin.

In this chapter, I also examine the discursive construction of the sine wave as the "most pure tone" as an outgrowth of Helmholtz's neoclassical aesthetics. I read the purity of sine waves, and their popular descriptions of being without color and lacking "body," as signifiers of whiteness and cultural value in the electronic production of tone color or timbre. Sine waves are commonly contrasted with alternately devalued and desired constructions of noise and/or timbral variation, which are represented by asymmetrical or "impure" waveforms. This case study shows how the modern practice of conceiving electronic sounds as individuals is not neutral or without history, but entwined with histories of scientific determinations of difference and desires for social ordering and control.

Chapter 5, "'Divided Parts, Reunited': Ideas and Machines of Synthesis" traces a history of the idea of synthesis, and cultural notions of the natural and synthetic, that inflect discourses of synthesized sound. It outlines a history of devices that may be considered as ancestors of modern synthesizers, including the Greek hydraulis and early modern automata built to imitate the sounds of nature, and nineteenth-century scientific instruments for the electrical production of sound. It also describes how synthesized sound, as musical material to be produced by specialized instruments, was consolidated over the first half of the twentieth century by social and professional networks of composers, engineers, and hobbyists who forged connections among modernist musical aesthetics, the new science of acoustics, and an enthusiasm for electricity and electronic devices. Following Carolyn Marvin's research on electrical experts in the nineteenth century who used a common set of texts and rhetorical signification to construct their expertise, I suggest that knowledge and techniques of synthesized sound have been constructed by "textual communities" of practitioners (Marvin 1988, 12). Representations within these texts—including patents, journals and lectures of professional organizations, radio and electronics magazines, acoustics and electroacoustics textbooks, commercial synthesizer manuals—have played a central role in constituting audio-technical knowledge, informing inventors' sense of the history of their field and training new generations of practitioners. A critique of representational conventions in audio-technical discourse, as carried out by this project, is thus a necessary and productive intervention.

Contributions: Synthesis as a Feminist Theory

Despite the cultural pervasiveness of synthesized sound, there is a broad range of literature in sound and media studies about technologies of sound reproduction, and relatively little critical analysis of synthesis. The proliferation of work on sound reproduction suggests that the field of sound studies has, thus far, largely drawn on themes in visual culture studies. Much work on sound reproduction technologies reframes a central theoretical concern in studies of film and photography: relations of original and copy, and the fidelity of reproductions to originals (Sterne 2006b, 836-37; see also Mowitt 1987; Rothenbuhler and Peters 1997). This dissertation aims to contribute to sound and media studies by historicizing the logic of synthesis, and examining electrical signals as a form of technical and aesthetic representation.

Synthesized sound is noteworthy in comparison to other audio technologies and musical instruments, and is tied to particular strands of cultural history, because synthesis is based on a generative premise: the creation of new wholes from contingent unions of discrete parts. It is this premise that articulates the history of synthesized sound to stories of creation and genesis, like the biblical taming of waves and Francis Bacon's *New Atlantis*; to discourses of life sciences concerned with relations of component organs and whole organisms; and to notions of the synthetic as technologically-constructed artifice.

Synthesis can generate a different set of theoretical possibilities versus the concept of reproduction, and it can be an especially useful concept for feminist theories. Discourses of technological reproduction have been characterized by male desires to both appropriate and safeguard the maternal, procreative function (Doane 1999, 29). In audio-technical cultures, sound reproduction technologies have often been directed toward the devaluation and control of technological forms culturally coded as female (Sofia 2000, 185). For example, sound "fidelity" as an aesthetic priority aims to preserve a strong signal and a pure reference to an idealized origin (which can be interpreted as an expression of male subjectivity in sound) against the degrading potential of a feminized, immersive medium (Keightley 1996, 161; Morton 2000, 13-47; Sterne 2003, 215-86). As well, stories of male birth and the backgrounded labor of working women's bodies have been used in sound and electronic music cultures to bolster male claims to invention and artistic innovation (Smith 1995, 69, 283; Sterne 2003, 180-81).

In audio-technical discourse, material aspects of electronic sound and the technologies for its generation and control can be figured as narratives of sexual desire and fulfillment, much as Susan McClary has argued regarding the tonal organization and compositional structures of Western music (McClary 1991, 7-19). Instead of signifying fidelity to origins and the reproduction of an existing cultural order, synthesized sound is a communicative medium that foregrounds artifice and the experience of embodied pleasure. Timbre, a symbolic presence of the body in sound and music, has long been suppressed in Western music. Producers and audiences of electronic dance music challenge these aesthetic priorities by exploiting the affective qualities of timbral fluctuations in synthesized sound (Gilbert and Pearson 1999, 59-63; see also Dyer 1990, 413-15, 417). A logic of sound reproduction, which is predicated on fidelity to origins and facilitated by technologies of storage and supply, arguably signifies a normative "uterine social organization (the arrangement of the world in terms of the reproduction of future generations, where the uterus is the chief agent and means of production)." By contrast, a logic of synthesis opens up ways of thinking a more radical and non-normative clitoral economy—a social organization where cultural production is not based on birthing metaphors—in which female and/or non-procreative sexual pleasure may be foregrounded, and patriarchal origins and lineage backgrounded or effaced (Spivak 1981, 183).

Synthesizers are known for their capacity "to simulate the sounds of conventional instruments, from the harpsichords of *Switched-On Bach* to the string sounds used on many pop albums" (Goodwin 1990, 261) and to do "'second-order simulation,' where a digital device... simulate[s] the sound of an analog device reproducing the sound of an acoustic instrument" (Théberge 1997, 196). These complex sound simulations are synthesized from simple electronic waveforms; this differs from techniques of reproduction, whereby original recordings are embedded in a storage medium and played back. Consider an advertisement for the ARP Soloist synthesizer, which shows a picture of the keyboard instrument accompanied by the incredulous question: "This is a tuba?" This is followed by a litany of other instruments that the synthesizer also "is": "...and a bassoon, an English horn, a clarinet, an oboe, a flute..." (ARP 1972, n.d.; Fig. 2). The synthesizer constitutes all of these interchangeable forms by the analytic reduction of any sound into its fundamental parts and its reassembly into

Fig. 2. ARP Soloist synthesizer advertisement (ARP 1972, n.d.).

anything else imaginable. All sounds are potentially synthesizable and are fundamentally linked to each other through relations of analogy. As Katherine Hayles has noted: “Analogy... is a powerful conceptual mode that constitutes meaning through relation... [It is] a universal exchange system that allows data to move across boundaries. It is the *lingua franca* of a world (re)constructed through relation rather than grasped in essence” (Hayles 1999, 91, 98). Synthesized sound can be a model for thinking how individual entities of all sorts emerge out of contingent relations of partial and analogous elements, and are ever transformable through new arrangements and relations.

Partiality is a key concept in feminist standpoint theories and critiques of scientific objectivity, especially throughout the work of Donna Haraway. Haraway theorized partial perspectives as culturally and historically located knowledge claims, in contrast to the universalizing perspectives of those “unmarked positions of Man and White” in discourses of scientific objectivity (Haraway 1988, 581). In her figuration of the cyborg, a hybrid of organism and machine, she suggested that human nature is always-already technological and characterized by partial and contradictory elements, which might be embraced and inhabited to better account for relations of power: “a cyborg world might be about lived social and bodily realities in which people are not afraid of their joint kinship with animals and machines, not afraid of permanently partial identities and contradictory standpoints” (Haraway 1991, 154). More recently, Haraway has reframed these ideas through the concept of *naturecultures*, a formulation of world in which the natural and cultural are imploded and interwoven, "where the fleshy body and the human histories are always and everywhere enmeshed in the tissue of interrelationship where all the relators aren't human" (Haraway 2000, 106). Haraway's concept of the *knot* as any entity that substantializes a stream of inherited material and semiotic histories (Haraway 2000, 94), resonates metaphorically with the analog synthesis *patch*—that temporary, tangled configuration of wires that joins many disparate parts into one signal.

Indeed, similar ideas of partial identities and perspectives were formulated through synthesis metaphors by Daphne Oram, the composer, electronic musical instrument designer, and studio manager at the BBC in the 1950s and '60s (Hutton 2003; McCartney 2006). Oram's book, *An Individual Note of Music, Sound, and Electronics* (1972) is a whimsical philosophical account of analogies between humans, circuits, and electronic sound. She imagined each human like a complex synthesized tone made of thousands of partial elements:

> It is as if the human being has thousands upon thousands of energy stores, each tuned for a purpose, each charged with a potential which allows it to sound forth. It is as if each human being is an instrument of concord and discord, consisting of thousands upon thousands of finely tuned circuits; each circuit with its own control of pitch and loudness... so that it becomes part of the great pattern which makes the individual.
>
> To visualise a human being in this way we would need a most wonderful mixture of fundamentals, harmonics and overtones, all subtly changing from moment to moment...
> (Oram 1972, 27)

Oram constructed a kind of material-semiotic theory: on one hand, she was writing poetically of analogies between humans and electronic sounds; but she also pointed out that the material presence of electrical activity within the human body actually means that each individual has a uniquely "personal wavepattern" (Oram 1972, 121). Applying ideas from synthesis to intersubjective relations, she imagined that humans might seek "harmonic relations" by adjusting to proper tuning in encounters with other humans and objects (Oram 1972, 46). For Oram, the world was one of sympathetic vibrations and impactful resonances, where one's influence is felt across the boundaries of species and after the fleshly body's decay:

> I find it very exciting to think that our own personal wavepatterns may, according to their richness, energize many "vessels" when we "die." How fascinating to feel that part of oneself—perhaps just one of one's overtones—might, "in a twinkling of an eye," energize by sympathetic resonance an atom or a molecule... of an arbutus tree... of an amethyst... of a sea anemone...
>
> Do we need to wait for the death spark...? Is one not creating resonance and absorbing resonance all the time...? (Oram 1972, 121-22)

Oram employed the metaphor of sound synthesis (as about relations of parts and wholes), and the materiality of electrical charge, to convey the same modalities of partial perspectives and interconnections that Haraway would call the "tissue of interrelationship where all the relators aren't human" (Haraway 2000, 106). The evolution of synthesized sound is a history of such interrelationships.

While feminist methods can be useful for rethinking who and what counts in histories of electronic music and audio technologies, feminist affinities can also be located within audio-technical discourse. Like the premise and promise of synthesis, feminist theory involves processes of taking things apart—disentangling the stakes in those encounters and "plays of forces" that constitute historical events (Foucault 2000, 226-27), like untangling a synthesis patch, and imagining alternative and productive recombinations. The task of a feminist theory is at once analytical: "about understanding how things work, who is in the action" (Haraway 2003, 7) and generative: "render[ing] more mobile, fluid, and transformable the means by which the female subject is produced and represented" (Grosz 2005, 193), and calling out ways that "worldly actors might... be accountable to and love each other less violently" (Haraway 2003, 7).

Sound represents a new direction for feminist theories, which have been more thoroughly devoted to critiques of visuality and technologies of visualization. Extended studies of sound, gender, and feminism in electronic and electroacoustic music cultures have been few and far between (McCartney 1999; Pini 2001; Rodgers 2010); and, over twenty years since its publication, Kaja Silverman's study of the female voice in psychoanalysis and cinema remains a singular contribution to the intersections of sound, feminist theory and philosophy (Silverman 1988). This dissertation aims to contribute to the formation of a field of feminist sound studies.

2. ON METAPHOR AND FEMINIST HISTORIOGRAPHY OF TECHNOLOGY

> The root metaphor and lasting legacy of the analog era is [this concept of] an assembly of elements in relations of interdependence, altogether constituting a complex and organized whole.
> – Derek Robinson, "Analog" (2008, 23-24)

Metaphors in audio-technical discourse are a mode of communication by which humans define themselves in relation to nature, machines, the body, and each other. Metaphors reveal how technologies are deeply and broadly historical: they show how technologies are situated within centuries-long discourses of myth, human experience, and scientific experiment, and also how technologies are interconnected with contemporaneous developments across cultural fields. Metaphors and analogies that link sounds to water, color, and life are so fundamental in audio-technical discourse that they are barely noticeable, and yet it is hard to conceive of sounds apart from them. There are stakes in these metaphorical investments. While histories of electronic music and audio technologies have focused primarily on the accomplishments and perspectives of white male subjects (McCartney and Waterman 2006, 4), metaphors in audio-technical discourse usher in a world of others: women, racialized others, animals, insects, dinosaurs, storms. Against the typical uses of metaphors in audio-technical discourse that privilege the perspective of a mythic white, Western, and male subject, it is possible to inflect existing metaphors with different subjective or ethical positions than their common usage readily suggests. The worlds that are made within discourses of synthesized sound constitute an "elsewhere" (de

Lauretis 1987, 25), a location within discourse from which we might imagine histories of technologies differently, as evolution narratives that indeed synthesize a vast network of humans, other species, things, and environments in contingent relations. In this chapter, I will elucidate my use of metaphor in historiographic method by defining metaphor and associated terms and explaining its usefulness toward a feminist historiography of audio technologies.

Some Definitions and Uses of Metaphor

The terms metaphor and analogy are often employed interchangeably, yet there are subtle distinctions (Stepan 1986, 262; Spitzer 2004, 3). A metaphor is a figure of speech that transfers a descriptive term to another object or concept, different from that to which the term literally applies (*OED*, "metaphor"). Every metaphor mediates various analogies or structural correspondences (Stepan 1986, 261; Black 1979, 31). It is this very function of metaphor as a mediating device—a rhetorical tool—that makes it useful toward feminist historiographic revisions (Garrison 2005, 253). An analogy connotes agreement or similarity between things; specifically, it marks a likeness among relations of attributes of an object or concept. Analogies have historical significance in Western philosophy and theology, having long served as a conceptual tool by which humans measure their relationships to each other and to notions of divinity; the analogy of finitude, for example, connects every living being (Silverman 2009, 41). Analogy was a prominent conceptual tool in nineteenth-century natural history, referring to resemblance of form or function between parts or organs of different species, such as the tail of a fish and that of a whale (*OED*, "analogy"). In Foucault's analysis, it is a defining feature of the modern episteme that relations between organic structures are understood according to analogies of identity and difference among these structures' constituent elements (Foucault 1994, 218). These historical meanings and uses of analogy inform discourses of synthesized sound, which likewise are expressed in terms of duration and finitude, part-whole relations, and classifications of formal attributes.

My use of metaphor in historiographic method resonates in some ways with Thomas Kuhn's concept of the paradigm. In his theorization of the paradigm, Kuhn seeks to identify those foundations of scientific knowledge and consensus which, among a community of specialists, account for "the relative fulness of their professional communication and the relative unanimity of their professional judgments" (Kuhn 1996, 182). For Kuhn, a paradigm represents a "disciplinary matrix" comprised of ideas and values shared among the community (Kuhn 1996, 182-87). Scientific models function in paradigms to "supply the group with preferred or permissible metaphors" (Kuhn 1996, 184). Metaphor therefore can be considered to be "the vital spirit of a paradigm (or perhaps its organizing relation)" (Haraway 2004, 9). In scientific practice, metaphors and analogies help to constitute the field of inquiry in that the analog and primary referent are both altered in meaning through their encounter (Haraway 2004, 10; Hesse 1966, 163). In other words, scientific "discovery" is constituted in part by "the metaphor that permits us to see similarities that the metaphor itself helps constitute" (Stepan

1986, 271).

The paradigm has been a device used by historians of scientific practice to structure historical accounts according to significant epistemological and cultural shifts (Haraway 2004, 3). I orient my project explicitly around metaphor because it better allows for tracking circulations of language among diverse communities of experts and other streams of discourse. Metaphor is also useful for mapping the multiple temporalities and overlapping durations of paradigmatic concepts and values across cultural fields. Metaphor is a communicative device that bridges *across* expert and non-expert communities by appealing to a broader cultural consensus of meaning than any particular scientific paradigm (Stepan 1986, 271). Through analogies, scientists transfer knowledge across otherwise disparate fields, and this is especially fundamental to the field of electroacoustics. Analog devices are named as such because mathematical formulae (which are informed by theories of motion and associated metaphors like the wave) facilitate analogies among mechanical, electrical, and acoustical systems (Olson 1958, iv; Robinson 2008, 22-23).

For centuries, and especially following the scientific revolution of the seventeenth century, metaphor was associated with poetic imagination and subjective experience, and contrasted to objective, scientific knowledge (Stepan 1986, 261; Lakoff and Johnson 1980, 191-92, 195-97). As late as 1950, Norbert Wiener found it necessary to formally address the concerns of colleagues who were critical of the central role of analogy in cybernetics (organisms are like machines), because its subjective connotations seemed unsuitable for serious science (Hayles 1999, 97-98; Wiener 1950). However, over the last half century, scholars working across several disciplines the humanities and social sciences have established that metaphors and analogies are constituent elements of scientific thought (Hesse 1966; Haraway 2004; Ortony 1979; Lakoff and Johnson 1980; Stepan 1986; Edwards 1996). For example, analogies of race and gender played a significant role in scientific determinations of human variation in the nineteenth century, and enabled a host of hierarchized social categories to be seen as manifestations of measurable corporeal differences (Stepan 1986, 267; Wiegman 1995, 32-33). In the field of developmental biology, scientists' engagements of competing mechanist and organicist metaphors shaped a paradigm shift in understandings of embryonic form in the early-twentieth century (Haraway 2004, 4-7). Cognitive scientists at mid-century, informed by cybernetic theories, developed metaphors of minds as computers, rendering them as problem-solving, symbol-processing systems (Edwards 1996, 2). What is clear among these few but diverse examples is that conceptions of bodily form, function, and differentiation have been a primary product of the operation of metaphors and analogies across a range of scientific and technological discourses.

It is my contention that audio-technical discourse is no exception, in that metaphors pertaining to sound mediate a host of analogies that give meaning to human understandings of bodily forms and embodied relations. Histories of sound and audio technologies are inextricably entwined with histories of the body and classifications of bodies according to attributes; for example, Helmholtz, writing in the 1880s as Darwin's ideas circulated, adopted similar language to discuss variations in tone quality among "different individual instruments of the same species" (Helmholtz 1954, 19). Given the common concerns for form in acoustics research and the life sciences over the nineteenth century, it is not surprising that the term *organology* has historically applied to the following three domains of inquiry: the comparative analysis of the organs of animals or plants; the theories common to nineteenth-century race science that differences in character correspond to structures in the human brain; and the study of the history of musical instruments (*OED*, "organology").

Metaphor as Material-Semiotic Figuration

Metaphor integrates the discursive, material, affective and expressive domains of technological encounters. The linguist George Lakoff and the philosopher Mark Johnson, in their influential study of metaphor and human experience, determine that metaphor is "pervasive in everyday life, not just in language but in thought and action" (Lakoff and Johnson 1980, 3). Not only do metaphors inform how we think and speak, but they also inflect what we do and how we comport ourselves (Lakoff and Johnson 1980, 14-21). Metaphor orients lived experience and encapsulates modes of living in language. Paul Ricoeur, writing on the poetics of metaphor, depicts "the logical force of analogy and comparison" as a kind of "power to speak of the inanimate as if alive" (cited in Spitzer 2004, 97). As the phrase "figures of speech" implies, through metaphor, discourse itself acquires “something analogous to the differences in form and features to be found in real bodies” (cited in Spitzer 2004, 95). Waves, colors, and growth and decay are some of the metaphors and analogies that at once express lived realities and bodily differentiation in the language and form of sound, and in turn inflect how people orient themselves toward sound in embodied experience.

Feminist philosophers offer ways to understand how such conceptual frameworks of representation influence the production of subjectivities, the psychical dimensions of corporeality, and the extensions of bodies and technologies in the world. Elizabeth Grosz’s theory of corporeality in *Volatile Bodies* addresses the “inside” and “outside” of the body together, assessing psychical and social dimensions interactively (Grosz 1994, 22-23). This theory productively moves beyond Cartesian dualisms that conventionally treat mind and body as distinct realms. Grosz denies “that there is the ‘real,’ material body on one hand and its various cultural and historical representations on the other... these representations and cultural inscriptions quite literally constitute bodies and help to produce them as such” (Grosz 1994, x). Her theory of corporeality is especially useful for studies of technology, in that a significant way in which “the subject’s corporeal exterior is psychically represented and lived by the subject” (Grosz 1994, xii) is through embodied interactions with technologies. Technologies are lived and imagined as an apparatus that extends the body’s physical limitations, or serves as a whole or partial delegate of otherwise fully-embodied tasks (Ahmed 2006, 46-49; Latour 1988, 303). These corporeal engagements and extensions recirculate as psychical representations of the body's constitution and capacities. The degree to which technologies manifest as physical extensions into space (and their corollary representations in psychical spaces) is always differentiated by social and cultural factors including gender, race, sexuality, and ability (Ahmed 2006, 132; Young 2005, 27-45). These insights suggest that metaphors in audio-technical discourse operate within both psychical and social experiences of technologies.

Methodologies in science and technology studies also provide strategies for integrating the operations of metaphor in language and embodiment with the function of audio-technical discourse in social contexts. Technical language, of which metaphor is a constitutive part, mediates between technological design and use. Madeleine Akrich observes that there is often slippage between the users of technologies projected by designers and the "real" users; in her terms, there are discrepancies between "the world inscribed in the object and the world described by its displacement" (Akrich 1992, 209). Metaphor, I suggest, opens up analyses that "move between the inside and the outside of technical objects," to compare how they are conceived and designed with how they are implemented and transformed in use (Akrich 1992, 206). Bruno Latour similarly notes that technologies are "anthropomorphic" in a dual sense, in that they take on human shape and give shape to humans. Latour gives the example of an automatic door-closer, which acts as a delegate for human actions and also shapes human action by prescribing certain corporeal dimensions and behaviors among humans who pass through (Latour 1988, 303). He proposes the term *incorporation* to describe the transfer of technical language into embodied techniques, through an example of driving a car: “There is a large body of skills that we have now so well embodied or incorporated that the mediations of the written instructions are useless” (Latour 1988, 305). With language functioning as a kind of interface, a “body of skills” comes to reside in our bodies. The technical language of instructional manuals, along with the behavioral prescriptions of technological forms, become incorporated over time into embodied routines. Language recedes as a matter of consideration, and emerges in a manner of common practice.

Metaphors underlie our conceptual system, and yet “our conceptual system is not something we are normally aware of. In most of the little things we do every day, we simply think and act more or less automatically along certain lines” (Lakoff and Johnson 1980, 3). There are stakes in this process of habituation and forgetting. Nietzsche noted that truth is a “mobile army of metaphors... which after long usage, seem to a nation fixed, canonic and binding: truths *are* illusions of which one has forgotten they are illusions” (Nietzsche 1909, 180; see also Miller 2006, 64). Consciousness and questioning of technological imperatives arguably becomes more elusive as language moves into habitual routine; in the case of metaphor, the particularity of subject positions it produces tends to proceed as universal and normative.

In language, metaphors embody a crystallization of materially and socially experienced relations of power into shared representations. As cultural studies scholars have demonstrated, this is a political, and even ideological, process. In Stuart Hall's definition, ideology consists of "the mental frameworks—the languages, the concepts, categories, imagery of thought, and the systems of representation—which different classes and social groups deploy in order to make sense of, define, figure out and render intelligible the way society works... the practical as well as theoretical knowledges... within whose categories and discourses we 'live out' and 'experience' our objective positioning in social relations" (Hall 1996, 26-27). Metaphor, as a constituent element of these mental frameworks, is therefore a paramount force in cultural politics: it marks the shifting balances of power among groups and individuals in representation as well as in situations themselves (Edwards 1996, 152). Metaphors help to organize all sorts of theories that "assist in constituting the subject positions inhabited by individuals" as well as "the cultural representations of political situations" (Edwards 1996, 148).

As Ricoeur concludes, in a reading of Aristotle, metaphors serve a principally rhetorical function: "liveliness of speech" is a means toward "persuasion of one's hearers" (Ricoeur 2003, 39). Metaphors serve a political function because they work to suppress information about the world, or modes of experience, that do not fit the readily implied analogies (Stepan 1986, 272). Analogies, too, constitute knowledge and power by processes of exclusion; they simultaneously assimilate and internally reify the analogous components, while "excluding the fields of force that make them heterogeneous, indeed discontinuous" (Spivak 1985, 75). Moreover, metaphors and analogies in technical language can be ideological especially because presumptions of scientific rationality, objectivity, and neutrality work to conceal the partiality of universalizing claims (Edwards 1996, 153).

Technical language, and the technologies and techniques it describes, are indeed machines of social differentiation. Akrich proposes that it is therefore crucial to study exclusion and disputes in the deployment of technologies to identify how some social actors are marginalized by certain concepts and designs (Akrich 1992, 209-11). Carolyn Marvin, in her social history of electric communication technologies, underscores the role of language in the formation and perpetuation of communities of experts in the late-nineteenth century. She uses the term "textual communities" to describe groups of electrical experts that organized around authoritative texts and their accepted interpreters (Marvin 1988, 12). For electrical experts in the late-nineteenth century, "The proper naming of persons, gadgets, and concepts... was among the most important performative indicators of technological literacy... correct technical language correctly used [was] essential to the expert's claim to professional authority" (Marvin 1988, 15, 46). As in later communities of acousticians and engineers, technical language was used by electrical experts as a marker of access to knowledge and power, to define who is "inside and outside" social and professional networks (Marvin 1988, 4).

Against cultural theorists who emphasize the politics of technical language, Mark Hansen puts forth an argument that contemporary critical theory has consistently treated technology as representation while neglecting its role as a material reality and force in the world. Hansen calls this critical move "*technesis*, or the putting-into-discourse of technology" (Hansen 2000, 4). I am sympathetic with Hansen's call to account for the robust materiality of technology, however, I argue for its integration with discursive analyses, and with explicitly feminist theories that account for the dynamism of matter (Barad 2003; Grosz 2005, 43-52). In my view, Hansen goes a bit far in attributing agency to technology, extending to it a common anthropomorphic metaphor even as he critiques it: "Technology must not be construed as a mere figure or metaphor; its role within thought must not be reductively equated with its far more robust ontological status as 'agent' of material complexification" (Hansen 2000, 19). Hansen's valorization of the materiality of technology as an autonomous and dynamic force runs the risk of eliding feminist critiques of the passivity of matter, which have shown how technology itself has been mobilized to conquer a feminized and primitivized matter or nature (Merchant 1980, 164-72). In chapter 3, for example, I discuss how epistemologies of the behavior of particles in wave motion were produced through wave metaphors in audio-technical discourse and articulated to performative demonstrations that were allegories of social relations. A row of boys pushing against one another was at once a figuration of moving particles and a representation of social worlds. The materiality of technology is undoubtedly a productive force; however, it is never autonomous from discourse, but always co-emergent with it. The robust materiality of technology is infused with discursive structures of power and knowledge all the way down, and metaphor is a site of their interconnection.

Waves and Historical Perspectives

In conceiving this project, I embrace waves as a metaphor for the overlapping temporalities, relative forces, and distributions across cultural fields of the various events, ideas, and social organizations that comprise any given historical moment. Since the 1970s, feminists have used wave metaphors to narrate the history of their own political consciousness and movements, where each wave signifies a new generation of women with a distinct set of concerns and orientation to politics. Ednie Kaeh Garrison and others have argued for rejecting this typical use of the wave metaphor, since generationally-defined waves are often inadequate representations of feminist identifications and organizations (Garrison 2005, 240-43; Spigel 2004, 1211-12). Garrison suggests that radio waves are a more useful metaphor in feminist historiography, as signifiers of multiple frequencies and dissonances, and of the potential for collective organization through technologies of communication (Garrison 2005). In a similar spirit, I have argued elsewhere that feminist waves can be conceived as sound waves, where debates reverberate and interact in myriad configurations over time and are subject to various inflections and interpretations based on one's relative power or position (Rodgers 2010, 18).

There are metaphoric resources in audio-technical discourse that can animate or extend feminist approaches to historiography. The multiplicity of temporal dimensions of history—a concept that informs this dissertation—is well captured by an analogy of sound and/as water waves made by the physiologist and acoustician Hermann von Helmholtz: “a great multitude of different systems of waves mutually overtopping and crossing each other... different trains of waves, great and small, wide and narrow, straight and curved,” with a “rhythmic motion, perpetually varied in detail” (Helmholtz 1954, 26, 251). Waves are arguably a more useful metaphor for the temporal dimensions of history than the more linear concept of trajectories, since they connote cyclical as well as directional movements. The long history of synthesized sound includes overlapping waves of varying temporal scale: oft-told and retold allegories of maritime voyage; scientific efforts to render invisible physical phenomena visible, such as sounds and interior bodily processes; various machines built to emulate the sounds of human voices, beasts, and birds; and numerous other phenomena. To begin to account for these proliferating movements, as Foucault has suggested, is “at once too much and too little: too many diverse kinds of relations, too many lines of analysis, too little necessary unity. But this is precisely the point, both in historical analysis and political critique. We aren’t, nor do we have to put ourselves, under the sign of a unitary necessity” (Foucault 2001, 227-28). The flux of historical waves, an open-ended unfolding of processual relations, always-already exceeds the unitary male figure, or the coherently defined technology, which are archetypal subjects of historical accounts (see Irigaray 1987; Smith

2000; Scott 1988; Gitelman 2006, 3).

In the next chapter, I critique passages by Helmholtz and others as occupying a detached, objective perspective on waves that has characterized scientific writings on sound and prioritized masculinist and colonialist perspectives. I uncover other perspectives in the writings of Ursula Le Guin, Virginia Woolf and others, including positions within the waves. A feminist historiographic method arguably alternates between these positions: adopting a detached perspective to identify patterns and events, while also adopting critical reflexivity on historian's position within the fluid "streams of consciousness" that comprise received systems of thought. This dual position within, and with a distanced perspective on, historical waves implements a kind of "embodied objectivity," a reflexive and situated form of knowledge, rather than the "conquering gaze from nowhere" that has characterized objectivity in scientific practice (Haraway 1988, 581).

The production of any historic narrative involves poetic decisions and the ordering of figures through analogical relations (White 1973; Foucault 1994, 219). The historian confronts the historical field as a grammarian confronts a new language, constituting the field "as a ground inhabited by discernible figures" which are "classifiable into distinctive orders [and] conceived to bear certain kinds of relationships to one another" (White 1973, 30). The "discernable figures" I have chosen are tropes that are often taken as objective truths about sound; they are the "figures of speech" and representation through which notions of embodiment, identity, and difference circulate in audio-technical discourse. And as much as metaphors and analogies constitute audio-technical knowledge and technological designs, the form of analog media (such as a synthesized sound) provides a model for thinking the processual and contingent events of history: "an assembly of elements in relations of interdependence, altogether constituting a complex and organized whole" (Robinson 2008, 23-24).

Worlds of Sound and Feminist Worlding

The origins of this project's inquiry are grounded in affective experiences of music-making and other creative audio-technical practices. In the *Pink Noises* interviews, conducted before my dissertation research began, the topic of synthesized sound elicited speculation by several artists on concepts of nature and artifice, and relationships among sounds and forms of life. The composer Annea Lockwood described her work with synthesized sound in an early electronic music studio in Cologne in the 1960s: "the sounds which were assembled with all that care, all that mathematical interrelationship... struck me as not really being alive... So then of course I had to ask myself *what, for me, constitutes life in a sound*?" She left this as a rhetorical question but, in subsequent decades, some of her most prominent works feature recordings of rivers interspersed with audio interviews of people whose lives the river intersects. Lockwood implied that synthesized sound lacks the kind of "life energy" that permeates flowing water and the cadences of human voices. By contrast, composer Mira Calix is drawn equally to working with analog synthesizers and wooden instruments because they seem to *share* lifelike qualities: technologies made of analog circuits or wood seem to fluctuate and breathe like "little creatures." Jessica Rylan prefers to use analog circuits when designing synthesizers because they follow "very simple, natural laws, just like breaking a tree branch, or like water, or even like birds flying in a V—they push and are pushed into that pattern because it's the path of least resistance." The multimedia installation artist Christina Kubisch suggests that sounds associated with natural environments, like recordings of rainforests and birds, often seem "less genuine" than the ubiquitous electrical and synthesized sounds in contemporary industrialized contexts (Rodgers 2010, 107, 117-18, 122, 131, 142). Inspired by evocative statements like these, I wanted to investigate how and why synthesized sound calls forth such myriad and interwoven connotations of nature and artifice, of machine-generation and liveliness—and what is at stake in these articulations.

As an electronic music-maker myself, I have often wondered what complex histories are contained in the simple lines and shapes that appear on synthesizer interfaces and in textbooks. Common technical and aesthetic terms for the properties of electronic sounds, like "duration," "character," and "decay," have led me to ask philosophical questions of what it means for living and nonliving things to come and go, to be legible as similar or different from others, and to impress upon and be incorporated within ecological processes. I explored such themes in my MFA thesis, "Butterfly Effects," a quadraphonic computer music composition and sound installation written in the programming language

SuperCollider. In this piece, I mapped metaphors and themes of life-cycles, weather systems, and behavioral patterns of migrating butterflies onto aesthetic aspects of synthesized sounds that were dynamically generated in real time (Rodgers 2006). This dissertation is a companion piece and elaboration on that project, investigating similar themes through a feminist-historiographic, material-semiotic, expository analysis.

The above accounts from *Pink Noises* and my own creative practice suggest that encounters and cross-pollinations of humans, technologies, and others extend beyond the paradigmatic concepts of technological design and use that inform some methodologies of science and technology studies, popular music studies, and media studies. Trevor Pinch and Wiebe Bijker's social constructionist methodology (1992), which informs Pinch and Trocco's study of the Moog synthesizer (2002), emphasizes how social groups influence an artifact's evolution by identifying problems and suggesting alternate design solutions or modifications. The authors use the concept of "interpretative flexibility" to convey that there is flexibility in how an artifact is designed, used, and refined. Technological design choices are socially contingent, defined against competing claims, and subject to revision or rejection. Pinch and Trocco (2002, 220-21) document the significance of tinkering in the development of analog synthesizers, a concept that Steve Waksman elaborates on in his analysis of the electric guitar. In the history of the electric guitar, tinkerers have sought to create desired sounds and achieve a certain independence from the guitar-manufacturing and music industries by customizing mass-produced instruments to more individualized specifications (Waksman 2004, 676-77). In a similar vein, Lisa Gitelman emphasizes the concepts of technological definition and use, suggesting these as alternative terms to production and consumption. She argues that the production/consumption dichotomy tends toward determinism by implying that technologies explain social and cultural change; too often this positions male inventors as agents of change and places female consumers in reactive roles. Gitelman emphasizes the collective processes through which technologies are defined by a broad range of users through different kinds of knowledges and practices (Gitelman 2006, 62). All of the above are useful models to think with, however, within these discussions, concepts of technological use and transformation seem confined to social activities and networks.

The concept of *technological worlding* might better account for the ways that encounters with technologies affect, and effect transformations of, imaginary as well as material and social realms of experience. *Worlding* is a concept with Heideggerian roots; in "The Origin of the Work of Art," he suggests that "To be a work [of art] means to set up a world," to reveal something "in the light of its being" (Heidegger 2001, 43, 35). In this sense, "worlding" is to reveal through allegorical reference certain waves of inheritance and possible futures of a given object, rather than to presume accuracy in representation; "World is never an object that stands before us and can be seen," but is instead a process of the unfolding and unconcealing of meaning (Heidegger 2001, 43). There are other seeds of this concept in the terminology used by Madeline Akrich to describe technical and social interactions: engineers "inscribe" a particular vision or formation of the world in technological design, and this forms a "script" or "scenario." Objects are "rendered real or unreal" only in their interactions with social actors. There is inevitable slippage between the projected and real users of a technology, and between "the world inscribed in the object and the world described by its displacement" (Akrich 1992, 207-09). This capacity of technologies to both hold and generate worlds also underlies Haraway's definition of technoscientific figurations, such as the chip, seed, or gene (and I would add synthesized sound to this list), as "condensed maps of contestable worlds" (Haraway 1997, 11). Implicit in worlding is "a creation of strife; understanding worlding involves an analysis of that strife... seeing the historical, political, and economic dynamics of strife through its unconcealment" (Khanna 2003, 4-5; see also Spivak 1999, 211-13). So, one musician's liberatory experience in a synthesized "world of sound" (see Fig. 3, and the epigraph) at the same time backgrounds other(s') worlds, such as those more immediately and adversely affected by the labor and toxic waste in electronics manufacturing and disposal (Sterne 2007; Grossman 1980; Fuentes and Ehrenreich 1983). Worlding can also manifest fantasies of control, as in the "microworlds" constructed in the formal systems of computer cultures, which extend the promise of perfect technological mastery within homosocial communities of young male

Fig. 3. Synthesizer advertisement: "a world of sound in a nutshell" (Micromoog 1975).

programmers (Turkle 1988, 42-43). The metaphors of sounds as waves and individuals, which I elaborate on in subsequent chapters, work together to comprise a narrativizing strategy in audio-technical discourse through which scientists and composers have explained physical phenomena to themselves and others, and historicized their own work and social interactions. Their world of sound—constructed through analog signifying practices—consists of waves populated by differentiated individuals; it is a *mise-en-scene* with figures to move through it, and a world that often expresses desires for technological control.

From another vantage point, Annea Lockwood's "*What constitutes life in a sound?*" can be read as a feminist question about technological worlding, calling out sound as a contestable world of representation and lived experience. Especially in that "the visual is the known—we have ways of dealing with it, talking about it and studying it" and "the auditory is the unknown, the unfamiliar, the new" (Pinch and Bijsterveld 2004, 637), the world of sound may present novel opportunities for feminist worlding. I will not claim recuperate some "really real" sound "out there" in the physical world as a starting point for feminist revisions (or re-soundings) of visualist metaphors. Rather, as I seek elsewheres in audio-technical discourse from which old histories and new worlds can be re-imagined, I am concerned with how sounds circulate as material-semiotic figurations—waves and particles in motion (which we apprehend as the natural or material), ever articulated to visual representations and narrative strategies (the cultural or semiotic). The next chapter begins this exploration with analysis of the sound wave and themes of maritime voyage in audio-technical discourse.

3. "AN UNEASY OCEAN OF AIR": WAVES AND MARITIME VOYAGE IN EPISTEMOLOGIES OF ELECTRONIC SOUND

> Man lives in an uneasy ocean of air continually agitated by the disturbances called sound waves.
> – Frederick Hunt, *Origins in Acoustics* (1978, 1)
>
> The sound of the chorus came across the water and I felt leap up that old impulse, which has moved me all my life... to be tossed up and down on the roar of almost senseless merriment, sentiment, triumph, desire.
> – Virginia Woolf, *The Waves* (1931, 150)

Over many decades, the figure of the sound wave has spanned many communities of musical and audio-technical practice to become a kind of "metaphor we live by" (Lakoff and Johnson 1980). The wave is a fundamental concept in digital audio and recording textbooks (Roads 1996, 14-16; Huber and Runstein 1997, 23-28). Its cyclical form is an iconic image that appears on countless audio technologies, from hardware synthesizer interfaces to software editing environments. There are vestiges of maritime voyage in the language that describes the structure of our ears (canals), and our technologies for working with audio (channels on a mixer). Wave metaphors and maritime themes are so ubiquitous and integral to the design of contemporary audio technologies that they have largely escaped critical reflection.

This chapter investigates cultural origins of imagining the electronic production of sound as a means for the generation and control of waves. I survey the uses of wave metaphors and themes of maritime voyage in late-nineteenth and early-twentieth century texts that were foundational to the fields of acoustics and electroacoustics, and to ideas and machines of sound synthesis. These texts were written by experimenters who formulated key theories of sound in the 1860s and ‘70s, including Hermann von Helmholtz, John Tyndall, and Lord Rayleigh, and by another generation of writers and acousticians who reworked these ideas in the first half of the twentieth century (Miller 1937 [1916]; Lamb 1960 [1925]; Barton 1926; Jeans 1937). These acousticians and authors established a logic of controlling sound waves that persists in contemporary audio-technical discourse.

By analyzing “the narrative character of cultural representations... the stories built in to the representational process itself” (Clifford 1986, 100), I identify a “network of analogies” that converged in epistemologies of electronic sound around the turn of the twentieth century (Foucault 1994, xi). These include analogies between sound, electricity, and water waves; between fluidity and female corporeality; and between maritime voyage, scientific and colonialist enterprise, and the consolidation of an archetypal white, Western, male subjectivity. Acoustics experimenters and authors aligned the physical properties of sound waves with connotations of fluidity and excess that have been associated with female bodies throughout Western history and philosophy. To analyze and control sound meant to experience the pleasure and danger of unruly waves, and to seek their control from a distanced perspective; both the objectified material of sound, and the subject position of acoustics researcher, were gendered in audio-technical discourse. As well, through themes of maritime voyage and discovery, the experiential navigation and technological control of sound waves were articulated to colonialist paradigms of racial exoticism and conquest. An epistemology of electronic sound was built on the perspective and advancement of a white, Western, male subject, so that the technological control of sound waves became a symbolic containment of gendered and racialized excess.

Sound Waves as Fluid Disturbances and Maritime Frontiers

Analogies between sound and water waves were widespread beginning in ancient times, offering a convenient way for observers to visualize the otherwise elusive phenomena of sound (Helmholtz 1954, 26). Perhaps the most enduring analogy of this sort is between the effects of throwing a stone into a pool of water and the propagation of sound waves in air. This is a recurring example in acoustics and physics texts (Hunt 1978, 23-24, 27; see also Helmholtz 1954, 9-10; Jones 1898, 236; Huber and Runstein 1997, 23-24). Ancient analogies of sound and water waves were bolstered by early modern experiments which demonstrated that air motions associated with musical sounds are oscillatory, and by observations that sounds bend around corners, which is a diffractive phenomenon also associated with water waves. Mathematical theories of sound waves began with Isaac Newton's *Principia* (1686), and wave equations for describing sound propogation were further refined by Euler, Lagrange and others in the eighteenth century (Pierce 1989, 3-6). Sound and water wave analogies also took hold in a nineteenth-century context in which knowledge of sound was driven by the ability of experimenters to visualize its effects (Sterne 2003, 44-45). It seems that the solidification of wave theory in science fostered more imaginative uses of the metaphor. As wave theories became more mathematically detailed, applications of the wave metaphor grew more elaborate. Late-nineteenth century writers like Helmholtz and James Jeans extended the wave metaphor by describing sound with florid analogies to such things as whirlpools, steamboats, and ships, particularly when translating their work for a popular readership (Jeans 1937, 3, 56, 124-25; Helmholtz 1954, 26).

Ideas for the generation and control of electronic sound waves by synthesis techniques emerged in a Euro-American cultural context at the turn of the twentieth century in which wave metaphors and fascinations with the sea abounded (Helmreich 2009, 15, 34-35). Sound and electricity were both understood as fluid media and were conceptually linked to each other through water-wave metaphors and associated terms such as current, channel, and flow. Heinrich Hertz's research on electromagnetic waves in the 1880s contained these metaphoric associations, and his work informed the analogies that subsequent generations of acoustics researchers drew between sounds and electrical signals (Thompson 2002, 34, 61, 96). Additionally, emerging networks of hydroelectric power in the U.S. technically and representationally linked water waves to large-scale systems for moving electrical currents. In the popular imagination, hydroelectric power symbolized a simultaneous control of water and electrical waves that seemed to be a necessary and inevitable manifestation of technological progress (Hughes 1983, 106-07, 135-39).

Concurrently, scientists were developing a universal theory of light, heat, and sound that would define all of them in terms of motion. By the 1920s, it was popularly understood that waves, and particles in wave motion, comprised everything in the universe (Beer 1996, 298). Wave-particle duality was a central concept in quantum physics that coalesced in the early-twentieth century and suggested that all energy and matter exhibited properties of both waves and particles (Ponomarev 1993, 111). This concept permeates contemporaneous technical descriptions of sound waves. Particles and waves were like the characters and setting of a story, the figures and the ground; particles represented bodies in varying stages of orderly or disorderly motion and rest, and waves signified the manner of the particles' displacement and/or the medium through which they moved. Material reality was thus rendered in audio-technical discourse through gendered and racialized terms: particles were constructed as agential white, male subjects; waves were described with tropes and narratives associated with female corporealities and imperial conquests.

In acoustics texts, sound was characterized by wave *motion* (often illustrated as simple harmonic motion) and wave *propagation*, and both of these concepts manifested a scientistic ordering of space and regulation of movement. D. C. Miller, a physicist who would later become president of the Acoustical Society of America, wrote: "Simple harmonic motion has several evident features: it takes place in a straight line [the middle of which is the position of rest of the particle]; it is vibratory, moving to and fro; it is periodic, repeating its movements regularly; there are instants of rest at the two extremes of the movement" (Miller 1937, 6). Sound entailed a journey of vibrating particles back and forth (Fig. 4), whereby contact with other particles initiated wave propagation: “the continuous passing onward from point to point in an elastic medium of a periodic vibration... produce a series of waves following each other at regular intervals” (Miller 1937, 13-14). Helmholtz also identified these two aspects of sound: “the motion of individual particles of air—which takes place periodically backwards and forwards within very narrow limits—and the propagation of the sonorous tremor” or wave (Helmholtz 1954, 8). The imagined space of simple harmonic motion was one of formal constraint, in which motion took place in a “straight line” within “very narrow limits.” As such, it was an orderly pattern bounded by states of rest, with particles ever at risk of disturbance.

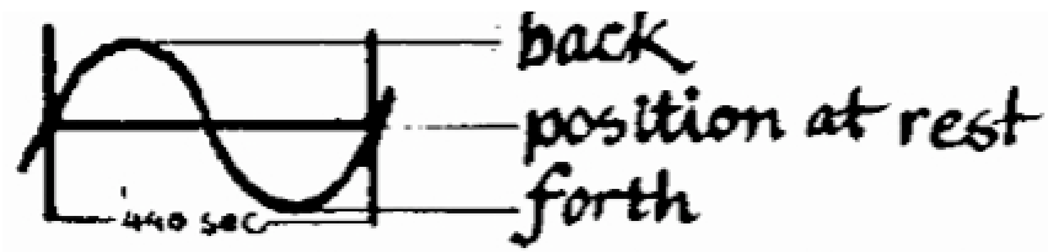

Fig. 4. A long-standing and commonplace representation of a sound wave as oscillation back and forth to a position at rest, ARP 2600 synthesizer owner’s manual (ARP 1971, 4).

Authors of acoustics texts typically defined sound as fluid disturbances of an idealized state of rest. Sound waves instigated the physical displacement of male subjects, and corollary sensory impressions and affects. Miller wrote: “These *disturbances of all kinds*, as they exist in the air around a sounding body, constitute sound waves” (Miller 1937, 5; emphasis added). Tyndall told of “sources of disturbance” and the “shock and jostle of the sonorous waves” (Tyndall 1869, 254, 81-82). Barton described sound as an “external physical disturbance" that excited and stimulated the auditory nerves in the ear (Barton 1926, 1). States of rest were an idealized norm against which these auditory disturbances were measured: "If there were complete rest and immobility, there would be complete silence" (Euclid, 330-275 BCE, cited in Hunt 1978, 17; see also Lamb 1960, 103). This logic has remained largely unchanged. A 1990 textbook summarized that simple wave motion entailed a journey of particles outward and back; and wave propagation consisted of "A *disturbance*... passed along from point to point as the wave propagates... [while] the medium *reverts to its undisturbed state* after the wave has passed" (Rossing 1990, 33, emphasis added).

Sounds as fluid disturbances took the form of external phenomena as well as interiorized sensory experience. Helmholtz spoke of "a sounding body, which shakes the air" in the "atmospheric ocean" (Helmholtz 1954, 10); Frederick Hunt opened his history of acoustics similarly: "Man lives in an uneasy ocean of air continually agitated by the disturbances called sound waves" (Hunt 1978, 1). Many acoustics texts drew parallels between the motion of sound waves in the world and the vibrations of fluids within the ear canal, which were understood as "synchronous with those originating at the external source in the atmosphere" (Barton 1926, 341). Jeans conjured a most vibrant analogy of sound and water waves that transposed the turbulent fluidity of the sounding world onto the interior of the subject:

> Sound reaches our ears in the form of waves which have travelled through the surrounding air, much as waves travel over the surface

> of a sea or river; some of these waves travel down the inch-long backwater formed by the auditory canal, and finally encounter the ear-drum, which forms a barrier at the far end...
>
> We may often feel a sea-wall tremble under the pounding of the waves, and a delicate seismograph many miles inland will record the impact of sea-waves on a rocky coast. In the same way, sound-waves in the air exert a varying pressure on our ear-drums which may set them into motion (Jeans 1937, 6-7).

The ear was a destination of sound waves, one that "accepts... all the strife and struggle and confusion" of vibratory motion in the surrounding environment (Tyndall 1869, 82). It was also an orifice or borderline that opened onto an interior, labyrinthine structure; in one author's description, the tympanic membrane was the point at which sound waves crossed over from the exterior to the interior world, the "frontier between physics and physiology" (Lamb 1925, 1).

Structures within the ear (solids, fluids, and membranes) were depicted as a terrain of interconnected parts through which vibrations "travel" (Barton 1926, 335-43). The term ear canal itself evoked a channel of water for navigation, an arm of the sea. Francis Bacon's *Sylva Sylvarum* (1626) contained one of the first applications of the term *canal* (derived from channel, a waterway for boats) to a pipe for amplifying sound, as well as to tubular structures within the body, such as the ear canal (*OED*, "canal"). Like twentieth-century biotechnology discourses that transposed tropes of outer-space travel to "inner space" representations of immune systems (Haraway 1991, 221-25), Bacon and followers imagined formal structures of the ear in relation to symbols of maritime voyage drawn from concurrent scientific and colonialist exploration projects. Themes of maritime voyage symbolized the promise of scientific exploration to conquer the unknowable, fluid landscapes of sound waves in the furthest reaches of the world and the innermost spaces of the ear, and these metaphors have persisted in audio-technical discourse (Fig. 5).

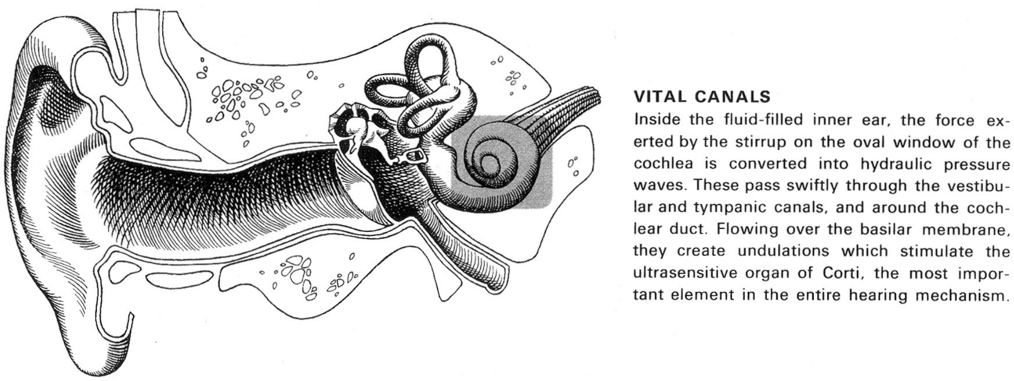

Fig. 5. The “hydraulic pressure waves” in the “fluid-filled inner ear” and its “vital canals,” as shown in a *Life* magazine illustrated book on sound and hearing (Stevens et al. 1965, 42).

Like sound waves in the “uneasy ocean of air” that man encounters in the exterior world, the movements of fluids inside the ear threatened the subject’s sense of balance: “They are also responsible for the giddiness we feel after spinning round too often or too rapidly, and for... the even less agreeable sensations we experience when we are on a small ship in a turbulent sea” (Jeans 1937, 3). Helmholtz likewise noted the different types of feelings generated by waves, and their relationship to a sense of order:

> Water in motion, as in cascades or sea waves, has an effect in some respects 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 peculiar feeling of pleasant repose or weariness, and the impression of a mighty orderly life, finely linked together... Small undulations, on the other hand, on small surfaces of water, follow one another too rapidly, and disturb rather than please (Helmholtz 1954, 251).

Sound waves could provoke feelings of stimulation and pleasure, but ultimately required the male subject to establish balance and control—to return to shore, a home state of repose, the foundation of "a mighty orderly life."

Sound waves represented a space of travel, characterized by fluid disturbances that displaced male subjects and generated surprising or pleasurable feelings until these subjects returned "home" to a position of rest or balance. This discourse is consistent with colonialist narratives in which a white, Western, male subject voyages out for purposes of scientific discovery, domination, and affective contact with racially exoticized others. As bell hooks has written, the longings for pleasure and danger that are associated with encounters with Otherness have "led the white west to sustain a romantic fantasy for the 'primitive' and the concrete search for a real primitive paradise, whether that location be a country or a body, a dark continent or dark flesh" (hooks 2006, 370). The seemingly natural wave motion and affective experience of sound—a voyage of particles outward and back, and the corollary transportation of a white, male voyager to a pleasurable, sensory experience and back to a state of rest—enables imperialist and masculinist ideologies to circulate in audio-technical discourse as natural and inevitable. In her pioneering work in feminist musicology, Susan McClary demonstrated that tonal music is organized so that the dominant mode controls other keys in a way that signifies phallic mastery, and that musical narratives are tonally resolved by a journey through and conquest of "Other" musical areas, thus encoding colonialist paradigms in their structure (McClary 1991, 155-56). There are similar stakes in the definition of sound waves as oscillations between disturbance and rest: the experience of sonic *disturbances* functions as a symbolic production of alterity, and their management as a containment of gendered and racialized excess.

Luce Irigaray, in her essay "The 'Mechanics' of Fluids," claims that feminized fluids are "*a physical reality* that continues to resist adequate symbolization and/or that signifies the powerlessness of logic to incorporate in its writing all the characteristic features of nature." Fluids are often envisaged in an ideal state "so as to keep it/them from jamming the works of the theoretical machine." Authors of acoustics texts figured sound waves as unruly disruptions in need of containment, especially as they passed through the fluid media of water or air. While theories about sound were immersed, so to speak, in water analogies, the behavior of sound in *actual* water proved difficult to measure. Tyndall, Rayleigh, and Barton all expressed difficulty in representing the behavior of sound in water, except in ideal terms. Tyndall noted that mathematical theories often deal "solely with the propagation of sound... in an *ideal fluid*, which unites all the properties *hypothetically*" (Tyndall 1869, 324). He concluded that "The velocity of sound in liquids may be determined theoretically" (Tyndall 1869, 37). Rayleigh devoted no fewer than thirteen chapters of *The Theory of Sound* to explicating acoustic radiation in fluid media, including air and water. In the introduction to the book, Robert Bruce Lindsay observed: "This is by far the most difficult part of the subject matter of acoustics and has remained so to the present time. Since there is no such thing as a perfect fluid the exact hydrodynamical equations describing with precision the motion of a compressional disturbance in a fluid medium like air or water must necessarily be extremely complicated" (Rayleigh 1945, xxviii). Barton likewise concluded that motion from the propagation of sound in water waves was "more complicated" than its movement through coil or cord (Barton 1926, 8).

According to Irigaray, "historically the properties of fluids have been abandoned to the feminine" (Irigaray 1985, 106-07, 111, 116). These properties include formlessness and uncontrollability, which threaten the coherence of subject and object as distinct entities, and also hold connotations of abjection (Young 2005, 81; see also Grosz 1994, 195). Iris Marion Young explains: "The point is that a metaphysics of self-identical objects has clear ties to the domination of nature in which the domination of women has been implicated because culture has projected onto [women] identification with the abject body" (Young 2005, 81). Elizabeth Grosz elaborates on this idea by examining Irigaray's essay alongside Mary Douglas's *Purity and Danger*. For Douglas

> what is disturbing about the viscous or the fluid is its refusal to conform to the laws governing... the solid and the self-identical, its otherness to the notion of an entity—the very notion that governs our self-representations and understanding of the body. It is not that female sexuality is like, resembles, an inherently horrifying viscosity. Rather, it is the production of an order that renders female sexuality and corporeality marginal, indeterminate, and viscous that constitutes the sticky and the viscous with all their... horrifying connotations (Grosz 1994, 195).

An Irigarayan reading suggests that the analogy between sound and water waves in acoustics texts articulates the physical behavior and experience of sound to the connotations of formlessness and unknowability that historically have been associated with female sexuality and corporeality, and to the horrors of submersion and dissolution that threaten the coherence and dominance of the male subject. As Stefan Helmreich has written, in nineteenth-century Euro-American culture, “The life-taking and life-giving ocean... embodied a dualistic femininity, alternately maternal and witchlike... [It] had become a master symbol of the sublime, of the awesomely beautiful and terrifying, of the natural that exists on such an overwhelming scale” (Helmreich 2009, 15). Likewise in audio-technical discourse, feminized waves were both form-giving—making possible the very sense of what sound is—and perpetually in excess of formal representation.

Actual sound waves were difficult to represent, and were knowable primarily through analogy to visual tropes and inexact mathematical formula. But the movement of *particles* in wave motion and propagation provided a vehicle for authors of acoustics texts to imagine male, homosocial interactions. Tyndall, for example, narrated and performed a description of simple harmonic motion by personifying the particles as boys:

> I have here five young assistants... placed in a row, one behind the other, each boy’s hands resting against the back of the boy in front of him... I suddenly push A, A pushes B, and regains his upright position... We could thus transmit a push through a row of a hundred boys, each particular boy, however, only swaying to and fro (Tyndall 1869, 5; Fig. 6).

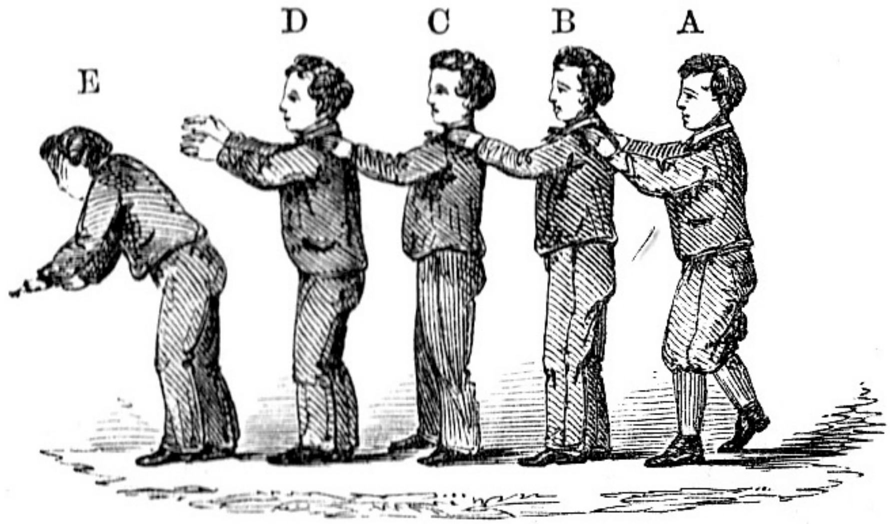

Fig. 6. A demonstration of wave motion and propagation, with particles personified as boys (Tyndall 1869, 4).

Even such simple contacts were not without consequence. The boy at the end of the line "is thrown forward. Had he been standing on the edge of a precipice, he would have fallen over; had he stood in contact with a window, he would have broken the glass" (Tyndall 1869, 5). The causes of such troublesome impacts were the fluid and feminized disturbances of sound waves. A 1965 *Life* magazine illustrated book about sound includes a similar picture designed for another historical moment, in which moving particles are rendered as "little men" doing industrious "work"—colliding and transferring energy in a lonely crowd of mid-century mass culture, itself a feminized cultural space against which white, middle-class American men sought to fortify their masculinity (Fig. 7; see also Waksman 2004, 677-78). These examples show how audio-technical representations are condensations of worlds in which social differences have been produced and naturalized as neutral, physical properties of sound.

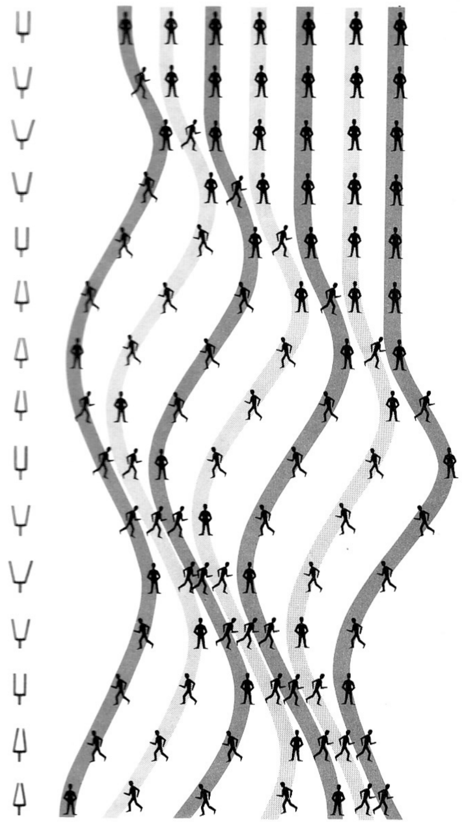

Fig. 7. Illustration of a sound wave in a 1965 *Life* magazine book on sound and hearing, with the caption: "Sound's movement through the atmosphere is the work of air particles, represented by little men above, that continually bump against one another and pass along the energy provided by the sound source" (Stevens et al. 1965, 11).

Objective Perspectives and Communication Through Fluids

Audio-technical descriptions of sound waves follow logics of scientific rationality in which knowledge and power are consolidated through practices of detached observation (Haraway 1988, 581; Daston 1992). Many accounts in acoustics texts set up a *mise-en-scene* for the observer to establish such a perspective. Tyndall positioned himself as a leisurely traveler, observing mechanical vibrations: "In travelling recently in the coupé of a French railway carriage I had occasion to place a bottle half filled with water on one of the little coupé tables. It was interesting to observe it. At times it would be quite still; at times it would oscillate violently" (Tyndall 1869, 101). And, to measure complex patterns of wave propagation: "From a boat in Cowes Harbour, in moderate weather, I have often watched the masts and ropes of the ships, as mirrored in the water" (Tyndall 1869, 253); in another example, he is a rugged adventurer who scaled heights for a clearer perspective over the water (Tyndall 1869, 19-20). Helmholtz also wrote of taking a certain pleasure in observing complex wave patterns from a lofty perspective:

> a great multitude of different systems of waves mutually overtopping and crossing each other... is best seen on the surface of the sea, viewed from a lofty cliff, when there is a lull after a stiff breeze... A passing steamboat forms its own wedge-shaped wake of waves, or a bird, darting on a fish, excites a small circular system... I must own that whenever I attentively observe this spectacle it awakens in me a peculiar kind of intellectual pleasure (Helmholtz 1954, 26).

Helmholtz's pleasure came specifically from the sense that the imagined behavior of sound waves was rendered visible in his observations of the sea from a comfortable distance. In all the above examples, the observer makes a claim to truth about the behavior of sound by assuming a detached perspective from unpredictable waves: calmly viewing a shaky glass on the table, perching on a boat to view the water, advancing to a cliff far above the sea. Indeed, to touch or fall into the waves would compromise the male subject's objective position and signal a loss of control.

A male subject who will navigate and control the waves is born out of a desire to manage the volatile fluidity of sound; this subject is a kind of mythic voyager reincarnated as a natural philosopher, acoustics researcher, or composer. In one of James Jeans' more elaborate accounts, this subject gains self-identity by casting off the fluid scene of origins in progressive stages of evolution. The subject emerges and differentiates himself from a formless sea, evolving from a primitive fish species to attain a complex ear organ that enables human survival and domination of nature and, ultimately, the cultivation of musical tastes. Jeans states: "In some such way as this, the human race became possessed of its ears. At first they would merely be helps in the struggle for existence. But we can imagine primitive man one day discovering in them an interest and a value of another kind... On that day music was born" (Jeans 1937, 1-4). One way to read this fish story is as a psychoanalytic narrative of the male subject's entry into the symbolic order through a disavowal of the maternal space from which all subjects emerge. Jeans's narrative of a progression from marine life (fully immersed in water), to an "anxious" amphibious phase, to a final state in which man survives on dry land, parallels the movement of the subject from the enveloping space of the womb to full separation from the mother and self-recognition in the world. Grosz's account of Western representations of the female body and maternality as modes of uncontrollable fluidity—"a formlessness that engulfs all form, a disorder that threatens all order," and those "liquidities that men seem to want to cast out of their own self-representations"—supports this reading (Grosz 1994, 203).

Jeans's attribution of the "power of analysis" of sounds to evolutionary adaptations endowed his narrative, and the scientific study of sound more generally, with a measure of authority that seemed inevitable and indisputable. Man, the "subject of science" (Irigaray 1987), had risen to the top of the so-called workshop of nature: "In their mastery of nature, the creative God and the ordering mind are alike. Man's likeness to God consists in sovereignty over existence, in the lordly gaze, in the command... The man of science knows things to the extent that he can make them" (Horkheimer and Adorno 2002, 6). The logic of synthesis that proclaims in theory that any sound can be made is contingent upon techniques of analysis that are predicated on such a distanced gaze.

Despite the need for an objective distance to properly observe the waves, authors of acoustics texts also indicated a desire for contact with sound/water waves in order to be challenged, and to overcome their unpredictabilities with demonstrations of mastery. Like the mythic seafarer Odysseus, whom Max Horkheimer and Theodor Adorno theorize as the prototypical bourgeois subject, the sonic experimenter "achieves estrangement from nature by abandoning himself to nature, trying his strength against it in all his adventures" (Horkheimer and Adorno 2002, 38). For example, to measure the velocity of sound in water, experimenters literally set out across the waves. This may seem merely practical as a scientific experiment, but when read as part of a narrative tableau that takes shape across multiple acoustics texts, it becomes something closer to a ritualistic performance of an archetypal male subjectivity. Leonardo da Vinci dipped one end of a tube in the water and placed the other end to his ear, awaiting a response;

Colladon and Sturm, in an 1826 experiment, embarked on a boat, struck a bell, and waited for the sound to reach their colleagues (Fig. 8); Tyndall's companions shouted out to him across a glacier, assessing the effect of the weather on the speed of sound. Storms and treacherous waters functioned as impediments to the observers' communications (Tyndall 1869, 19-20), and conversely, the ability to hear faraway sounds most clearly was associated with calm waves: days when "the sea was of glassy smoothness" (Rayleigh 1945, vol. II, 137).

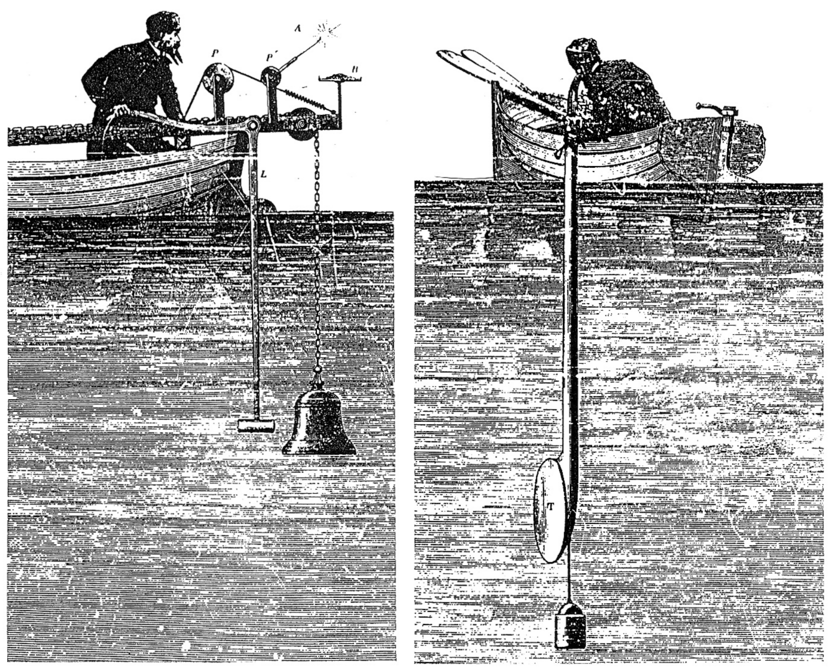

Fig. 8. Colladon and Sturm's measurement of sound velocity at Lake Geneva, 1826 (Beyer 1999, 35).

Such depictions of turbulent waves as impediments to male subject formation re-present themes in the Judeo-Christian tradition, notably the stories of creation, Noah's ark, Jonah and the great fish, in which the enveloping waves must recede, by the power of the creator, for the advancement of the male subject, the proliferation of species, and the progress of civilization. In audio-technical discourse, waves must be tamed through objective processes of analysis in order to be re-created in any desired form through techniques of synthesis.

Mediating instruments were crucial to the incorporation of sound waves into logics of analysis and systems of communication. In several experiments recounted in acoustics texts, tubes and other solids served as mechanisms to contain and channel sound waves against the formless excess of the surrounding fluid medium. Irigaray's analysis is again useful in accounting for the construction of gender in these texts. She argues that, aside from its representation as an ideal, the "reabsorption of fluid in a solidified form" is necessary for its intelligibility in a phallic economy (Irigaray 1985, 111). Young likewise asserts that the fluidity or indeterminacy of female body parts, especially the breasts, is solidified through technologies of constraint such as clothing and surgery (Young 2005; Grosz 1994, 205). In Colladon and Sturm's experiment, the unintelligibility of sounds in water was resolved by recourse to the solid medium of the tube. The listener on Lake Geneva "[applied] his ear to a tube carried beneath the surface" (Rayleigh 1945, vol. I, 3). This harks back to the earlier test by Leonardo, who observed that "if you cause your ship to stop, and place the head of a long tube in the water, and place the other extremity to your ear, you will hear ships at a great distance from you" (cited in Hunt 1978, 76). Rayleigh concluded that to communicate sound from air to water or water to air, "A beam of wood, or a metallic wire, acts like a speaking tube, conveying sounds to considerable distances with very little loss" (Rayleigh 1945, vol. II, 89). And to transmit sound across fluid media "the most effective of all is a tube-like enclosure, which *prevents spreading altogether*" (Rayleigh 1945, vol. I, emphasis added).

The historian of communication John Durham Peters has suggested that ideals of unimpeded communication across a distance, beyond the presence of the body, manifested later in the nineteenth century with telegraphy as a means for the "capturing and dispersion of signals" across the fluid ether (Peters 1999, 78, 137-40, 178). But the experiments by Leonardo, Colladon and Sturm, and others who used speaking tubes in water are evidence of earlier concerns with sonic transmission and fidelity across a distance. These sonic experimenters' uses of tubes to preserve their own voices from diffusion in the immersive sea resonate with ongoing methods for guarding against loss in techniques of sound reproduction, the perceived degradation in quality of the audio signal as it passes through the surrounding medium (Sterne 2003, 215-86). In these examples, communication is idealized as the preservation of male subjectivity in sound against the threats of dissolution amidst feminized, fluid media.

New Atlantis and the Genesis of Synthesis

Francis Bacon's *New Atlantis*, with its maritime context and biblical undercurrents, is a prominent origin story of synthesized sound. Bacon appears as a kind of patriarchal figure and interlocutor across many acoustics texts and electronic music histories via an oft-cited passage from the story about sound:

> We have also sound-houses, where we practise and demonstrate all sounds and their generation. We have harmonies which you have

> not, of quarter-sounds and lesser slides of sounds... We represent small sounds as great and deep; likewise great sounds, extentuate and sharp; we make divers tremblings and warblings of sounds... We represent and imitate all articulate sounds and letters, and the voices and notes of beasts and birds (Bacon 1952, 213).

Variations on this passage are cited as a sort of manifesto in the Columbia-Princeton's Electronic Music Studio's review of their activities in the late 1950s (*Preliminary Report* 1957, n.d., 4); and are mentioned as a foundational moment for the concept of creative sonic experiment in many histories and textbooks of electronic music (see Chadabe 1997, 3; Jenkins and Smith 1975, 146; Deutsch 1976, v). Twentieth-century inventors, composers, and educators cited the *New Atlantis* to situate their work within a history and mythos of scientific experiment that signifies, at once, both rationality and adventure. They attached their endeavors to the promise held out by this famous tale of technological utopia: that the establishment of dedicated studios ("sound-houses") would foster knowledge and mastery of new technologies for producing any sound imaginable through the application of scientific inquiry.

New Atlantis was Bacon's unfinished work, drafted in the years before his death in 1626 in a hybrid style of travel narrative, utopian fantasy, and social commentary (Salzman 2002, 20). It was published in 1627 in the same volume with *Sylva Sylvarum*, a compilation of Bacon's observations, experiments, and information that comprised his natural history and philosophy. Some scholars conclude that these texts should be understood as two parts of a whole, with the *New Atlantis* representing Bacon's vision for an exemplary scientific society that carries out the principles outlined in *Sylva Sylvarum* (Salzman 2002, 43). Others see the unfinished, open-ended form of the fable as a deliberate rhetorical device, designed to engage readers in the scientific enterprise that *Sylva Sylvarum* lays out (Hutton 2002, 57). Bacon has been labeled a "father of modern science" for his program of experimental techniques to make use of the natural world for cultural advancement, and for his role as an inspiration for the modern research institute (Merchant 1980, 164; Serjeantson 2002, 84). He is a fitting interlocutor for narratives of sound waves because he recognized analogies and myths as fundamental components of scientific communication. He saw fables and figurative language as useful tools for conveying new ideas, and believed that unfamiliar concepts could be well communicated by analogy to the familiar (Hutton 2002, 51).

In *New Atlantis*, Spanish sailors set off for China and Japan, lose their course, and instead find the island Bensalem (the New Atlantis). The opening line ("We sailed from Peru...") is a conventional introduction to a travel narrative (Salzman 2002, 32); it establishes the journey as a collective endeavor among a team of seafarers, not unlike those who would later set out to measure the velocity of sound in water. Moreover, "The entire process of the crew's encounter with New Atlantis contains a biblical register: they arrive out of a 'wilderness' and, after praying to God, are saved by 'a kind of miracle', whereby they are 'cast on land, as Jonas was out of the whale's belly'" (Price 2002, 11). They lost their way "in the midst of the greatest wilderness of waters" (*New Atlantis,* cited in Price

2002, 5)—as in Frederick Hunt's history of acoustics, Bacon's voyagers are archetypal men at sea in an ocean of air. Once the crew arrives on the island, they are introduced to the conventions of Bensalemites. They learn about its College of the Six Days' Works—also called Salomon's House—another reference to the story of creation in the book of Genesis (Albanese 1990, 508). It is here, in a litany of projects conducted at Salomon's House, that we are told of their experiments with sound.

Far from being a utopian anticipation of future sound technologies, as it is often understood when quoted out of context in histories of electronic music, Bacon's "sound-houses" passage was grounded in his familiarity with music technologies and performance techniques of the period. These included automata (clocks and musical instruments that imitated natural sounds by mechanical and hydraulic means, well publicized in publications and illustrations), the skills of pantomime artists and ventriloquists who imitated others' voices, and performances by court musicians that relied on expensive technologies to communicate particular emotional effects (Gouk 1999, 31, 162-63, 168). In *Sylva Sylvarum*, his "evident familiarity with a wide variety of instrumental sounds enabled Bacon to cite examples of different musical qualities and textures. He proposed a whole series of experiments to see how the materials used in the construction of instruments, their shape, including the the length and thickness of strings or pipes, and various other factors, determined qualities such as pitch and timbre" (Gouk 1999, 168). Consistent with his broader scientific program, in his vision for sound technologies Bacon sought to combine rigorous investigation of natural phenomena with performative demonstrations that drew upon traditions of magic and its invocations of wonder (Gouk 1999, 31). So, rather than being a prescient prediction of future synthesized sound technologies, the sound-houses passage suggests that an impulse to generate sound through scientistic means—to create the sounds of beasts and birds, and to call forth a sense of wonder at those creations—is a recurrent desire in dominant Western modes of thought, manifested across a wide range of sound-generating technologies in different eras.

Bacon's philosophical program, including *New Atlantis*, has been criticized for sanctioning colonial agendas, patriarchal organization of society, and domination of nature expressed through a language of physical coercion and rape (Merchant 1980; Park 2006). The fictional form of travel narrative, in *New Atlantis* as elsewhere, is articulated to colonialist agendas and scientific discoveries: "Both expeditions to America and scientific programs propagandize themselves as voyages out, into uncharted territory, where the sense of excitement that attaches to new ventures covers over the work of domination that underwrites exploration of the globe and of nature both" (Albanese 1990, 506). Travel was understood to advance scientific knowledge through "unprecedented experiences" and encounters with "distinct flora, fauna, and technology" (Solomon 1998, 506, 162).

The invocations of *New Atlantis* in discourses of sound are implicitly informed by these themes. Authors of acoustics texts routinely articulated the advancement of scientific knowledge about sound to themes of voyage and discovery that are common to colonizing aims. For example, in an account of the promise of music and electricity published in 1937, composer Carlos Chavez claimed: “Only by [the study of the development of art in relation to man’s domination of nature] may we obtain a much-needed perspective on the present, just as a mariner, to confirm his route, must first ascertain his position on the vastness of the ocean” (Chavez 1937, 16). D. C. Miller characterized discoveries in music and science as a process in which the “indefatigable discoverer may be able to push forward into unknown regions, and... be thrilled with the desire for their possession” (Miller 1937, 263). The process of simple harmonic motion (in which particles voyage out, and return home) worked to naturalize the wave metaphors and tales of seafaring used to describe the acquisition of scientific knowledge about sound. Technical and theoretical accounts of sound thus served as allegories of a masculinist and colonialist “domination” of unpredictable forces of nature, and “possession” of “unknown regions.”

On one level, these were expressions of how particular natural philosophers, experimenters, and composers imagined themselves and their projects in specific cultural and historical contexts. In an essay on the influence of scientific discourses on literary modernism, Gillian Beer links wave theory to a typically modernist account of bombardment of the senses. Concepts of the ocean, or, as Nietzsche called it, the “sea of forces flowing and rushing together” were key modernist tropes that cut across cultural fields (Beer 1996, 313). But technical narratives of sound also take on a timeless quality. Cited and retold in multiple generations of technical literature, and informed by ancient and early modern observations and myths like the *New Atlantis*, their message seems inevitable: that sound, now as ever, is to be experienced and known through the bold traversal and rational management of turbulent waves.

Signal Flow, Audible Drift, and Odysseys: Waves in Synthesizer Design and Use

Wave metaphors and maritime themes run all the way through the long history of synthesized sound; more than merely abstract or poetic concepts, they are an integral aspect of audio-technical designs, synthesizer technologies, and uses. The technological possibility of synthesizing sound has roots in scientific observations of water waves and desires to navigate waters by predicting wave shapes and patterns. One of the first documented technologies to be called a *synthesizer* was Lord Kelvin (William Thomson)'s mechanical device to predict the tides, developed in the 1870s. Kelvin's harmonic synthesizer performed calculations to integrate simpler curves into a more complex waveform (Miller 1937, 110-11). The machine was an important technological bridge between Joseph Fourier's mathematical concepts of waveform synthesis, established in the 1820s, and the implementation of these concepts in musical instruments that generated sound electronically, such as Cahill's Telharmonium in the 1890s.

Water metaphors also infiltrate the ways that analog circuits and electronic oscillations have been imagined in audio-technical discourse. A press release on the design of the Random Probability System, a composition aid and prototypical music sequencer developed at RCA in the late-1940s, described the signal path through the system "just as floating sticks might follow different channels in drifting through a river delta with many branching streams" ("Electronic aid" 1961, 3). The switchboard-like patching matrix for controlling the signal flow was not unlike the rational grid system for mapping the seas imposed in the popular *Battleship* game, which was inspired by naval defense strategies and introduced around the time of World War II (*Battleship* 2010). Synthesizer historians Pinch and Trocco also refer to analog filters as analogous to technologies for the systematic control of flowing water, like "a gate in a stream" (Pinch and Trocco 2002a, 65). Such maritime themes linger in the logics of digital circuits, which are described with terms like "ports" and "channels" (Audity 1979).

Another example of how wave metaphors infiltrate the audio-technical designs and uses can be found in one of the central technical conundrums in the history of analog sound synthesis throughout the twentieth century, the problem of "audible drift." "Tuning... was a significant problem with analog technology. Analog synthesizers were neither precise nor impervious to temperature change" (Chadabe 1997, 157). Electronic oscillators tended to "drift" out of tune, creating problems for musicians and engineers who desired precise control over frequency (or musical pitch). Musicians or technicians needed to re-calibrate oscillators on a regular basis; oscillator manufacturers competed over whose product offered the best frequency stability at a given temperature, advertising such features as "low drift rate" (Belar 1949).

Audible drift would eventually be embraced by musicians as a desirable feature rather than a problem to be corrected. Moog synthesizers in the 1970s were commonly described by musicians and electronics enthusiasts as having a particularly “fat” sound precisely because its oscillators “tended to drift” in relation to each other, which generated variable sonic texture over time (Pollack 1998, 14). Paul Théberge writes: “The search for a ‘fat’ sound... has long been a preoccupation among popular musicians who use synthesizers... [It] can be defined as a sound that is the result of [a] ‘spreading out’ or expansion of the audio signal” (Théberge 1997, 208-09). Musicians working with electronic instruments have developed a vast array of paired terms, notably “fat/thin” and “warm/cold,” to metaphorically communicate differences between desirable and undesirable sonic aesthetics. Théberge suggests that one way that these musicians (who are typically white and male in his accounts) affirm their “outsider” position to mainstream culture is through “a curious reversal of the conventional social expectations concerning the value relationships [of the paired terms]... For example, a ‘fat’ synthesizer sound is considerably more desirable than a ‘thin’ one” (Théberge 1997, 207-08). These musicians may well be affirming an outsider position in terms of socioeconomic status and agency in creative expression, against the multinational corporations that designed and marketed synthesizers with increasingly inflexible designs after 1980. However, they are also archetypal sonic voyagers for whom the “fatness” associated with drifting, mysteriously out-of-control, oscillators can be understood to align with the sexualized and racialized notions of excess that have long characterized descriptions of out-of-control sound waves in audio-technical discourse. The problem of audible drift and its eventual embrace as a desirable “fat” sound exemplifies the dual desires of the white, Western, male subjects of these discourses for exerting control and mastery over unruly waves, and being seduced by the excess and pleasurable immersion that these waves signify.

Maritime themes have also inflected the naming conventions of specific electronic musical instruments and synthesized sounds. Synthesizers introduced to a mass market in the 1970s were given names like Voyager and Odyssey (by the Moog and ARP companies, respectively). The ARP Odyssey was celebrated in its owner’s manual as “the ultimate musical trip”: “Everything from thunder and lightning to gong, fuzz guitar, and feedback distortion is at your fingertips with the Odyssey’s controls and patch switches” (ARP 1976). The patch book for the Odyssey (ARP 1981), a compendium of diagrams that show users how to make sounds, included instructions for synthesizing the sounds of “Mayday at Sea” (Fig. 9). “Mayday” is the international distress call used by seafaring voyagers who face grave and imminent danger. The Odyssey synthesizer cited and reworked the Homeric epic of the same name: rather than endure the indeterminate fate of treacherous waters, with a synthesizer man could create the waves and the sounds of storms and creatures to please and challenge him. The ultimate musical trip for such sonic adventurers was to express themselves amidst unruly waves of their own technological generation and control.

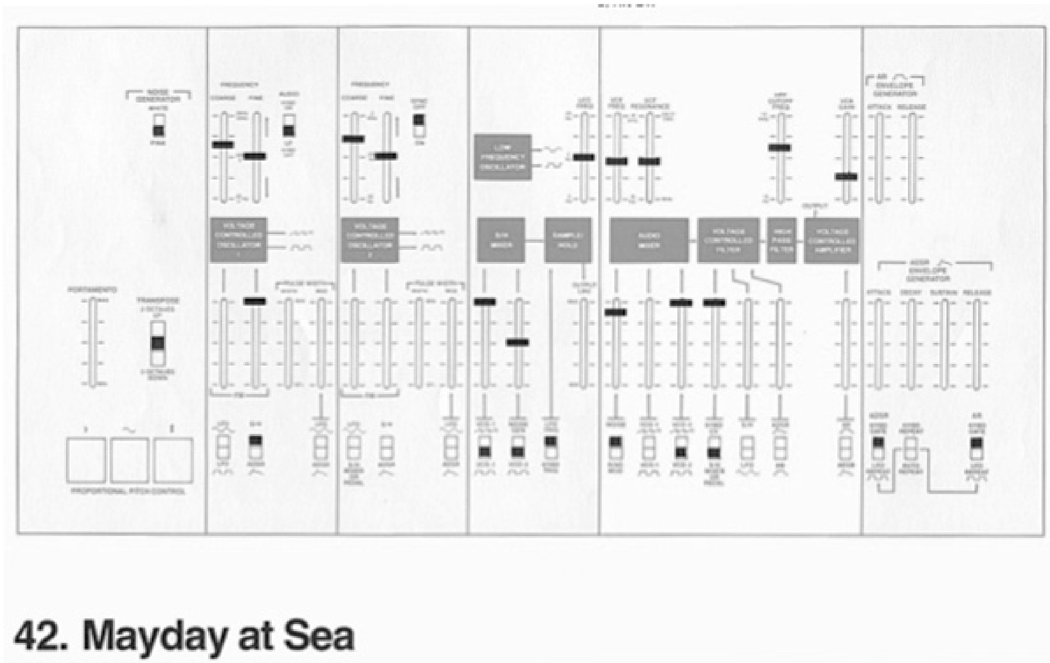

Fig. 9. Instructions for synthesizing the turbulent wave sounds of a “Mayday at Sea,” ARP Odyssey patch book (ARP 1981).

Refiguring Sound Waves as Allegories of Interconnection

How might we consider sound waves differently, as a means for generating feminist theories as well as alternate histories of audio cultures? Donna Haraway developed the concepts of situated knowledges and partial perspectives as a way for feminists to reclaim the sensory powers of vision from that “conquering gaze from nowhere.” This refers to the consolidation of knowledge and power in those “unmarked positions of Man and White” that have characterized practices of scientific objectivity (Haraway 1988, 581). Haraway proposed feminist forms of objectivity as those that recognize all knowledge claims as partial, and culturally and historically located. In a litany of questions that exposed the many contingencies of scientific objectivity (“How to see?

Where to see from? What limits to vision?...”), she asked: “What other sensory powers do we wish to cultivate besides vision?” (1988, 587) As I have shown, dominant epistemologies of sound have followed a typical Enlightenment consolidation of vision, knowledge, and power by articulating the acquisition of knowledge about sound to observations of visualized sound waves from a distant and objective subject position. However, the figure of the sound wave offers ways of imagining situated knowledges and partial perspectives that depart from merely visual senses and metaphors, and instead suggest affective and open-ended processes of touch and movement.

In one modernist trajectory, acousticians devised visual representations of sound waves in order to predict, control, and re-create them. Virginia Woolf offered another way forward in her experimental novel *The Waves* (1931), which employed sound and water wave metaphors to emphasize oceanic communality (Beer 1996, 315). In a similar spirit, in 1975, science fiction writer Ursula Le Guin produced a radically different version of *New Atlantis* than Bacon’s utopia of the same name. Le Guin’s story is a dystopic account of the American West Coast transformed by floods and destroyed by pollution, overpopulation, depletion of natural resources, and excessive government control. Because of these transformations, the North American continent is sinking and an ancient civilization is rising from the ocean. The story is told from alternate perspectives of a woman on the sinking continent, and from the communal voice of the ocean people (Cummins 1993, 166-67). Le Guin writes:

> Where did they come from, those dim, slow, vast tides?... We could not understand that; we could only feel their touch against us, but in straining our sense to guess their origin and end, we became aware of... something out there in the darkness of the great currents: sounds... Sound is a fragile thing, a tremor, as delicate as life itself (Le Guin 1975, 74).

In this and other passages, Le Guin uses sound and ocean wave metaphors allegorically, but in a different way than the examples in foundational acoustics texts. Le Guin's characters strain their ears to hear lessons from history; the touch of waves across distant shores signifies both the traversal of time (by symbolizing a connection between past, present, and future) and the traversal of space (by representing encounters of cultural difference that are about mutual exchange rather than domination). Waves represent the politics of encounter and contingencies of mutual contact rather than a disturbance or medium of conquest.

The age-old analogy of the stone thrown into a pool of water is typically told from the perspective of a distant viewer who observes the patterns of waves. We might alternatively adopt perspectives of being carried by, moved with, or submerged under the waves. Woolf wrote of the delirious sensations of being moved by sounds across the water: "The sound of the chorus came across the water and I felt leap up that old impulse... to be tossed up and down on the roar of almost senseless merriment, sentiment, triumph, desire" (Woolf 1931, 150). This subject position within the waves, far from being detached and controlling, is characterized by being affected by, and connected to, modes of experience beyond the boundaries of oneself.

Movements across waves also evoke processes of making new futures. As

Paul Gilroy and bell hooks have shown, diasporic journeys across water—whether forced or chosen, temporary or ongoing—resist containment in Euro- and Afrocentric nationalist paradigms; the Atlantic ocean is a complex "system of cultural exchanges" (Gilroy 1993, 14). Indeed, for many diasporic and queer subjects, "home" is neither a fixed origin or destination, but rather a feeling of "affectual yearning [that catalyzes] a homemaking that does not settle" (Casid 2005, xvi-xvii; hooks 1995). Instead of the common description of simple harmonic motion as an colonialist allegory in which particles/subjects voyage out, experience disruptive pleasure and danger, and return home, we can imagine sound waves as a metaphor for subjects in ongoing and incompleted states of transformation: like Irigaray's formulation of "'dissipatory' structures, which function through exchanges with the exterior world... and which are not organized to seek equilibrium but rather to cross thresholds" (Irigaray 1993, 124).

Nigel Thrift also discusses the ocean is a communicative medium for distributed communities, using whale societies as an allegory for networks of global interconnection. Thrift writes: "The latest research on bioacoustics shows that whales appear to use 'singing' as a means of communicating over thousands of miles of ocean... 'being with' other whales might mean communicating with whales who might be hundreds of miles away" (Thrift 2006, 142). Thrift goes on to discuss the ways in which "the world of whales intersects with the worlds of others" through the medium of the ocean, including its various prey, the multinational whaling industry, and environmental protection organizations. He suggests that human society is approaching a capacity, similar to whales, to "live with distant others" on a vast scale (Thrift 2006, 142-43). In other words, the things that humans draw near also enroll us in interconnected and unequal relations with others who are very far away.

Thinking sound waves as allegories of interconnection can lead humans to account for others who may remain forever unseen, but are linked in consequential ways. These global connections are constituted by networks of communication technologies as they circulate from stages of manufacture through use and disposal, and by shared environments, such as large-scale climate changes affected by polluting of the oceans. Anna Tsing refers to such distributed relationships in terms of friction: "the grip of worldly encounter" through which global connections of science, capitalism, and politics unfold (Tsing 2004, 1). Le Guin evoked the stakes of such interconnections by noting that sounds, like figures moving across the darkness of the great currents, are "as delicate as life itself" (Le Guin 1975, 74). Through a metaphoric understanding of sound as fragile, fleeting, and in transformation, humans may be displaced from the Enlightenment position of distant and knowing subject and repositioned amidst the currents, always provisionally defined in relation to other humans, species, things, and environments. The above passages provide ways forward for constructing a feminist epistemology of sound that can attend to the ethical implications of such encounters rather than perpetuate values of domination and control. The next chapter explores another metaphor, of electronic sounds as individuals, which evolved in tandem with scientific modernism; it investigates in more detail the articulations of electronic sounds in the nineteenth century to notions of differentiated embodiment, life, and mortality.

4. THE GROWTH AND DECAY OF WAVEFORMS: ELECTRONIC SOUNDS AS FORMS OF LIFE

> For what has been born must grow, reach maturity, and decay...
> – Aristotle, *De Anima* (1947 [ca. 350 BCE], 231)

> The growth of a tone involves the time required for the sound to build up... The decay of a tone involves the required time for the sound to fall to some fraction of the original intensity... The electronic music synthesizer should be capable of producing any desirable growth or decay characteristic.
> – Harry F. Olson and Herbert Belar, "Electronic Music Synthesizer" (1955, 596)

A recent book on the philosophy of sound puts forth this common assumption: "Sounds themselves... are *particular individuals* that possess the audible qualities of pitch, timbre, and loudness... They enjoy lifetimes and bear similarity and difference relations to each other based on the complexes of audible qualities they instantiate" (O'Callaghan 2007, 17). As the previous chapter demonstrated, wave metaphors connect electronic sounds to ancient and mythic themes—from the taming of waves in biblical creation stories, to the adventures of Odysseus and other allegories of maritime voyage. A second enduring metaphor, evident in this introductory quote, characterizes electronic sounds as individuals comprised of variable characteristics. This chapter describes the emergence of this metaphor in conjunction with technological and social developments in the nineteenth century. Sounds were constructed as individual entities through the use of graphical methods and in the context of scientific and cultural understandings of electricity as an animating force. By historicizing terms such as the "growth" and "decay" of waveforms, and reworking a concept from

Ludwig Wittgenstein, I theorize electronic sounds as “forms of life”—technologies that are articulated to historically- and culturally-specific notions of embodiment and mortality through metaphors in audio-technical discourse.

Prior to 1800, natural philosophers and experimenters described sounds in general terms by comparing them to other moving bodies in the universe and other aspects of sensory experience (Spitzer 2004, 154-56). Over the course of the nineteenth century and into the twentieth, new instruments of measurement and modern acoustic treatments made it increasingly possible to consider sounds, and components of sounds, in isolation and greater detail (Beyer 1999, 131-222; Thompson 2002, 61). Such shifts in audio-technical discourse took place in the context of scientific modernism and the expansion of industrial capitalism. Political, economic, and scientific discourses in this period figured the individual as a fundamental unit of capitalist society, the organism as a fundamental unit in biology, the atom and its subatomic structures as foundational to physics, and the phoneme as a simple building block of language (Foucault 1990, 139-43; Haraway 1991, 45; Brain 2002, 169).

Additionally, while the stethoscope, the x-ray, and techniques of psychoanalysis exposed new bodily interiors in medicine (Sterne 2003, 122; Cartwright 1995, 107-42), graphical methods in acoustics revealed an interior structure of sound—component parts such as frequency, loudness, and timbre; and within timbre, constituent partial or harmonic tones. As natural historians and phrenologists were concerned with analogies among organs of different species and relations of body parts to outward expressions of species identification or moral character (Wiegman 1995, 31-33), relations of component parts of individual tones to sonic aesthetics came into similar focus. Sounds, like modern bodies and subjects, came to be understood as complex wholes distinguishable by individual variations, and comprised of fundamental parts which could be analyzed and controlled by specialized technologies and techniques. These differential variations were communicated by the shape of the waveform, which represented aesthetically desirable or undesirable characteristics as determined by acoustics researchers.

A waveform is a visual representation that delineates a varying physical quantity, and expresses the shape or manner of that variation over time. The term surfaced in the 1840s in descriptions of the motion of water. In subsequent decades, it came to signify variations of electrical signals over time, including patterns of electrical activity within living bodies (*OED*, "waveform"). Waveforms were produced by graphical inscription instruments, which were widely adopted across scientific disciplines in the middle decades of the nineteenth century and especially influential in acoustics and experimental physiology research (Hankins and Silverman 1995, 129). These two fields were articulated and advanced together in Hermann von Helmholtz's physiological theories of acoustics. Helmholtz's experiments relied on graphical methods, and he grounded his theories of the experience of musical aesthetics in anatomical form and function. Through metaphors of electronic sounds as waves and individuals, which were brought together in the figure of the waveform and elaborated in Helmholtz's work, sounds acquired formal affinities to nineteenth-century representations of bodies in motion and bodily differentiation. Sounds took on analogous properties to organic processes like muscle contraction, respiration, circulation, and growth—properties such as *amplitude*, *duration*, and *periodicity*. Since the late-nineteenth century, the waveform and its properties have remained key concepts employed by acousticians, engineers, and musicians to analyze and electronically synthesize sounds (Hurtig 1988, 3-4).

In audio-technical discourse, the waveform represented the isolation of individual sounds amidst the formless flux of a universe filled with otherwise indistinguishable sounds. It also facilitated analyses of how individual sounds differ from one another, and thus enabled more detailed classifications of sounds according to aesthetic similarities and differences, much like the study and sorting of species. Audio-technical discourse was part of the larger proliferation of discourses that Foucault outlines in his theorization of biopower. Foucault describes a shift from the classical to modern period in which techniques of measurement, evaluation, and classification in such fields as medicine, education, demography, and economics focused the attention of the state and the self on the control of bodies and populations. These developments were indispensable to the rise of capitalism, which "would not have been possible without the controlled insertion of bodies into the machinery of production and the adjustment of the phenomena of population to economic processes" (Foucault 1990, 141). Sound offered “a means of access both to the life of the body and the life of the species” through the isolation of individual waveforms and their sorting into groups by aesthetic properties (Foucault 1990, 146). This way of conceptualizing sounds as differentiated individuals was consistent with manifestations of biopower, and indicative of how the discursive management of life infiltrated acoustical research and modernist music.

Graphical Methods as a Universal Language

Graphical methods became widespread in nineteenth-century scientific practice and constructed modern life as a “landscape of curves” (Brain 2002, 156). Beginning around 1800, graphical methods emerged out of two practices: analytic geometry, in which a functional relationship of two variables was represented by a curve; and graphical inscription instruments (also called automatic or self-recording instruments, and often named with the suffix “-graph”), through which a continuously moving stylus generated an indexical representation of an object in motion. Unlike graphs, which were merely diagrammatic representations of statistics, these new instruments purportedly revealed “secrets” of nature that could not be accessed by the unmediated senses. They significantly advanced the fields of physiology and acoustics by revealing new information about the interior or formal structures of bodies and sounds. Knowledge of the meanings of curves—the ability to interpret their shape—became a marker of scientific expertise (Hankins and Silverman 1995, 9; Jeans 1937, 17).

Scientists promoted automatically-recorded curves as a kind of "natural language" that could represent all phenomena objectively and facilitate communication across institutional and disciplinary boundaries (Hankins and Silverman 1995, 117-18, 129-30; Brain 2002, 157; Sterne 2003, 42). Emil du Bois-Reymond, a colleague of Helmholtz, believed that "the proper form of physiological representation should be a curve... whose general character one will be able in most cases to trace" (Rabinbach 1990, 66; Brain 2002, 165-66; Lenoir 1994, 186). For researchers in acoustics as well, graphical instruments produced an enticing visual language with universal applications. Helmholtz considered graphical methods to be especially useful for making auditory vibrations visible in order to "render the law of such motions more comprehensible to the eye than is possible by lengthy verbal descriptions" (cited in Lenoir 1994, 200). Lord Kelvin remarked in the 1870s that a "single curve, drawn in the manner of the curve of prices of cotton, describes all that the ear can possibly hear," whether it might be the "single note of the most delicate sound of a flute" or "the crash of an orchestra'" (cited in Kahn 1999, 78).

The universal language of curves was made possible by laws of thermodynamics that facilitated analogies among all physical forces. In 1847, Helmholtz's universal law of the conservation of energy established that various forces of nature are forms of a single form of energy that cannot be created or destroyed. A second law of thermodynamics, identified by Rudolf Clausius in the following decade, established that any transfer or conversion of energy results in a decrease of total available energy (Rabinbach 1990, 3). In the wake of these developments, graphical methods could distill knowledge of all phenomena (e.g., organic and inorganic, mechanical and electrical) into similar representations of motion in time and space (Brain 2002, 158). Sound became known as one of many forms of energy that behaved similarly and could be explicated through graphical methods (Zahm 1892, 16).

Laws of thermodynamics had significant social implications as they were articulated to capitalist concerns for the energy expenditure of laboring bodies. A new science of work emerged in Europe, centered on a utopian figure of the body without fatigue (Rabinbach 1990, 10). The French engineers Jean-Victor Poncelet and Arthur Morin developed various self-recording instruments for measuring work in industrial contexts and employed graphical methods to measure and maximize the body's productive uses of energy. Poncelet developed a visual representation of mechanical work in relation to the vertical elevation of a load. The instrument linked the continuous movement of a stylus with the object whose motion was to be measured. The curve of movement was plotted against a coordinate grid with the traversed space along the vertical axis, and the flow of time along the horizontal axis (Brain 2002, 163).

This new representational convention established by the Poncelet-Morin instruments was used to express diverse phenomena, much as the introduction of linear perspective in the Renaissance had wide-ranging applications. The instruments were taken up and adapted by scientists around Europe, and the body was freshly conceived as a field of energetic forces, each to be isolated and rendered visible by specialized technologies (Brain 2002, 165). The German physiologist Carl Ludwig's kymograph (1846) superseded the trained fingertips of the physician to measure pulse. Initially it was attached directly to an artery of a dog: "With each heartbeat the stylus would inscribe a small blip on a baseline that would slowly rise and fall as mean arterial pressure was raised or lowered following the changes in intrathoracic pressure caused by respiration" (Frank 1988, 215). Noninvasive techniques were soon developed, beginning in 1855 with Karl Vierordt's sphygmograph (literally, "pulse writer"), and continuing with Étienne-Jules Marey's adaptations of the instrument which improved the graphical rendering of circulation and contributed to the development of electrocardiography (Hankins and Silverman 1995, 137; see also Fye 1994, 937-39).

Graphical instruments were adopted in acoustics research simultaneous with their applications in physiology. The phonautograph, developed by Éduoard-Léon Scott de Martinville in the 1850s, produced indexical images of sound using a stylus to trace vibrations that were transmitted through a funnel and across a diaphragm (Sterne 2003, 36; Hankins and Silverman 1995, 133-35). Helmholtz conducted experiments with tuning forks that produced "simple" tones, and used graphical recording instruments to analyze the form of these tones alone and in combination. He worked with a variation of Scott's phonautograph that consisted of a vibrating tuning fork with a stylus on one prong; this produced a curve on paper attached to a rotating drum. Its configuration was also essentially the same as as the earlier myograph and kymograph instruments, used by Helmholtz and Ludwig to render visible electrical forces within the body (Lenoir 1994, 200).

Importantly, not only were the instruments and representational conventions in physiology and acoustics formally similar, but the underlying concepts of physiology in the age of graphical methods permeated Helmholtz's theory of sound. So, just as the whole body consisted of energetic forces to be isolated and rendered individually visible through graphical methods, Helmholtz argued that to understand complex musical tones: "we must begin by making the individual elements which have to be distinguished, individually audible" (Helmholtz 1954, 65). The analytic isolation of these individual elements was a foundational concept in sound synthesis.

Graphical methods endured as a mode of scientific representation and influenced subsequent techniques of sound synthesis and analog computing. While the phonautograph advanced techniques of sound recording by tracking continuous phenomena, in 1876, Lord Kelvin's harmonic synthesizer performed calculations to integrate simpler curves into a more complex waveform. Kelvin was concerned with measuring and predicting tidal fluctuations. The U.S. Coast and Geodetic Survey would build on his work to develop their own massive harmonic analyzer, referred to as "the giant brain," for similar purposes before the start of World War I. The physicist and acoustician D. C. Miller and colleagues also adapted Kelvin's instrument in the 1910s specifically for studying and synthesizing sound waveforms, a significant advance toward the design of instruments that would synthesize sound electronically (Brain 2002, 173; Miller 1937, 110-11). Harmonic analyzers were the prototypes for various differential analyzers and analog computing devices until World War II, including those central to the emergence of the cybernetics movement (Brain 2002, 174).

Graphical inscription instruments rendered signals as abstractions, and performed analytic reductions that were mobilized by scientists as a universal form of representation and communication. In this sense, they prefigured the advent of digital computers in the mid-twentieth century. The basic cybernetic premise that organisms and machines function alike in processing information was anticipated and arguably enabled by nineteenth-century laws of thermodynamics and graphical methods (Brain 2002, 177). "The discovery of energy as the quintessential element of all experience, both organic and inorganic, made society and nature virtually indistinguishable" (Rabinbach 1990, 46). Human labor, animal physiology, machines, and other forms of nature and social organization could all be explained with the same laws of energy, and represented by graphical methods.

This logic of interchangeability was evident in James Jeans's 1937 textbook lesson on "sound-curves." Jeans illustrated the waveform as a universal representation movement over time by analogizing the flow of current in telephone wire to changes in atmospheric pressure on a barometer chart (Jeans 1937, 11-12; Fig. 10). He went on to note that "all sounds can be represented by such a curve—a cough or a sneeze, the voice of a friend, or an orchestra playing a symphony" (Jeans 1937, 13).

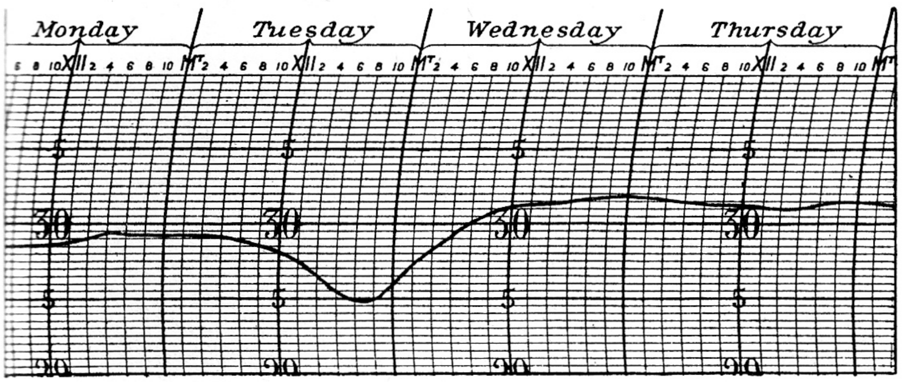

Fig. 3. A barometer chart. The horizontal scale indicates the passage of time, while the vertical scale shews the height of the barometer at each of the instants represented on the horizontal scale. We see, for instance, that at noon on Tuesday the barometer stood at 29·8 inches.

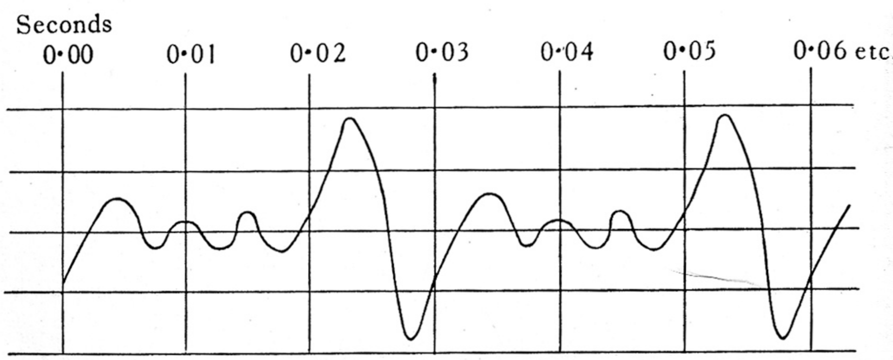

Fig. 4. A current chart. Just as variations of the pressure of the air can be represented by a curve in the way shewn in **fig.** 3, so the variations of the current in a wire can be represented by a curve such as that shewn above.

Fig. 10. Illustrations from James Jeans's lesson on the numerous phenomena that can be represented by waveforms, including fluctuations in barometric pressure and electric current (Jeans 1937, 11-12).

Waveform representations of sound could also signify laboring bodies in motion; Jeans described the collective labor of the symphony and its reduction into a sound recording as follows:

> All [musicians] are, or have been, at work to produce—just a curve... All the art, all the mannerisms, all the successes and failures of these many workers are embodied in the one single curve. This curve *is* the symphony—neither more no less, and the symphony will sound noble or tawdry, musical or harsh, refined or vulgar, according to the quality of this curve (Jeans 1937, 13).

Through a shared lineage of scientific instruments and analogies of energy and motion, sound waveforms were represented by similar conventions as diverse physiological processes and bodily movements, including respiration, circulation, and the expenditure of energy in labor. The waveform representation of sound persists across eras of mechanical to analog to digital instruments, and marks an ongoing scientific reduction of diverse phenomena into a common descriptive form: the extension of matter or bodies into space, and their variation over time.

The Waveform's Lively Aspects: Extension Into Space, Variation Over Time

The amplitude of a waveform signified lively matter in motion, held still for analysis. Its signification was situated in a nineteenth-century context in which autopsies and dissection became more routine, and perceptions of the relationship of life and death changed. Uses of sound reproduction technologies reflected cultural concerns for preserving the voice beyond death, and were consistent with the emergence of embalming techniques to preserve bodies (Sterne 2003, 287-309). Likewise, ideas of sound analysis and synthesis developed alongside new scientific practices for analyzing dead bodies and producing diagnoses in clinical practice. Medical practitioners began to view death less as an ultimate threshold at the end of life but, rather, as present throughout life during the gradual progression of disease (Curtis 2004, 229-30; Foucault 1994, 142). There were figurative relations between death and analysis, and life and synthesis:

> Death holds still the body. At the same time, the knowledge that comes from the corpse is meaningful only in relation to the living body... The gaze and the language of description rests on the stability of the corpse, but moves as well, newly informed, to the living body. This back-and-forth movement—between life and death, present and past, part and whole—exemplifies the medical task (Curtis 2004, 233-34).

Medical practice gained increasing authority to extend life artificially through applied knowledge or techniques; essentially, diagnoses and plans for the sustenance of living bodies were synthesized from aggregated information about a corpse. As Foucault claimed: "Death is the great analyst that shows the connections by unfolding them, and bursts open the wonders of genesis in the rigor of decomposition" (Foucault 1994, 144). Likewise, the graphical inscription of sound waves effectively held sounds still, like forms of life to be broken down by analysis, and produced faith in new technologies and expert techniques to accurately regenerate, or synthesize, waveforms—the "wonders of genesis" manifested in electronic sound.

The signification of living bodies in motion inflects the sound waveform through analogies in language and form. To survey the various uses of the term *amplitude* over centuries and across cultural fields is to track its articulation to epistemologies of sound through metaphor and scientific practice. Amplitude, as early as 1600, referred to extension in space or largeness; by the mid-1600s, to the angular distance of a celestial body from the horizon as it rises or sets; by the mid-1800s, in physics, to the distance a vibrating particle travels to and fro; by the 1880s, in Darwin's writings, to the extent of motion by growing plants; and, in the late-1800s, to the loudness of sound, the compression and rarefaction of air pressure which indicates the back-and-forth motions of vibrating particles (*OED*, "amplitude").

While the amplitude of a sound waveform marked changes in air pressure from particles' extension into space, its manner of extension was understood to vary over time. In this sense, the sound waveform encapsulated some of the contemporaneous ideas of individual variation introduced by Darwin's theory of evolution. In the seventeenth and eighteenth centuries, the Linnaeus classification system ordered nature by hierarchically organized types or essences. Darwin's theory diverged from this system radically, by emphasizing that change over time defines variations in species: "In other words, species, far from being fixed types, are individuals composed of unique features statistically accumulating over time in relation to the population or collectivities of which they are a part (Parisi 2006, 32). Graphical inscription instruments, adopted across scientific fields as Darwin's writings circulated, provided visible evidence of individually-varying physical characteristics among bodies of the same species—and of individually-varying sounds which, to the unmediated senses, might otherwise seem the indistinguishable from each other.

The innovation of graphical inscription instruments, compared to earlier investigations in anatomy and physiology, was indeed to display physiological fluctuations over time. The implied dynamism of these curves led Marey to consider graphical inscriptions as analogs of human sentience (Brain 2002, 166). By the turn of the twentieth century, electrocardiographic waveforms presented the heart's electrical activity as, quite literally, signs of life.

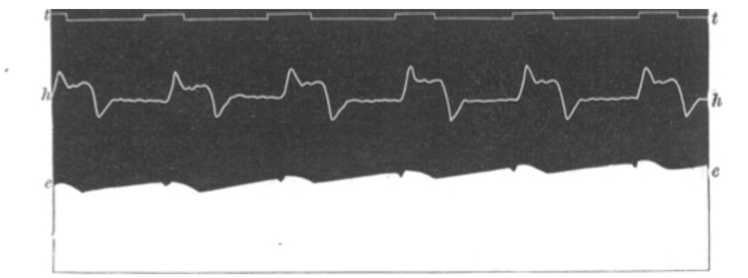

FIG. 1. Man. Heart led off to electrometer from front and back of chest (front to Hg; back to H_2SO_4).
***e.e.* electrometer. *h.h.* cardiograph. *t.t.* time in seconds.**

Fig. 11. Augustus Waller's first published electrocardiogram, showing electrical activity in the heart of "man" (Waller 1887, 17).

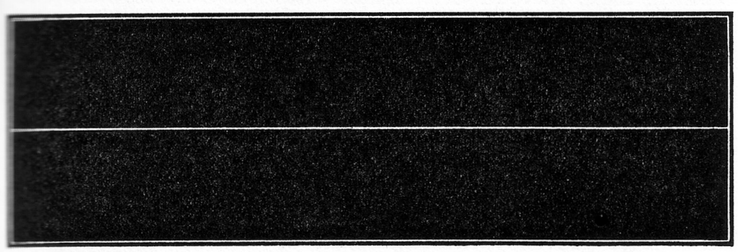

Fig. 7. The trace of a non-vibrating fork.

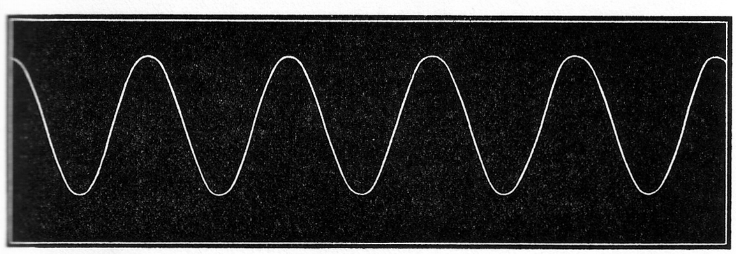

Fig. 8. The trace of a vibrating fork. The waves are produced by the vibrations of the fork, one complete wave by one complete vibration.

Fig. 12. Silence and sound, represented by the traces of a non-vibrating and vibrating tuning fork (Jeans 1937, 19).

Medical experts could determine from the shape of waveforms whether electrical activities in the body were normal or pathological (as in cases of cardiac arrhythmia); moreover, an unvarying baseline (or flatline) symbolized life's absence (Canguilhem 1991, 43; Fye 1994, 939-40). There are direct parallels between this representation of life and its absence, and sound and silence. In both cases electrical activity functioned literally and symbolically as an animating and sustaining factor (Figs. 11 and 12). Electricity, which was naturalized by graphical methods as a sign of movement and life within living bodies, held the promise for technological control of amplitude, duration, and timbral variation of sound waveforms through the animating techniques of synthesis.

Electricity, Amplitude Envelopes, and the Animation of Individual Sounds

The discovery of electrical activity within living bodies was integral to developments in graphical methods, and an important factor in establishing analogies between electronic sounds and life processes. In the late-1700s, the Italian physician and physicist Luigi Galvani had proclaimed electricity as a fundamental life force after discovering that the severed leg of a frog would kick as though alive when touched by an electric current (Marvin 1988, 129). This idea was elaborated upon in the first half of the 1800s by the Italian physicist Carlo Matteucci, who demonstrated that each cardiac contraction in a frog was accompanied by electric current, and by du Bois-Reymond, who in 1848 verified Matteucci's findings and located a similar "resting current" and "action potential" in muscles (Frank 1988, 227; Fye 1994, 938). Within a decade of Ludwig's kymograph, Helmholtz developed the myograph instrument to graphically render nerve impulses and muscular expansion and contraction over time (Brain 2002, 165). Around the same time, in *Origin of Species* (1859), Charles Darwin was especially intrigued by the case of electric fish, which use a specialized “electric organ” to generate electrical fields, thought to be applied toward a variety of communication and orientation purposes (Darwin 2003, 178-79, 404-06; Fig. 13).

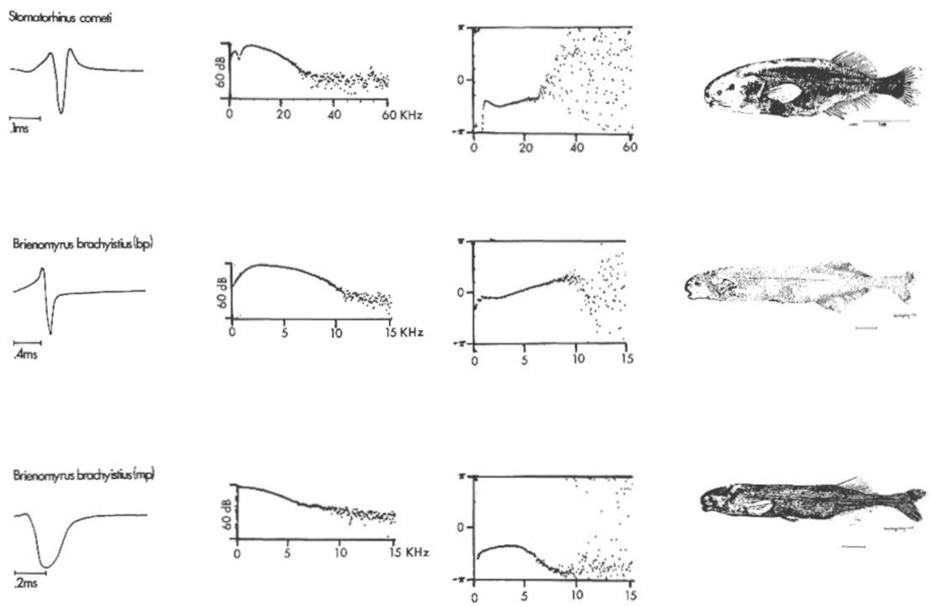

Fig. 13. Illustrations from a 1981 study of different kinds of electric fish and their emitted signals, which were of particular interest to Charles Darwin in *Origin of Species* (Hopkins 1981, 216).

And, in the 1870s, the English physiologist John Scott Burdon-Sanderson, experimenting with Venus flytraps borrowed from Darwin, determined that electrical activity in moving plants was analogous to the expansion and contraction of muscles in humans and animals (Frank 1988, 231). The presence of electrical activity among diverse forms of life naturalized the apparent liveliness of electronic sounds, and the eventual associations of terms like "growth" and "decay" with their formal structure.

In late-nineteenth century Euro-American cultures, there were spirited debates about whether new electrical technologies would enhance and preserve life, or usher in new risks of death and destruction (Marvin 1988, 110). "Electricity seemed linked to the structure of social reality; it seemed both to underlie physical and psychic health and to guarantee economic progress" (Nye 1990, 156). Many people considered electricity to be a healing agent or vital force; to have theological significance as a kind of "current of life," capable of sustaining life as the sun could; or to be a new resource for stimulating bodily energy, vigor, and virility (Marvin 1988, 122-31). People also considered whether or not bodies and machines were fundamentally different; electricity was compared to the circulatory and nervous systems, and electrical circuits to patterns of social organization (Marvin 1988, 141). Yet, as an unfamiliar force with less than fully-determined capabilities, electricity could also be an ominous presence. When "serious injuries were reported from thunderstorms, from handling electrical materials, and from pranks upon or by the unwary," and public spectacles showed how electrical prods could tame or kill the most threatening of animals, electricity was proven to be a potentially dangerous force (Marvin 1988, 122). Under expert knowledge and control, however, it was recognized as a source of power that could extend and surpass human limitations. "If electricity seemed capable of transforming the body, the engineer himself became the symbol of the rational man who had the skills to transform society" (Nye 1990, 166).

In this cultural context, electronically-generated sounds, which were first tested in the 1830s and became widespread following the invention of Lee de Forest's audion in the early part of the twentieth century, were a source of intrigue for having potentially infinite duration, exceeding mortal limitations. John Durham Peters has noted that "dissipation is the very essence of sound as we know it... Hegel even made the fading of the voice a philosophic principle, a distinguishing mark of human temporality and finitude" (Peters 2004, 177). Conversely, the "nature" of electronic sound has been characterized by the ability to go on forever. Upon hearing Cahill's Telharmonium for the first time in 1906, Mark Twain famously pronounced that he would like to prolong his life in order to fully appreciate the instrument's capacity: "Every time I see or hear a new wonder like this I have to postpone my death right off. I couldn't possibly leave this world until I have heard this thing again and again" ("Twain and the telephone" 1906). Music historian Thom Holmes includes "extremes of duration" on his list of electronic music's most distinctive characteristics: "Electronic music... is not affected by the limitations of human performance... The ability to sustain or repeat sounds for long periods of time... is a natural resource of electronic music" (Holmes 2002, 12). Although electrical flow is mediated by interruptions in service and circumstances of technological failure, electronic sounds have been taken up in audio-technical discourse for their imagined capacity for infinite duration, in contrast to perceived limitations of the human body and lifespan, and to the durational constraints of sounds from acoustic instruments designed with materials like wood and string.

However appealing the technological possibility of infinite sonic duration seems to have been, it also signified a form of nonhuman excess that required some measure of control. In inventors' and musicians' accounts of early electronic musical instruments like the Theremin (beginning in the 1920s) and the Hammond organ (from the 1930s), the awkward, abrupt "attack," or audible introduction, of an electronic sound was deemed a technical problem to be solved (Le Caine 1955b, 782; Dorf 1968, 74). Writing in 1937, composer Carlos Chavez cited touch and breath as distinctly human qualities that ideally should be articulated to the control of electronic sounds:

> We must think of the great richness, variety and elasticity of the attack on many traditional instruments in order to see clearly the great difficulty of this problem of the performance of electric instruments—the... so-called 'touches' on the piano, the widely varied attacks on the instruments with mouthpieces—in which the... inflections of the breath produce an infinite variety. To me, this seems at present one of the most difficult points to solve: to find a medium adequate to human anatomy, and taking advantage of the infinite facility of the electric production of sound (Chavez 1937, 164).

The characteristic feature of electronic sound's potentially infinite duration would need to be scaled back to more familiar capacities of human expression.

One way of resolving this dilemma of duration and expression—the task of balancing the potential infinity of electronic sounds with the nuances of human breath and touch—was the amplitude envelope, a twentieth-century technology of containment for individual sounds that evolved from waveform representations of sound in the nineteenth century. The word envelope, a mathematical term for the curved shape formed by joining successive peaks of a graph of an oscillation, was applied in electrical engineering and wireless communication discourses by the 1920s (*OED* "envelope," n.). Like a paper envelope for a letter (see Peters 1999, 166-67), the amplitude envelope has been used in tandem with efforts to transmit sounds across a distance (Braun 2002, 18; Roads 2001, 262). It was a discrete waveform representing the contour of a sound as it increased from silence to a maximum level, sustained, and faded back to silence; it marked the technical achievement of rendering sounds as individuals, and metaphorically articulated individual sounds to individual life-cycles.

The standard parameters of an amplitude envelope in contemporary audio-technical discourse are *attack*, *decay*, *sustain*, and *release*. In the mid-1960s, the composer Vladimir Ussachevsky and inventor Robert Moog collaborated to develop an envelope generator module for Moog synthesizers, building on earlier work by Harry Olson and Herbert Belar at RCA. They established a conventional method for quantifying the shape of an envelope into four successive parts: the attack, initial decay, sustain level, and final decay time. The designers of ARP synthesizers took up this idea and by the early 1970s labeled it ADSR (Fig. 14). This has remained the standard form and nomenclature of an amplitude envelope on commercial synthesizers since then (Pinch and Trocco 2002a, 58-59). It is an audio-technical convention that contains a long history of the mediation and representation of organic processes, bodily comportment, and communication practices.

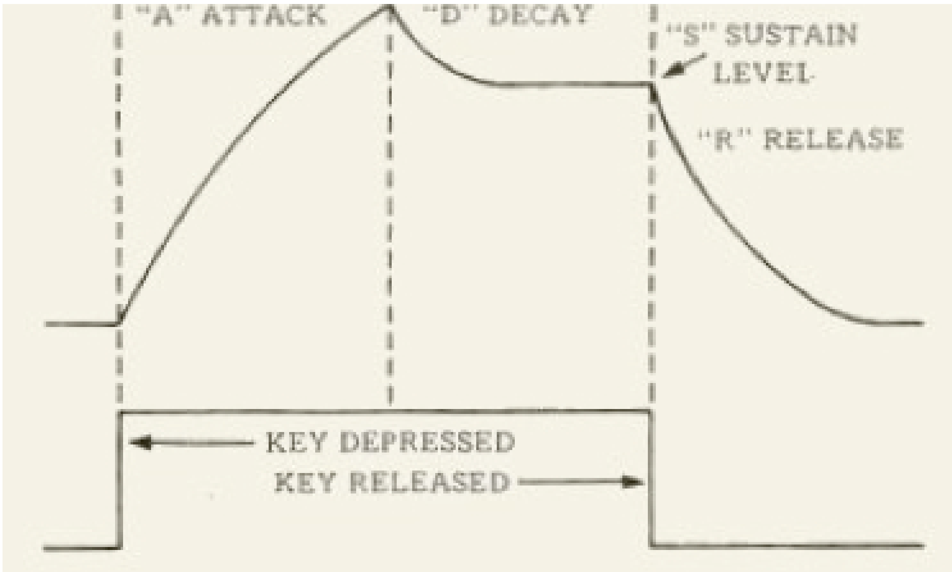

Fig. 14. ADSR envelope, ARP Odyssey owner's manual (ARP 1976, 30).

Associations of the ADSR terms with human speech, instrumental music performance, and other mediated forms of communication trace back, in some instances, at least a century earlier. Acoustics research and techniques of electronic sound generation emerged at the nexus of music, science, and communications; accordingly, acousticians, composers, and inventors combined terms from these various fields to describe properties of sound. Over the last quarter of the nineteenth century and into the early twentieth, the term *attack* commonly referred to a manner of precision or clarity at the beginning of a musical phrase; *decay* was a term in physics for the gradual diminution in amplitude of an oscillation or vibration; *release* referred, in phonetics, to the sound produced by the release of air through the mouth after a plosive consonant, as well as to the freeing for further use of a previously-engaged line in telephonic communications (*OED*, “attack,” n., “decay,” n., “release,” n.).

In *On the Sensations of Tone* (1863), Helmholtz discussed “the way in which [tones] begin and end” by referring to the “attacking and releasing” and the “rapidity of dying away” of tones of the human voice and stringed instruments (Helmholtz 1954, 66, 570). He also identified an analogical relationship between the physical “progress of decay” of older Italian instruments in the viol and violin families and the resultant tone, whereby the aging of the instrument “to a certain extent diminished the volume of sound” (Helmholtz 1954, 553). John Tyndall used the term decay as he compared the gradual subsiding of tones at various distances from foghorns (Tyndall 1869, 11, 296). He also noted the “wonderful and pleasing effects” of decaying sounds in mountainous regions, where “successive echoes became gradually feebler to the ear” (Tyndall 1869, 47). These examples illustrate how sounds in the mid- to late-nineteenth century were described with the language of energy and fatigue, as tones “became gradually feebler” and “died away.”

Waveform representations articulated electronic sounds to notions of ongoing life and life-cycles by depicting successive patterns of periodic oscillations as renewable patterns of growth and decay. Electricity’s capacity as a sustaining source of energy offset contemporaneous concerns about bodily fatigue, which the Poncelet-Morin instruments had sought to quantify. Over the latter half of the nineteenth century, “The concepts of energy and fatigue reflected the paradox of social modernity, at once affirming the endless natural power available to human purpose while revealing an anxiety of limits—the fear that the body and psyche were circumscribed by fatigue and thus could not withstand the demands of modernity" (Rabinbach 1990, 12). Fatigue was an obstacle for industrializing societies to overcome. In audio-technical discourse, electricity functioned as a sustaining force that enabled the decay cycles of sounds to be followed by renewed growth.

The technological control of sonic decay emerged in conjunction with acoustics research around the turn of the twentieth century (Thompson 2002, 81-85, 173-78). With applications of electricity to sound generation and reproduction, specific decay rates could be generated and controlled using mathematically demonstrable factors and coefficients (Rayleigh 1945, 81, 137; Fleming 1910, 2, 122). Analyses became ever more precise in 1903, when the physicist and electrical engineer W. S. Franklin derived an equation for expressing "decaying sound" in a room, again using the concept of energy conservation to imagine how "sound energy" diminishes in a room with an open window (Beyer 1999, 188; Franklin 1903).

Notions of organic growth were articulated to the lively aspects of sound and audio technologies in a variety of ways by the early twentieth century. One newspaper article documented the usefulness of a kinetoscope, an early motion-picture device, to capture time-lapse images of sound waves as well growing plants ("Motion pictures" 1902). Other noteworthy experiments demonstrated that plants flourished in response to beautiful music, but recoiled in the face of harsher sounds. As one observer claimed: “Waves of sound have, of course, a very considerable effect on human beings; to a delicate plant the effect is likely to be far more potent” (“Are your flowers musical?” 1912). Additional articles reported the success of high-speed sound waves in accelerating plant growth, including the so-called “sound-forced potatoes” (Kaempffert 1937; Henry 1948). Sounds, organisms, and machines were observed together as interrelational elements in a shared, mediated ecosystem. The impact of electronically-mediated sounds was felt in the growth of plants; and reciprocally, the aesthetic contours of electronic sounds were described by organic processes like growth and decay.

The basic cybernetic premise that organisms and machines functioned alike in processing information was a continuation of these themes. As Arturo Rosenblueth et al. wrote in a seminal cybernetic text: “The ultimate model for a cat is of course another cat, whether it be born of still another cat or synthesized in a laboratory” (Rosenblueth et al. 1943, 23). Harry Olson and colleagues were strongly influenced by cybernetics texts in their work on the RCA synthesizer, and embraced the terms *growth* and *decay* in their development of technologies to regulate the amplitude of electronic sounds. Olson and Belar emphasized that their synthesizer could produce “any desirable growth or decay characteristic,” including those not found in nature (Olson and Belar 1955, 596; Fig. 15).

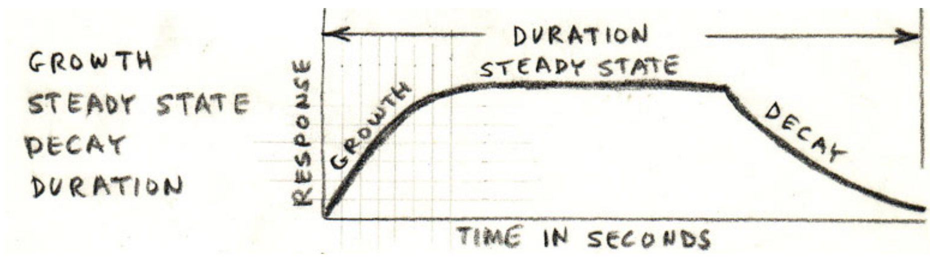

Fig. 15. Growth and decay characteristics of a sound; illustration by Harry F. Olson (Olson 1959, n.d.).

Olson and Belar theorized electronic sound synthesis as a technique of animation. In a confidential report at RCA in 1950, entitled "Preliminary Investigation of Modern Communication Theories Applied to Records and Music," they wrote:

> the synthesis of music compares with the conventional method of recording, as animated cartooning does with motion picture photography... In an animated cartoon, the synthesized actor can take shapes limited only by the imagination of the cartoonist. In a similar manner, synthesized music could create sounds beyond the range of present instruments... If it is pleasing to have a tone built up slowly, a synthesizer could make it do so, even if in nature we cannot (Olson and Belar 1950, 6).

Olson and Belar promoted their synthesizer's capacity to surpass bodily limitations through electronic generation and control of sound; unlike "conventional instruments, [where] the musician is limited to the use of ten fingers, two hands, two feet, and the lips, either separately or in various combinations, to perform the different operations" (Olson and Belar 1955, 595). While the curve of a sound recording had previously been understood to encapsulate the collective labor of an orchestra (Kahn 1999, 78; Jeans 1937, 17), a synthesized curve could, in theory, transcend that physical labor with electricity as an animating substitute.

Intersections of Scientific and Musical Aesthetics: The Sine Wave as Pure Tone

The processes of sound analysis and synthesis opened possibilities of re-creating the signs and forms of life signified by waveforms and electrical activity. While graphical methods were touted by scientists for facilitating objective communication across diverse fields (Hankins and Silverman 1995, 9), these methods were also very much implicated in the representational production of difference. Waveform representations of sounds and bodies alike manifested intersecting scientific, aesthetic, and sociocultural notions of normativity and pathology, identity and alterity, purity and variation. Because all of sensory experience could in principle be reduced to a waveform, artists could become, as the historian of mathematics Charles Henry noted in 1885, "workers of the line," manipulating its shape to desired effects (Brain 2002, 170). James Jeans described this as an imperative among many artists and designers: "The problem of designing a curve which shall give pleasure to the ear is not altogether unlike that of designing a building which shall give pleasure to the eye" (Jeans 1937, 20). In designing or synthesizing sounds, scientists and composers conferred certain aesthetic properties based on hierarchical notions of cultural value.

The intersections of scientific and musical aesthetics are exemplified by discourses on the purity of the sine wave. The sine wave is a mathematical and technological ideal—the only "pure" waveform said to be lacking timbre—

against which timbral variations are compared. The generation and control of timbral variation is a central contribution of synthesized sound to music production in the twentieth century (Gilbert and Pearson 1999, 59-63). This section explores how the sine wave became foundational to theories of timbre in sound synthesis through the work of Helmholtz. Cultural associations of timbre with a devalued materiality of the body have roots in Helmholtz's neoclassical aesthetics, through which the sine wave was figured as a pure form, said to be "without body." Notions of the sine wave as "pure" and "lacking body" were articulated to cultural valuations of whiteness and scientific objectivity, while timbral variation came to signify marked forms of material embodiment (e.g., raced, gendered, classed) and transgressive pleasures.

Helmholtz's work at the intersections of physiology and acoustics provides an example of how life sciences and aesthetics historically have been entwined. Throughout the history of biology, "the allegiance to concepts of organic form, borrowed heavily from poets and artists, guided the scientist's resolution of theoretical and empirical matters" (Haraway 2004, 40). The relation of biology and art dates to Aristotle's work at the outset of biology as a systematic study, in which "'totality of form,' the composition of the elements into a functioning whole... gave meaning to a study of the animal" and also to the perceived wholeness and organization of all of nature (Haraway 2004, 40). Romantic conceptions of form were indebted to this Aristotelian tradition; the poet Samuel Coleridge in the early-nineteenth century defined form as that which embodies the whole of an organism as well as its internal organizing principles, and whereby the form manifests the process of growth from which it emerged. This is a touchstone for modern biology "not in the sense that the poets provided acceptable biological explanations or laws... but in the sense that the artist and biologist face a common problem: creation of novelty and fundamental appreciation of the nature of organic form" (Haraway 2004, 39-40; see also Ritterbush 1968). The synthesis of sounds engages this very conundrum at the intersections of science and music: the genesis of whole sounds from internal organizing principles.

Helmholtz shared common concerns with form that were evident across the work of Goethe and Darwin. In the early-nineteenth century, Goethe, the poet, was one of the first to develop the concept of *morphology*, a term that evolved in biology to mean "the study of shape and structure as intimately related to the processes governing form and function" (Haraway 2004, 40). Some observers, including Helmholtz, saw Goethe's interpretations of morphology as intellectual precursors to Darwin's recognition of analogies among organic forms in *Origin*, though Darwin's theories moved in a substantially new direction (Barnouw 1987, 63; Lenoir 1987, 26-27). In any case, Darwin's depiction of variations within populations produced hierarchical mappings of degrees of perfection, and focused attention on the varieties of formal attributes within a single species and their relevance to survival (Parisi 2006, 32). Helmholtz was more than aware of Darwin's work, and his contributions to acoustics should be understood in its context. In his popular addresses, he praised Darwin's theory of evolution by natural selection alongside laws of thermodynamics as a paragon of scientific progress. For Helmholtz, Darwin's work truly revealed nature's structure and processes (Cahan 1993, 567-71).

Resonant with developments in life sciences and natural history, in which part-whole relations of the organism manifested as differentiated aesthetic attributes, Helmholtz demonstrated that the structure of sound (the simple, sinusoidal components of a complex waveform) bore a direct relation to a sound's timbral quality. Timbre makes a sound aesthetically distinct; the term itself is derived from meanings of "stamp" as a marker of individual character or quality (*OED*, "timbre"). As well, Helmholtz's contemporaries and the next generation of acoustics researchers were especially concerned with the behavior of sound in diverse conditions (Rayleigh 1945; Thompson 2002). These notions of relationality and variability, in which sonic forms change over time (indeed, grow and decay) in response to environmental conditions, underlies the field of acoustics and bears the influence of a Darwinian mode of thought.

The resonances between Helmholtz's theories of sound and Darwin's work on individual variation can be elucidated by Helmholtz's engagement with Goethe's legacy and his articulation of art, science, and aesthetics more generally. Late in his career, in an 1892 lecture on Goethe, Helmholtz concluded that scientists and artists were fundamentally aligned in a common pursuit of ideal types that would represent universal truths. Helmholtz did not commit to a theory of the nature of beauty in art, but he provided a conceptual outline of one:

> He was tempted to equate the perception of beauty with the grasping of the lawful, the regular, the ideal, discerned amid the flux and variation of the phenomena... Helmholtz was drawn toward the aesthetics of classicism, in which beauty arises in the perception of the ideal type amidst the imperfections of the particular (Hatfield 1993, 553).

In Helmholtz's view, artistic intuition retained out of the flux of experience that which is regular and invariant in nature; like sensory perception and scientific inference, it held in memory what is lawful or ideal, and filtered out what diverged from it (Hatfield 1993, 552).

In the context of a Darwinian world in which individual variations proliferated, it seems that Helmholtz wished to retain, in the realm of sound, a measure of control over the experience of purity and variation. The figure of the sine wave reveals how Helmholtz's scientific and aesthetic ideals inflected his theories of sound and subsequent techniques of synthesis that bear his influence. His predominant legacy in the history of synthesized sound applies to the electronic production of timbre (also referred to as tone color or quality), in that timbral variations are produced by the introduction and relative loudness of harmonics in addition to the fundamental frequency of a tone. The sine wave is figured in acoustics texts as the only "pure" tone, because it contains no harmonics apart from its fundamental frequency; it is an idealized tone, said to be free of color, or timbrally neutral. Indeed, the technical process of regulating additional harmonic frequencies is now known as *filtering*—which retains Helmholtz's logic of separating out the pure form from the flux of variations.

Helmholtz's taste in art, his gestures toward a theory of aesthetics, and his core scientific principles can all be described as neoclassical in that they tended to validate simplicity, order, harmony, and regularity (Hatfield 1993, 556). Helmholtz was a key figure in establishing a sonic epistemology that bridged ancient and modern themes, evidenced by the enduring metaphors of sounds as waves and individuals, and these were indeed the kinds of transhistorical connections that characterized neoclassicist endeavors (Hatfield 1993, 557). Helmholtz's research in physiological acoustics was principally concerned with the relationships between musical sound and its perception by listeners; the primary subjects of his work were pitch, tone quality, consonance and dissonance, and musical scales (Hatfield 1993, 525). While he drew significantly on research on the physics of sound conducted during the previous century, he also solidified the perpetuation within modern acoustics of certain classical values and modes of representation.

By the time Helmholtz began his investigations in acoustics in the 1850s, many aspects of the physical behavior of sound had been identified (Hatfield 1993, 525). Acoustics took shape as a field of scientific inquiry toward the end of the eighteenth century, as Ernst Florens Chladni's revelations of sounds as sand figures on vibrating plates marked the beginning of the visualization of sound waves as objects of analysis (Hankins and Silverman 1995, 130; Sterne 2003, 43-44). The field was advanced in the 1830s and 1840s with the emergence of the siren as an important investigative instrument. This period witnessed an important debate on the definition of tone between the German physicists Georg Simon Ohm and August Seebeck that would greatly influence Helmholtz's research and synthesis techniques in subsequent decades. Prior to the siren, a tone was thought to emerge from vibrations of solid bodies or air columns; it was thus presumed that the vibration producing a simple tone was necessarily sinusoidal or simple harmonic in form. The siren inspired scientists to rethink this definition in that it emitted a rapid succession of single, discrete sounds that were perceived as continuous, with the pitch determined by the frequency of pulses (Vogel 1993, 262-63). Seebeck maintained that only periodicity was constitutive of a tone; in other words, a tone was a "series of single pulses of arbitrary form" and not restricted to a sinusoidal or simple harmonic shape (Vogel 1993, 263-65). Ohm, meanwhile, applied Fourier's theorem to sounds to argue that complex tones were resolved by the ear into simple, sinusoidal components (Turner 1977, 3-4).

Helmholtz would later validate and extend Ohm's claim—even conferring on it the name "Ohm's law" (Turner 1977, 12)—arguing that the ear perceives only tones that correspond to sinusoidal vibrations, and that tone quality (or timbre) can be explained by combinations of partial tones at varying levels of intensity (Fig. 16). Helmholtz's tuning-fork apparatus, which allowed him to synthesize complex sounds from sinusoidal components, literally materialized Ohm's theory (Vogel 1993, 271-74). The Ohm-Seebeck debate, and Helmholtz's perpetuation of Ohm's line of reasoning, is a significant moment in the history of acoustics and electronic sound for a few reasons. It historicizes contemporary debates between analog and digital media, in which analog recordings are typically interpreted to be closer to unmediated "reality" or more "natural" than digital formats because analog encoding is perceived to be continuous unlike the discrete 0s and 1s of the digital (Sterne 2006a, 340-41). Helmholtz's extension of Ohm's theory is a historical moment when continuous tones (simple harmonic oscillations) were positioned as more naturally integrated to human perception than discontinuous ones (the discrete impulses of a siren). Also, had Seebeck's ideas gained traction, other ways of representing sound based on the concept of periodicity may have become commonplace, rather than representations based on a complex waveform resolved into simpler, sinusoidal shapes. (For example, a series of dots or lines at various intervals to mark the frequency of distinct pulses; or even the nodal or symmetrical patterns of Chladni figures.) Finally, this is a key moment in the history of sound synthesis, and not inevitable, when the sinusoidal form was resolved to be the fundamental material and most common representational building block of all sounds.

Following Helmholtz's work and until the present time, the sine wave has been figured in audio-technical discourse as the most pure tone, articulated to metaphoric concepts of being without color or lacking "body," and valued as constitutive of music rather than degraded and unpleasant noise. To recount a few representative claims: James Jeans, remarking on the "perfectly pure" tone of a

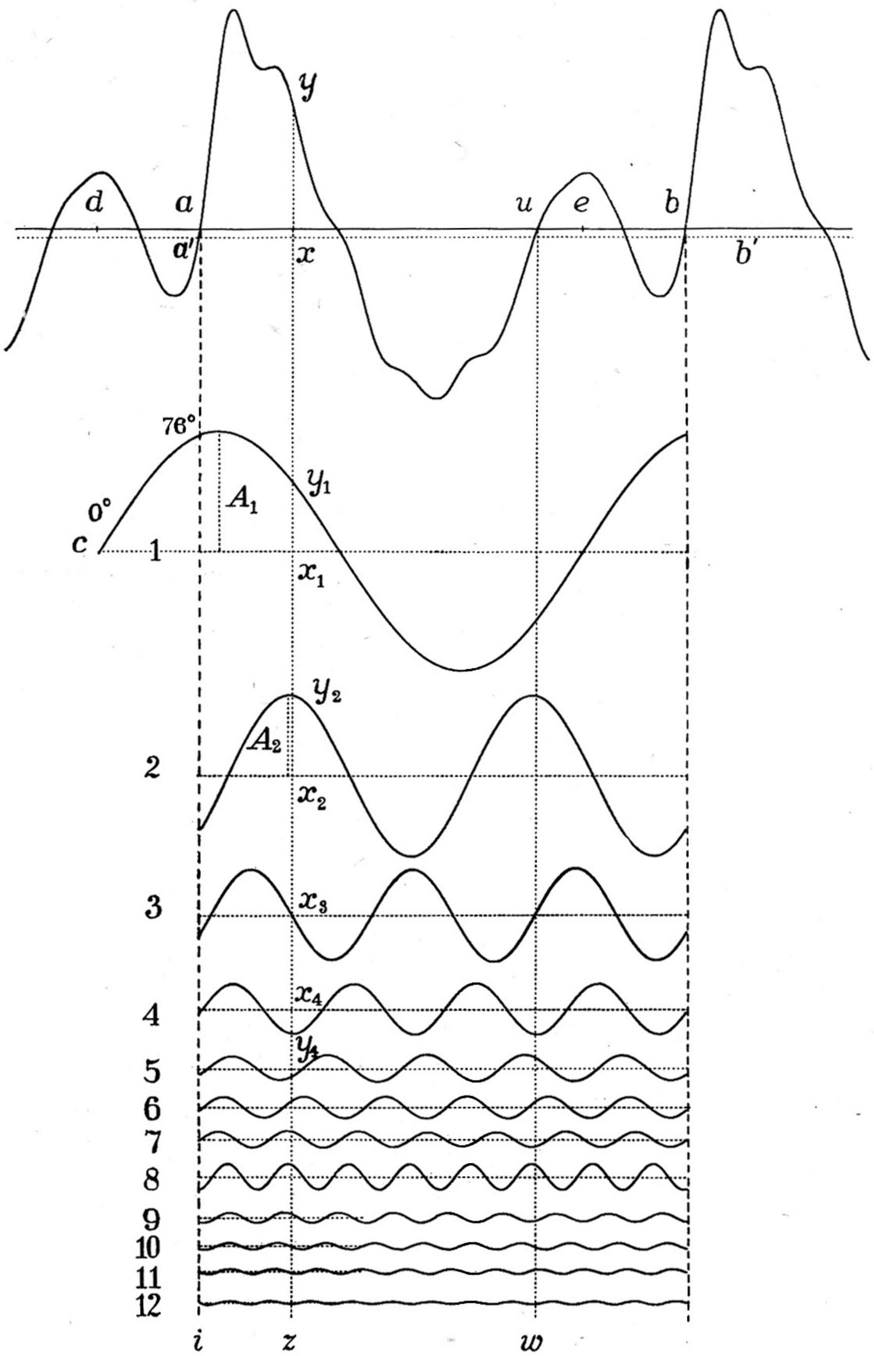

FIG. 98. An organ-pipe curve and its harmonic components.

Fig. 16. Illustration of Helmholtz's principle that the timbre of a complex tone can be explained by combinations of its harmonic components at varying levels of intensity (Miller 1916, 125).

tuning fork, described a graphical representation of its vibration: “The extreme regularity of these waves is striking; they are all of precisely the same shape, so that their lengths are all exactly the same, and they recur at perfectly regular intervals. Indeed, it is this regularity which distinguishes music from mere noise” (Jeans 1937, 20). The author of a 1988 textbook on multitrack recording, discussing “how the shape of a wave determines its timbre,” elaborated on the mathematical perfection of a sine wave: “This wave has smooth, consistent, and evenly-spaced peaks and troughs. It’s known as a perfect or ideal wave because it has no irregularities” (Hurtig 1988, 3; Fig. 17). And Aden Evens, in his recent philosophical exploration of sound, remarked: “An individual sine wave has a minimal timbre... [its sound] is thin, without texture, *a pure tone with no body behind it*” (Evens 2005, 4; emphasis added). As I have discussed, through graphical methods in physiology and acoustics, curvy waveforms came to symbolize life and lively variation compared to the flatline of stillness, death, and silence. Helmholtz’s affinities with neoclassical aesthetics help to explain how this one particular curve—the sine wave—became associated with purity, neutrality, and musical/cultural value.

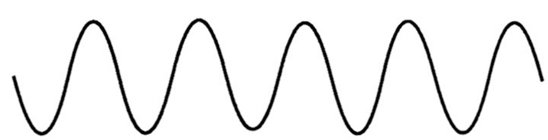

***Figure 1.5** A mathematically ‘perfect’ sine wave.*

Fig. 17. Illustration of a “perfect” sine wave in a textbook on multitrack recording (Hurtig 1988, 3).

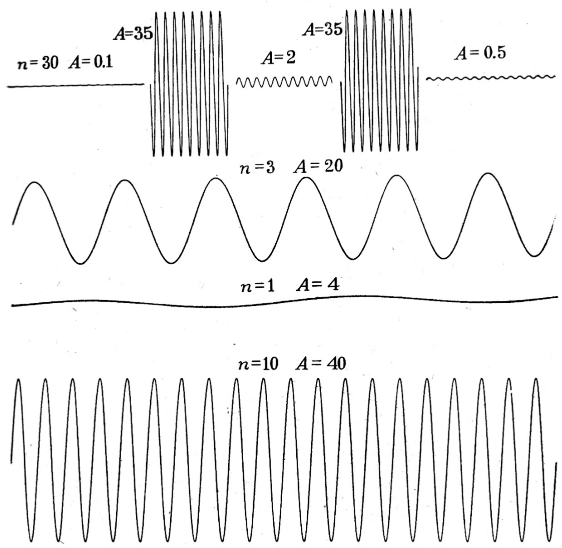

FIG. 13. Sine curves of various dimensions.

Fig. 18. Sine curves of various dimensions (Miller 1916, 15).

The sinusoidal form, as a smooth line and evenly-proportioned twofold curve (Fig. 18), is consistent with Helmholtz's neoclassical aesthetics and the desire for simplicity and order that manifested across his work and tastes. Such demarcations of the true, good, and beautiful at the nexus of capitalism, industrialization, and the foundation of western modernity were built on racialized signs and associated claims to cultural value. As Paul Gilroy maintains: "Notions of the primitive and the civilized which had been integral to pre-modern understanding of 'ethnic' differences became fundamental cognitive and aesthetic markers in the processes which... [gave] way to the dislocating dazzle of 'whiteness'" (Gilroy 1993, 8-9). Likewise, in her work on the color of stone in neoclassical sculpture, Charmaine Nelson (2007) has shown that the whiteness of marble was by no means neutral, but a conscious rejection of pigment as dangerous and sensual by expatriate American artists in their sculptural representations of black female subjects. Helmholtz was not as expressly engaged with the representation of racialized and sexualized subjects as visual artists were, although his discussions of tonality and harmony devalued non-Western musical traditions as primitive in ways consistent with dominant Western music discourses (Helmholtz 1954, 237; see also Jeans 1937, 161). More significantly in terms of his lasting contributions to acoustics and synthesis history, his formulation of the sine wave as an ideal manifestation of harmony and order signified cultural markers of beauty and restraint associated in audio-technical discourse with whiteness and scientific objectivity. Timbral variations would be understood in contrast to this comparatively disembodied ideal.

Helmholtz delivered over twenty popular addresses in the latter half of the nineteenth century, and in that role he was one of the leading figures for shaping opinions of scientific progress among the German and European social and political elite and middle classes (Cahan 1993, 559-60). He was an uncritical supporter of scientific progress and its harnessing of natural resources for human pursuits, and considered the integrated growth of science, technology, and economy in the nineteenth century to be a favorable manifestation of Francis Bacon's claim that "knowledge is power" (Cahan 1993, 575-77). He saw the mutual benefits of science, industry, and the state, and his own research benefitted from state support; in fact, funding from the King of Bavaria went toward the purchase of his tuning-fork synthesizer (Cahan 1993, 572-73; Vogel 1993, 269). In addition to his lectures, Helmholtz sought to popularize science in Germany by supervising the translation of John Tyndall's works into German, including Tyndall's lectures on sound. Overall, Helmholtz believed in science as a civilizing mission, whereby mastery over nature and the debunking of mystical beliefs were keys to modern life and social uplift (Cahan 1993, 593-95).

Consistent with these values, the pure form of the sine wave contains layers of meaning that reflect the fascination with, and distancing of, white, bourgeois "men of science" from variously sexed, raced, and classed bodies. Through its curved shape and name, the sine wave carries allusions to the sea and other fluids. The word "sine," which refers to a mathematically discerned bend or curve, derives from historical references to the bosom of a garment as well as the shape of the Persian gulf (*OED*, "sine")—again marking the presence of feminized, fluid forms and colonialist, maritime voyage in sonic epistemologies. Like ear *canals*, which mirrored the unruly fluids of the sounding universe on the interior of the subject, *sinus* cavities formed another curvy frontier to be explored and known by scientific methods (*OED*, "sinus"). Within and outside the body, feminized, fluid seascapes and/as soundscapes served as captivating territory for scientific discovery and technological regulation. One of D. C. Miller's exemplary "synthetic experiments" with his harmonic synthesizer, developed in 1914, was to use the machine to synthesize the curve of a white woman's portrait profile, and to demonstrate its abstraction into a periodic waveform. He used the repetition of its "simple" curves as an illustration of the principle that complex timbres are constructed of simpler forms, where "beauty of form may be likened to beauty

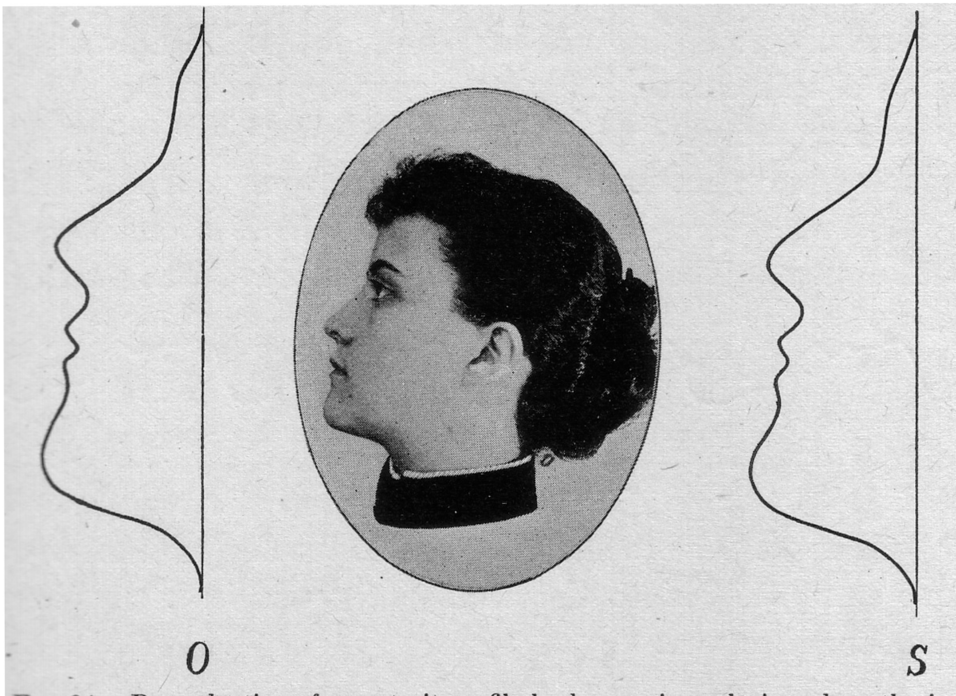

FIG. 94. Reproduction of a portrait profile by harmonic analysis and synthesis.


FIG. 95. Wave form obtained by repeating a portrait profile.

Fig. 19. D. C. Miller's synthesis of the curve of a woman's profile, and its repetition into a periodic waveform (Miller 1916, 119-20).

of tone color, that is, to the beauty of a certain harmonious blending of sounds" (Miller 1937, 119-20; see also Kahn 1999, 95-99; Fig. 19). In the imagination of Helmholtz and followers like Miller and Jeans, the sine wave was a paragon of pure form, a model for other "simple" waveforms associated with the construction of tonal beauty, harmony, and musical pleasure.

The sine wave can also be interpreted as a symbol of white and male bourgeois restraint, consistent with the subjects who practiced nineteenth-century scientific objectivity. Like a model of the fluctuating lines registered by Poncelet-

Morin instruments, the sine wave was an idealization of efficient motion and energy expended by willfully-controlled, laboring bodies. Nineteenth-century scientific biographies and autobiographies presented the role of scientists as one of diligence in effort, combined with restraint of the will to impose any hypotheses that would interfere with the objective rendering of nature's truths by graphical methods and instruments. Men of science and their chroniclers compared work in the laboratory to labor in industrial factories. But, as a mark of their bourgeois class position or aspirations, they emphasized their superior discipline in exercising patience, vigilance, and self-restraint amidst tireless, ongoing effort (Daston and Galison 2007, 230-31). The smooth line of the sine wave perhaps remains legible and audible as "without a body" because it is an ideal shape that lacks the variability of actual bodies in motion. Instead, its form epitomizes nineteenth-century scientists' values of repetitive effort (ongoing cycles of a waveform) and willful restraint (smooth, precise curves with no excessive deviations).

If the source for beauty of tone color was the simple form of the sine wave, analogized in these examples to the perceived simplicity of a white woman's profile or the willfully-restrained comportment of the bourgeois scientist, it follows that timbral complexity and dissonance would correspond to alternately devalued and desired, racialized and classed notions of deviation and excess, representable by more complex and asymmetrical waveforms (Figs. 20 and 21).

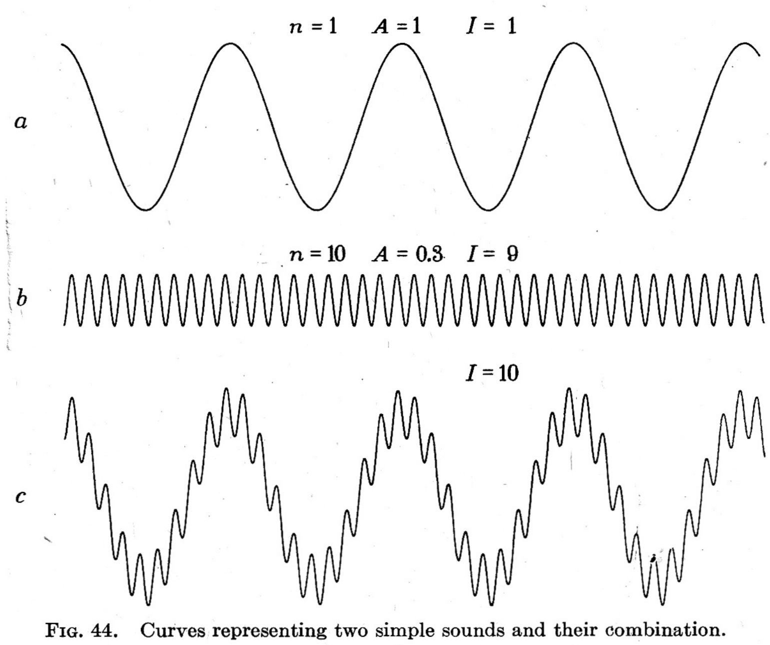

Fig. 20. Illustration showing the construction of a more complex waveform from simpler components (Miller 1916, 55).

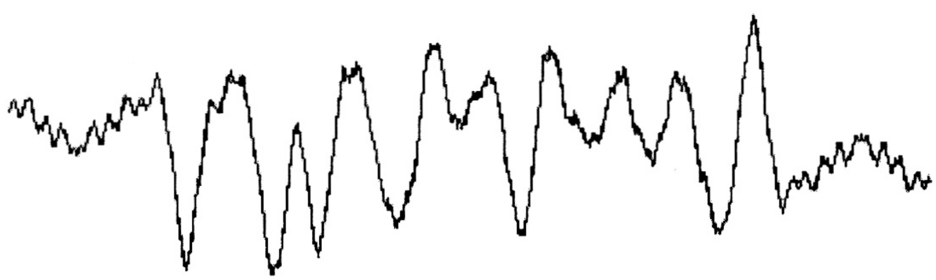

Fig. 21. A complex, aperiodic waveform, characteristic of noise (Huber and Runstein 1995, 35).

The modern conception of sounds as individuals with varying characteristics, classifiable by aesthetic properties, was co-emergent with scientific epistemologies used to produce cultural hierarchies of raced, gendered, and classed bodies. Whether Helmholtz was theorizing an individual sound, a musical instrument, or the ear itself, he believed that the discrete parts that make up the whole are determinants of aesthetic characteristics, which, in turn, manifest cultural values of beauty, order, and character (Peters 2004, 186; Helmholtz 1954, 553; see also Miller 1937, 160-61). Like the relation of partial elements to aesthetic qualities of whole tones, in nineteenth-century discourses of phrenology, researchers posited that shapes and attributes of the brain and skull corresponded to outward expressions of moral character (Wiegman 1995, 30-35). And as the sine wave signified purity and order, aperiodic waveforms represented noise—increasingly a symbol of social and cultural transformations in the modern American city, a sign of urban congestion and disorder, and a target of progressive noise abatement campaigns by the early-twentieth century (Thompson 2002, 115-20). The shape of sound waveforms, these examples suggest, is entwined with histories of scientific determinations of difference and desires for social ordering and control.

Helmholtz and followers' construction of the sine wave as pure form is especially noteworthy for articulating notions of physicality and embodiment to timbre in audio-technical discourse. At numerous points and cultural locations within the history of electronic sound, among commentators ranging from acousticians to synthesizer designers to cultural critics of electronic dance music, the electronic production of tone color has been hailed as a way of adding desired expression to the dull purity of the sine wave, or as a way of communicating sensual pleasure—where timbral variation is experienced as the materiality or physicality of sound (Gilbert and Pearson 1999, 59). Jeans, for example, observed that the regularity of the sine wave can result in unpleasant monotony, which he depicted as the “dull, flat hum” of the tuning fork, and encouraged the careful design of more compelling waveforms (Jeans 1937, 20). As well, timbre has been historically marginalized in Western classical music traditions; instrumental training valorizes tonal purity over textural variation, and timbral fluctuations are typically absent from musical notation. The marginalization of timbre, along with rhythm, in the Western classical music tradition has gone “hand-in-hand with the denigration and/or valorization of bodily pleasures” (Gilbert and Pearson 1999, 59-60), which are most commonly associated with non-white, feminized, and lower-class bodies and cultures. Gilbert and Pearson argue that the foregrounding of rhythm and timbre through synthesis techniques in contemporary electronic dance music cultures is an oppositional reaction to that tradition. In a complementary perspective, Alexander Weheliye (2002) has noted that in contemporary black popular music, Afro-diasporic musicians, working in response to legacies of slavery and colonialism, actually *claim* sonic artifice—the creative manipulation of timbre with electronic synthesis and effects—as a way of exposing the body and the category of human as always-already contingent and never natural. Nineteenth-century discourses on the purity of the sine wave, which emerged from a conventionally unmarked gendered, racialized, and classed scientific epistemology (a white, male, bourgeois subject position), inform and inflect this notion of timbre as an expression of physicality and pleasure in sound, and the possibilities for its technological manipulation.

In examining the intersections of acoustics, physiology, and neoclassical aesthetics in Helmholtz's work and the figure of the sine wave, it is also relevant to note that modern physiology perpetuated key aspects of the Greek medical tradition that valued states of equilibrium: "Nature (*physis*), within man as well as without, is harmony and equilibrium. The disturbance of this harmony, of this equilibrium, is called disease" (Canguilhem 1991, 40). Modern physiology consists of "a canonical collection of functional constants related to the hormonal and nervous functions of regulation," where the task of medical therapeutics is to restore the "habitual ideal" or normal state of organs (Canguilhem 1991, 122-26). Sound waves, considered to be a disturbance of states of rest ever since the ancient example of the stone thrown into a pool of water, were re-imagined by scientists in the nineteenth century through the modern technology of the sine wave. The sine wave was a means of mathematically representing—and, ultimately, electronically generating—an idealized pattern of voyage and return, growth and decay, neutrality and sensual color, controlled deviation and restoration of order.

In his experiments to test out Ohm's claims on the nature of tone, Helmholtz relied on various mathematical idealizations and analytic reductions, such as studying only the steady-state portion of tones, and not accounting for extraneous noise and hiss (Vogel 1993, 273). In a sense, he was already working in certain idealized conditions in the laboratory as he isolated and valorized ideal sinusoidal forms. More recently, Aden Evens has bolstered this notion of the sine wave as technoscientific artifice, noting that it has "an *unworldly* thinness. Pure sine waves are unlikely to occur in nature, so we encounter them primarily in the context of electronic technologies" (Evens 2005, 4, emphasis added; see also Hurtig 1988, 3). Since it can only be approximated by acoustic instruments, like a tuning fork or flute, the sine wave came to symbolize a means by which electronic sounds could be built in the laboratories of science and music to surpass perceived physical limitations and assume various lively forms.

Electronic Sounds as Forms of Life

As this chapter has outlined, the electronic synthesis of sound was informed by the momentum and intersection of several developments in the latter half of the nineteenth century. Universal laws of thermodynamics, mechanistic models of physiology, and evolutionary theories of individual variation proliferated in scientific discourses. Graphical inscription instruments made possible the analysis of sounds as well as diverse organic processes, which were all expressed similarly through the figure of the waveform. Popular discourses constructed electricity as a kind of animating force, present within living bodies and signifying as well the lively potential of new electrical technologies. Electricity provided a means for synthesizing sounds with aesthetic variations that were analogous to various forms of life.

From the perspective of the present, claims by instrument designers in the twentieth century that a synthesizer can create an entire "world of sound" (Micromoog 1975) can be historicized in relation to the diversity of the objects of study in experimental physiology and acoustics in the nineteenth century. The organic processes of plants, animals, and humans were all distilled into the universalized curves of graphical methods, analogized to each other by the animating presence of electrical activity, and described with the same terms like amplitude and decay.

Harry Olson was fond of promising that with the RCA Electronic Music Synthesizer, any sound that could be imagined and described could then be generated by electronic means (Olson and Belar 1955, 595). Many letters in the RCA archives suggest that the public took Olson's promise literally, in good faith. A Hollywood sound designer, for example, sent a letter to Olson in 1955 with elaborate descriptions of the imagined sounds of various kinds of dinosaurs of different weights and throat structures, with corresponding suggestions of how to synthesize them electronically. A professor of medicine at Johns Hopkins Hospital in Baltimore also wrote to Olson, constructing detailed comparisons of the human heart's productions of various sounds and murmurs to the mechanical processes of musical instruments. A psychiatrist on Long Island wrote in to say that one of his patients was "quite expert in imitating the French horn and the trumpet" so realistically, that research in synthesis might benefit from comparing his mimicry to the original instrumental sounds (Mueller 1955; McKusick 1956; Abramson 1956).

The florid interchangeability in these examples among human vocal expressions, sounding bodily interiors, and imaginary beasts—as all a part of the world of synthesized sound—is a legacy of the universal language of graphical methods. Any curve that could be analyzed could be synthesized; and electrical forces could be located in diverse objects of experiment and similarly represented: the electrical impulse in a frog's leg, a dog's artery, a human heart, a moving plant. These analogical relations are what make a synthesizer also like "a tuba... and a bassoon" (Micromoog 1975); and what sustain the classifications of sounds in synthesizer patch books into "families" of instruments that include the synthesized sounds of stringed and percussion instruments alongside those of weather events and animals (ARP 1981). Through the universal language of graphical methods, all sounds became potentially synthesizable and analogous to forms of life.

Electronic sounds can be theorized as "forms of life" in that they are constructed by language and technologies in social contexts in ways that reveal cultural understandings of the body, liveliness, and mortality. Ludwig Wittgenstein's concept of language in social context, and Langdon Winner's application of this concept to technologies, underlie my uses of this phrase. Wittgenstein develops the term "language-game" to refer to the totality of "language and the actions into which it is woven" (Wittgenstein 2001, 4). Language-games span a wide range of human activities, from professionalized scientific practices to more mundane daily habits; his examples list "Presenting the results of an experiment in tables and diagrams" alongside "Making up a story," implying that each type of practice equally constructs meanings through social interaction, and involves the dual aims of instrumental and poetic communication (Wittgenstein 2001, 10). The functions of words are as diverse as specific tools in a tool-box (Wittgenstein 2001, 6). The task of choosing among them is directed toward affective as well as merely effective communication, like an expressive performance on a musical instrument: "Uttering a word," he suggests, "is like striking a note on the keyboard of the imagination" (Wittgenstein 2001, 4). Language inherits histories and remains dynamic in the present. So, to follow Wittgenstein's claim that "to imagine a language means to imagine a life-form" (Wittgenstein 2001, 7) is to attend to the ways in which language circulates in, and organizes, both cultural history and social life. Language becomes part of what it means to be alive; without the meanings and understandings that are established over time in social context, language is "nothing but sounds" (Wittgenstein 2001, 108). Language itself is animated by social practices, and things, in turn, seem to come into "being"—that is, they become integral to human life—by the synthesis of sign and referent through embodied, lived experiences (Wittgenstein 2001, 19-21): "Every sign *by itself* seems dead. *What* gives it life?—In use it is *alive*" (Wittgenstein 2001, 108).

Winner extends Wittgenstein's concept of "forms of life" to technologies more generally: "As they become woven into the texture of everyday existence, the devices, techniques, and systems we adopt... become part of our very humanity [and] call into question what it means to be human" (Winner 1986, 12-13). The use of terms like "growth" and "decay" to describe the amplitude and duration of sound waveforms, and the recognition of tone color as a marker of sonic variation or "character," exemplify how electronic and synthesized sounds and their properties have been woven into human practices through representations that express historically- and culturally-specific understandings of embodiment, life, and mortality. A persistent desire to make sense of such lively variation, mortality, identity, and difference underlies that "constant urge" of humans, so identified by the electronic instrument designer Hugh Le Caine, to build "strange creatures of the imagination"—automata and other sound-making devices—of which synthesizers are a modern manifestation (Le Caine 1959, 1).

5. "DIVIDED PARTS, REUNITED": IDEAS AND MACHINES OF SYNTHESIS

> Whatever urge it is that prompts man to build automata, it is a constant one, and the strange creatures which are the product of his imagination and skill give us an interesting indication of his mechanical ability as it varies with time and place.
> – Hugh Le Caine, "A Touch-Sensitive Keyboard for the Organ" (1959, 1)

> There is a tendency on the part of today's public to assume that everything even remotely connected with the media of electronic music was discovered yesterday. The advocates of a new composer... like to profess that their man invented electronic music, or perhaps even discovered music itself. However, the historical record contradicts such a premise... Studies in sound began in antiquity.
> – Otto Luening, "An Unfinished History of Electronic Music" (1968, 9)

The previous two chapters discussed the roles of the ancient metaphor of the wave and the modern metaphor of the individual in constituting knowledge of electronic sound at the turn of the twentieth century. This chapter follows other significant and overlapping historical waves: ideas of synthesis, and cultural notions of the natural and synthetic, that inflect audio-technical discourse; the evolution of devices that prefigure modern synthesizers; and the formation of new social and professional networks of composers, engineers, and hobbyists over the first half of the twentieth century who consolidated knowledge of synthesized sound as musical material to be produced by specialized instruments.

Synthesized sound is a modern incarnation of ideas and practices that date to antiquity, including efforts to analyze components of sound, build machines that imitate sounds of nature, and automate tasks in music composition. In his short story, *Automata*, writer and composer E. T. A. Hoffmann remarked:

> it would be the task of a really advanced system of the "mechanics of music" to observe closely, study minutely, and discover carefully that class of sounds which belong... to Nature herself, to obtain a knowledge of the tones which dwell in substances of every description, and then to take this mysterious music and enclose it in some sort of instrument, where it should be subject to man's will, and give itself forth at his touch (Hoffmann 1814).

This is an ongoing dream of synthesized sound technologies: that techniques of analyzing nature can foster new technologies (or, in Le Caine's words, "strange creatures") that re-create its mysterious sounds, and make them available to be activated at will.

While this impulse informed numerous experiments in the mechanical, electromechanical, and electronic generation of sound in preceding centuries, synthesized sound and synthesizers as musical instruments took shape between roughly 1890 and 1960. During this period, social and professional networks of composers, engineers, and hobbyists were increasingly connected as "textual communities"—consolidating their knowledge through common uses of audio-technical language and visual representations that circulated in shared texts (Marvin 1998, 12; Meissner 1936, 1441). In forums such as audio engineering journals and conference presentations, acoustics textbooks, patents, and radio and electronics magazines, they forged connections between modernist musical aesthetics, the new science of acoustics, and a cultural enthusiasm for electricity and electronic devices.

Among these communities of experts in music, sound, and science, the analytic breakdown of sound into constituent parts helped to crystallize both the idea of sound synthesis and the form of the synthesizer. The form of the synthesizer manifested a system of knowledge that analyzes sound into such constituent elements as frequency, amplitude, timbre, and duration, in that the generation and control of discrete aspects of sound was delegated to separate components of the instrument (Olson and Belar 1955; Moog 1964). The expression of synthesized sound in particular technological forms—itself a kind of synthesis of historical developments—also emerged in relation to the availability of various constituent technologies, such as electricity, vacuum tubes, punch card systems, transistors, and integrated circuits (Chadabe 1997, 1; Holmes 2002, 52-53; Manning 1985, 117; see also Lubar 1992; Brinkman et al. 1997; Symons 1998). Overall, synthesized sound and synthesizer instruments are deeply entwined with twentieth-century cultures of music, science, and technology, but also rooted in ideas of synthesis that were in circulation long before.

Meanings of Synthesis

The term *synthesis* surfaced in seventeenth- and eighteenth-century philosophy to refer to the action of proceeding in thought from causes to effects, or from principles to their consequences. Newton, writing in *Optics* (1721), explained: "The Synthesis consists in assuming the Causes discover'd, and establish'd as Principles, and by them explaining the Phaenomena proceeding from them" (*OED*, "synthesis"). Synthesis was paired with the concept of analysis, which referred to the process of resolving phenomena into fundamental causes or parts, with or without physical isolation of those elements. A synthesis was contingent upon its constituent causes; and these causes were identifiable by analysis, which presupposed and depended upon a synthesis. Thus, synthesis and analysis (as well as the various effects and causes, wholes and parts, that these concepts called forth) were understood to be co-producing and emergent from one another.

In the early eighteenth century, contemporaneous with Newton's writings, the term synthesis began to appear in medical and chemistry texts to refer to the unification of parts by application of scientific techniques. In 1706, synthesis was defined in a text on surgery as "that Method whereby the divided Parts are re-united, as in Wounds." Synthesis had existed previously in the relatively immaterial realm of logic, but now was mapped upon the material of the human body and made tangible through scientific methods. As early as 1733, a lecturer cited the improvement of analysis and synthesis techniques as necessary to advancing the field of chemistry. By the 1860s, these terms had spread across a range of scientific fields: synthesis referred to techniques in chemistry for the production of compounds from elements; in physics, it described Tyndall's illustration of the composition of white light from constituent colors, and Helmholtz's production of vowel sounds through analysis and reunification of parts of sound, among many other examples (*OED*, "synthesis").

The idea of synthesis infiltrated general philosophical and cultural usage over the course of the nineteenth century to refer to the combination of parts or elements, whether immaterial or material, into a complex whole. Often, it expressed a connection between the experience of being human and notions of the divine. In 1836, Samuel Coleridge wrote of "The happiest synthesis of the divine, the scholar, and the gentleman" that coexisted in one man; a writer in 1882 described "The Christian life [as] the synthesis of these divine graces" (*OED*, "synthesis"). Overall, synthesis has been a conceptual tool by which humans have described and made sense of consciousness, mortality, and the experience of self in relation to world.

Following advances in organic chemistry in the late nineteenth century, developments of synthetic dyes increasingly were applied to consumer products. Synthesis took on new connotations as public opinion registered reactions to synthetic materials. Synthetic materials were understood to be "man-made" imitations of natural substances produced by processes of analysis and synthesis, which held two conflicting connotations. On one hand, there was suspicion that synthetic materials were not as good as natural ones. A 1907 article in *Nature* reported that "Since 'synthetic' indigo was put upon the market in 1897, some uncertainty has existed regarding its tinctorial value as compared with the natural dyestuff." Alternately, there was evidence of a kind of faith in science and technology that the synthetic could exceed the natural and provide a better, brighter, more durable substitute. In 1932, for example, one writer commented on a woman's discovery that "synthetic stockings wore better than pure silk"; a 1944 report related the process by which scientists "copied nature's methods" to synthesize sucrose in the laboratory as a preferable substitute for sugar (*OED*, "synthetic"; "Synthetic sugar" 1944).

This cultural production of the synthetic and natural has some parallels with the social genesis of sound fidelity during the same period, which "became an ever-shifting standard for the functioning of sound-reproduction technologies, a means by which to measure the distance between original and copy: it was an impossible vantage point from which to measure the fidelity of machines to a fictitious external reality" (Sterne 2003, 285). Similarly, synthesized sound technologies elicited comparisons of machine-generated sounds to imagined "natural" phenomena or acoustic events, and these comparisons resonated with debates about the synthetic and natural happening across cultural fields (e.g., Are synthetic stockings more durable than silk? Is the technological possibility of synthetic chemicals to be celebrated or feared?). Although they advanced by different methods, both sound reproduction and synthesis were seen as expressions of technological artifice (Théberge 2004, 763-67; Horning 2004, 708-14). As social and technological processes of sound reproduction produced the very ideas of "original" and "copy" (Sterne 2003, 219), sound synthesis implied that all sounds (including "natural" or "acoustic" ones) were articulated to processes of mediation, poised for analysis and re-synthesis.

The earliest applications of the term synthesis to techniques of sound generation coincided with its dispersion across scientific discourses in the late nineteenth century. Lord Kelvin's harmonic synthesizer, while not sound-generating, was an important prototypical device that could synthesize the shape of a wave from its constituent parts, based on Joseph Fourier's mathematical theories (described below). Helmholtz referred to the "analysis and synthesis of vowel sounds" in his landmark treatise *On the Sensations of Tone* (1863). Thaddeus Cahill, who drew upon Helmholtz's work when developing his Telharmonium instrument in the 1890s, was the first to attach the term synthesis to the "composite electrical vibrations" that comprised a sound, in his 1897 patent (Cahill 1897, 2). The terms synthesis and synthesizer, as applied to musical devices, then faded until Harry Olson applied them to the instruments he designed at RCA in the early 1950s.

In the interim decades, electronic musical instruments typically were named after their inventor (e.g., the Theremin and Hammond organ), or incorporated scientific and/or musical references with prefixes like "radio-" and "electro-," and/or suffixes such as "-phone," "-tone," or "chord" (Davies 1984a, 658). This pattern reflected the prominence of radio and electrical technologies in the cultural imagination during this period and the influence of radio technologies on musical instrument designs, as well as an ongoing tactic of electronic musical instrument designers to market their novel devices by linking them to familiar musical concepts. As well, the term synthesis likely faded from the 1910s to '40s because many electronic musical instrument inventors were making use of the newly invented audion, a vacuum tube oscillator. Instruments like the Theremin and Trautonium employed these electronic oscillators along with various means of controlling volume and pitch through gestures, levers, and foot pedals, but not with techniques of synthesis as such (Manning 1985, 2-3).

The notion of the synthetic, however, did not disappear from audio-technical discourse or the popular imagination between World War I and II; it was mobilized alongside notions of "mechanical" and "electronic" music. Several terms in this period were used to describe music that was electronically generated, electrically amplified or reproduced. Hugh Davies, a historian of electronic musical instruments, provides a detailed account of how such terminology changed over time:

> Up to about 1930 "electric organ" meant a pipe organ with electric action, and "electric piano" an electrically powered player piano... Around 1930 several music journals carried regular articles on "mechanical" music, which dealt not with clockwork music machines but with all the recently introduced electrically powered means of producing, storing and diffusing sound and music: radio, gramophone, the sound film and electric and electronic instruments. In the 1930s some of the more frequently found descriptive terms for such instruments were "electrotonic," "electro-magnetic," "electrogenic," "radio-electric" and "ether-wave." Common to both the inter-war and post-war periods are the terms "electronic," "electric(al)," "electroacoustic," "electrophonic," "synthetic," "electron music" and "electromusic." Today "electroacoustic" and "electronic" are the most widely used terms for the large area of music generated or modified by electric and electronic instruments and associated equipment... (Davies 1984a, 658).

This terminological variation was indicative of various cultural shifts. Following the discovery of the electron around the turn of the twentieth century, and John Ambrose Fleming's influential publication "The Electronic Theory of Electricity" (1902), some technologies previously referred to as "electric" became newly named as “electronic.” And, while late-nineteenth century experiments disproved the existence of ether—“the mother of all media that allowed light, electricity, and magnetism to work at a distance” (Peters 1999, 102)—the term clearly took awhile to fade from common use and captivated the imagination of electronic musical instrument inventors well into the twentieth century.

What is important about this period of terminological flux to the development of modern synthesizers is that the terms “mechanical,” “electronic,” and “synthetic” were applied to music and new musical instruments interchangeably, which worked to conflate their meanings in epistemologies of sound synthesis. Before this point, “synthesis” did not necessarily refer to an electronic or even mechanical process or device; it could be mathematical or philosophical. But with the crystallization of synthesizer instruments in the postwar period, all three of these connotations would remain present: a synthesizer was necessarily an electronic instrument which, if not properly mechanical, was expected to automate tasks in sound production or music composition; it also retained connotations of the synthetic in the aesthetic characteristics associated with its sounds.

Olson and colleagues resurrected the idea of synthesis and the term synthesizer because it seemed to communicate the essence of Fourier’s and Helmholtz’s theories, as well as resonate within the context of modern communication and cybernetic theories. In a 1950 report, they wrote: “Modern communication theory has not only thrown new light on the band width requirements, but also introduced new and reemphasized old concepts of physics" (Olson and Belar 1950, 2). They worked through earlier theories by Fourier and Helmholtz in comparison to Norbert Wiener's *Cybernetics* and Shannon and Weaver's *Mathematical Theory of Communication*, and concluded that the analysis and synthesis of sound and music were analogous to the process of decoding and coding a signal in a communication channel (Olson and Belar 1950, 5). Olson's promise that any sound that could be imagined could be synthesized (Olson and Belar 1955, 595) also resonated with the assertion in a seminal cybernetics text of the technological possibility of a synthesized cat (Rosenblueth et al. 1943, 123). Effectively, Olson and colleagues were updating Helmholtz's ideas of synthesis, which emerged through analogies among forms based on graphical methods, to an idea of synthesis suitable for the cybernetic age, where analogies were expressed as patterns of data on a punched-paper coding system (Hayles 1999, 98; Manning 1985, 103).

The term synthesizer transferred into widespread use following Robert Moog's adoption of the term in the late-1960s, although it was not adopted by electronic musical instrument inventors uncritically. Both Moog and the inventor Don Buchla initially resisted using the name *synthesizer* for their instruments. Moog wished to distinguish his more compact, voltage-controlled machines from the room-sized, punched paper-controlled RCA synthesizer, but ultimately realized that RCA had, for better or worse, established the word in the public imagination. Moog's catalog incorporated the word synthesizer for the first time in 1967 (Pinch 2008, 472n.14; Moog 1996, 21). Buchla disliked the connotation of the synthetic as an imitation or emulation. He observed that "synthetic was a scientific word before it was a public word, and it meant a putting together out of the component parts, a creation of the parts." He was dismayed that there had been a kind of "semantic inversion" in public discourse where the scientific definition of synthesis had become articulated to popular notions of the synthetic. Just as rayon was understood to be "artificial silk," Buchla explained, synthesized sound was often interpreted to be an artificial version of an well-known instrument (like the violin). Buchla "regarded electronic instruments as not there to imitate violins and imitate this and that, but to create and experiment with new timbres" (Buchla 1997, 2-3). Consequently, he chose to avoid the words synthetic and synthesizer and refer to his machines, which were more experimentally designed and never as widely distributed as Moog's, as electronic musical instruments (Pinch and Trocco 2002a, 41).

Over time, synthesized sound has come to be known as simultaneously having a certain imitative function but also representing the genesis of new kinds of sounds. The Roland TB-303 bassline synthesizer, for example, was initially marketed in the early 1980s to emulate acoustic bass sounds, but it failed in such extravagant fashion as to inspire new genres of electronic dance music based on the elaborate timbral variations it produced (Gilbert and Pearson 1999, 124-25). Now, there are countless hardware and software imitations of the original TB-303 instrument—"second-order simulations," designed to emulate the coveted analog synthesizer with the distinctive sound that was intended by manufacturers to imitate something else (Théberge 1997, 196). Synthesized sound, and its alternately embraced and dismissed connotations of the synthetic, calls attention to the processes of mediation, of analysis and synthesis, that produce and implode the very categories of nature and artifice, of original and imitation.

Techniques of Sound Analysis

Techniques of sound analysis are integral to sound synthesis. Social and professional communities that have organized around audio-technical discourse have used language and visual representations to constitute these techniques. This section outlines a long history of analyzing and interpreting sound that comprises part of the cultural field in which modern synthesizers emerged.

Observers and inventors have sought to describe and quantify basic attributes of sound since antiquity. Various cultures developed different organizational systems for dividing octaves into gradations of pitches and ordering these into complex scales. Many systems recognized seven note scales (equivalent to the white notes on a piano) augmented by smaller intervals (chromatic tones, derived from the Greek term for color, *k'roma*) (Hindley 2002, 35). Philosophers from ancient times through the Middle Ages and into the Renaissance understood musical harmonies in relation to fundamental harmonies of the universe, and used simple numeric ratios to link musical systems to the order of the cosmos. With the development of modern science in the sixteenth and seventeenth centuries, philosophers began to use experimental techniques to examine the physical properties of sound. Natural philosophers took note of curious acoustical phenomena and published their findings; Francis Bacon, for example, included a section on sound in *Sylva Sylvarum* (1627). Isaac Newton's theories informed investigations of vibrating strings; Galileo Galilei, Marin Mersenne and others studied the motion of vibrating bodies and measured the speed of sound (Thompson 2002, 18).

Mathematical and physical investigations of harmonics were of particular significance to the development of synthesized sound, which would facilitate the technological possibility of timbral control. Harmonics are frequencies that are whole-number multiples of the fundamental frequency of a tone. A sine wave, for example, is said to produce a "pure" tone at a specific frequency, with no harmonics. The middle A on a piano, which is said to be a more complex tone, is characterized by a fundamental frequency of 440 Hz (cycles per second), plus harmonics at 880 Hz, 1320 Hz, and so on. The presence of harmonics (a physical property of sound) relates to how listeners perceive and distinguish timbral qualities of different types of sounds or musical instruments. A related concept is that of *partials*, or frequencies of a tone that do not have a harmonic relationship to the fundamental. These also contribute to the timbral qualities of some sounds (Roads 1996 16, 136, 544-45; Huber and Runstein 1997, 33). The term *harmonic* was first applied to this understanding of musical tones around 1700 by Sauveur, who devised a method for counting acoustic vibrations (Roads 1996, 500).

Philosophers and musicians in the eighteenth century understood that musical sounds were comprised of several harmonic vibrations around a fundamental tone, but lacked sophisticated mathematical and mechanical tools to isolate and analyze them. A significant theoretical advance was made in 1822 with the publication of French engineer Joseph Fourier's (1768-1830) *Analytic Theory of Heat*. Fourier developed the idea that periodic waveforms can be deconstructed into many simple sine waves of various amplitudes, frequencies, and phases (Roads 1996, 1075-76). In 1843, Georg Ohm (1789-1854) applied Fourier's theory to the properties of musical tones and perception, claiming that "all musical tones are periodic [and] every motion of the air which corresponds to a complex musical tone... is capable of being analyzed into a sum of simple pendular vibrations, and to each simple vibration corresponds a simple tone which the ear may hear" (Miller 1937, 62; see also Roads 1996, 545).

As I discussed in the previous chapter, much of Helmholtz's work built upon Ohm's theory. In *On the Sensations of Tone* (1863), Helmholtz argued that the quality of a musical tone depends on the number and relative strength of its constituent partial tones. By demonstrating this point with tuning forks, Helmholtz showed that a sound was comprised of a fundamental tone accompanied by harmonics that create timbre, or tone color. His theory suggested that a sound could be analyzed into component parts, and then synthesized anew based upon this knowledge (Helmholtz 1954; Holmes 2002, 13-14). Decades later, physicist D. C. Miller noted the significance of this theory on the field of acoustics: "From this principle it follows that nearly all the sounds which we study are composites...” (Miller 1937, 62). Rudolf Koenig added to Helmholtz’s theory the assertion that phase relationships among partials (the starting-points of periodic waveforms relative to one another) also affected tone quality (Miller 1937, 62-63).

Fourier analysis remained a tedious task of complicated mathematical calculations for much of the nineteenth century. Contemporaneous with Helmholtz’s research, Lord Kelvin’s harmonic analyzer and synthesizer in the 1870s simplified the process (Miller 1937, 110-11; Roads 1996, 1075-76). Kelvin’s device was concurrent with other novel sound visualization techniques, but his was especially relevant to the development of synthesized sound because it treated a sound wave as a wave*form*—a distinct object with a shape that could be mechanically described and recreated.

The evolution of sound analysis, the companion technique to synthesis, was closely linked to these many advances in sound visualization: “Visualizing sound... was a central task of the new science of acoustics... Sound had, according to the accepted techniques of science, to be seen in order to be quantified, measured, and recorded [which] required the simultaneous construction of sound as a discrete object of knowledge” (Sterne 2003, 44-45). Various experimenters attempted to visualize sound by observing its effects through sand on vibrating plates, on flames, and on other media like smoke and water jets (Hankins and Silverman 1995, 130; Sterne 2003, 43-44). Others began to represent sound using mechanical tracing techniques. The Wheatstone Kaleidaphone (1827) provided a means for projecting audible vibrations onto a screen, and the Scott-Koenig Phonautograph (1857) traced vibrations on a rotating cylinder of paper using a diaphragm and stylus (Roads 1996, 500-502; Thompson 2002, 19; Sterne 2003, 39).

Sound recording technologies were developed soon after, building on these techniques of sound visualization. Thomas Edison's Phonograph (1878) was inspired in part by the Phonautograph, and inscribed representations of sound on cylinders first made of tin foil, and later wax. Emile Berliner's Gramophone (1887) used rotating discs made of lacquer, which later became the standard medium. Methods of storing and playing back sounds on magnetic tape were developed in the early decades of the twentieth century (Roads 1996, 500-03). These various sound recording technologies facilitated new, critical listening practices by enabling listeners to examine sounds more closely and learn to evaluate different kinds and qualities of sound (Sterne 2003; Thompson 2002). Sound recording technologies thus helped to inform a growing community of experts at the intersections of music, sound, and science who would also be invested in the development of electronic musical instruments and synthesis techniques.

Between 1900 and 1930, new tools, techniques, and terminology transformed the study of sound. Scientists and engineers developed new ways to measure and manipulate sound, and the public became "sound conscious," increasingly aware of the significance of acoustical technologies in modern life

(Thompson 2002, 59). By 1930, "The New Acoustics" was proclaimed by its practitioners as a newly formed and energized scientific field, and a new professional organization arose to support further research and technological development (Thompson 2002, 5). The Acoustical Society of America (ASA) was founded in 1928 by a group of physicists who opened their organization to all scientists and engineers interested in sound. By 1932, the organization had expanded to almost eight hundred members, including physicists, engineers, psychologists, musicians, and others. It also received financial support from diverse sponsors, including musical instrument manufacturers, manufacturers of architectural materials, and telecommunications companies (Thompson 2002, 105).

During this same period, radio and electronics hobbyists developed other, often more informal, approaches to conceiving and interacting with audio technologies and musical instruments. These techniques of electronics tinkering would play a significant role in the development of analog synthesizers in subsequent decades (Pinch and Trocco 2002a, 220-21). In the 1920s and '30s, amateur radio operators were an "active, committed, and participatory audience" of mostly young men who sought signals from faraway locations through technological tinkering at home (Douglas 1987, 205; see also Waksman 2004, 678). They "became attuned to the quality of sound that technological adjustments might bring," and this aspect of tinkering carried over into inventive strategies of early electric guitarists and guitar designers, notably Leo Fender and Les Paul, who were also radio enthusiasts (Waksman 2004, 679). Steve Waksman has described tinkering as an "impulse to rearrange technological details" (Waksman 2004, 675) that combines broader cultural concepts of "technological enthusiasm" and "do-it-yourself."

Technological enthusiasm emerged in tandem with the growing awareness of technologies in everyday life in nineteenth-century America: "Enthusiasm for technology is what led individuals not only to use technology, but also to take pleasure in it, and to apply themselves to it as a form of recreation" (Waksman 2004, 677). Hobbyist magazines instructed readers about technical practices and constructed an ideology around the cultural value of technological engagement. A related concept of "do-it-yourself," or DIY, was rooted in the spread of suburbs in the U.S. in the late-nineteenth and early-twentieth centuries. DIY manifested a desire of white, middle-class men to recover manual labor as a proper domain of masculine activity in the context of a bourgeois home and white-collar workplace, and to carve space for themselves in an increasingly isolated and feminized space of the suburban home (Waksman 2004, 677-78). There was a similar cultivation of values in ham radio cultures that sought "the right balance in masculine culture between rugged, competitive individualism and cooperative, mutually beneficial teamwork" (Douglas 1999, 334; see also Waksman 2004, 695). These types of tensions and negotiations were present in the design of electronic musical instruments in the mid-twentieth century, which was characterized by collaborations of individual composers with engineers who were trained with an ethos of teamwork, and especially in the postwar era, during which several prominent synthesizer inventors (including Hugh Le Caine, Don Buchla, and Robert Moog) moved between roles in formal engineering education and/or employment in government institutions, and more informal tinkering practices (Pinch and Trocco 2002a).

After World War II, the introduction of magnetic tape, the long-playing record, and stereo recording produced a need among professional recordists for new standards of practice. Like the acoustical physicists who broke ranks with the American Physical Society in 1928 to form the ASA (Thompson 2002, 104), a small group of radio and recording engineers left the Institute of Radio Engineers in 1948 to establish the Audio Engineering Society (AES) as a more specialized area of inquiry (Horning 2004, 708-09). The founding members "included recording engineers, inventors, audiophiles, and hobbyists, all of whom were interested in improving the sound of recordings and furthering the development of high fidelity sound, a concept that meant little to engineers, who were more concerned with measurements, components, and theory" (Horning 2004, 709).

It is noteworthy that hobbyists were among the AES founders, in contrast to the professionally established physicists who founded the ASA two decades earlier. This suggests that a wider range of technological practices, spanning formal scientific training as well as hobbyist tinkering, gained cultural currency from 1930 to 1950. Hobbyist activities and influence would continue to expand in the 1950s, as electrical components became more affordable and vacuum tube technologies were displaced by transistors: "Hobbyists took up electrical projects in increasing numbers as Radio Shack, Lafayette and Heathkit competed vigorously for their business. Magazines such as *Popular Electronics* were brimming with projects for budding self-taught gadget makers. [There was] a new generation of young people interested in all things electrical… [and some] would turn their attention to improving the state of electronic music instruments." Le Caine, Buchla, and Moog were "part of this new wave of inventors" (Holmes 2002, 147).

Hi-fi enthusiasts were among these hobbyists, and represented another emerging market of audio experts in the 1950s. RCA sought to encourage connections and cross-overs among synthesizer and hi-fi enthusiasts in marketing their demonstration recording of the Electronic Music Synthesizer to "hi-fi fans." While they had no plans to mass-produce the synthesizer, they recognized that its novelty could encourage interest in a wide range of audio equipment. A 1955 report from RCA Laboratories concluded: "The synthesis of many tones, demanding excellent reproducing equipment to achieve the best effect, will stimulate increased interest in hi-fi equipment and recording" ("The synthesis of music" 1955, n.d.). The design of modular synthesizers in the 1960s, which emphasized flexibility and customization, is partly indebted to hi-fi audio setups that became popular in the preceding decade, in which specialized components of a system contributed to a desired overall sound (Keightley 1996; see also Perlman 2004).

Organizations such as the ASA and AES consolidated communities of scientists, engineers, composers, and hobbyists through the establishment of standards, the circulation of technical publications and notices of works-in-progress, and annual meetings for social and professional networking (Horning 2004, 709). Language and visual representations in textual materials and social interactions played a crucial role in constituting knowledge and techniques of sound analysis and synthesis in these cultures, which underscores the importance of my critiques of audio-technical discourse in earlier chapters (Théberge 1997, 207-08; Porcello 2004).

Mechanical, Electromechanical, and Electronic Generations of Sound

In addition to their inheritance from a long line of inquiries into the physical aspects of sound, modern synthesizers share affinities with mechanical musical instruments and sound-generating devices from earlier eras. One of the oldest documented musical instruments is the pipe organ known as the hydraulis, dating to the third century BCE. Like modern synthesizers, it was a technological means for regulating waves. It consisted of pipes tuned to different pitches, mechanisms for regulating the amount and distribution of airflow to the pipes, and a method for maintaining steady airflow using hydraulic pressure (either from a natural source like a waterfall, or a manually-powered water pump). As early as the first century, a keyboard device was attached to control the flow of air (Hindley 2002, 36). Later, the hydraulis was modified with separately controllable sets of pipes, each identified by the names of other instruments whose timbres the sounds most closely resembled. This prefigured the multitimbral organ instruments that were common in medieval churches (Davies 1996, 4).

Pipe organs with multiple register-stops worked by a process similar to what is now called additive synthesis. Additive synthesis combines several elementary waveforms together to form a more complex one. In pipe organs, pulling on a register-stop routed air to a set of pipes; the air was released to the pipes by pressing on an organ key. By pulling on several register-stops, one could combine the sounds of several pipes of various sizes (which corresponded to different frequencies) for each key pressed. This technique of mixing frequencies to create complex timbres would later surface in Thaddeus Cahill's Telharmonium, the Hammond organ, and Karlheinz Stockhausen's use of multiple oscillators in his Cologne studio (Roads 1996, 134).

Automata, a category of mechanical devices that includes a range of sound-producing instruments, are another precursor to modern synthesizers. These gained popularity with the revival of Greek culture in the Renaissance and the rise of mechanistic philosophy. The writings of Ctesibius (a Greek inventor to whom the hydraulis is attributed) and others had been preserved in Arab and Byzantine culture, were newly translated, and exerted considerable influence on Renaissance thought and automata design. Automata in in the fifteenth and sixteenth centuries were pleasures of the wealthy, adorning gardens of royal mansions and palaces. Early mechanisms were powered by compressed air or steam, inspired by the Greek hydraulic and pneumatic systems. With input from the skills of clockmakers, these were replaced in the seventeenth century by revolving barrels or cylinders fitted with pins and driven by springs, which made possible the production of sound from a completely self-contained mechanical system. Observers noted that this technological innovation enabled better imitations of human speech and animal sounds, and more realistic automations of instrumental performances (Bedini 1964, 24-38). By the nineteenth century, automata had become sources of entertainment for children rather than the province of a privileged few (Sterne 2003, 75). However, their influence on scientific thought remained strong. Helmholtz considered the work of seventeenth- and eighteenth-century automata to be comparable to the most significant scientific achievements. He was impressed by the durability of their materials and consistency of design, which proved less fragile than human bone structure and more reliable than human effort (Bedini 1964, 41).

Synthesizers also continue a lineage of musical instruments incorporating electricity that traces to the eighteenth century. The first musical instrument in which electricity formed an essential part was La Borde's Clavecin électrique (1759), which used static electricity as part of its basic mechanism: a keyboard activated clappers that were charged with static electricity, which initiated the ringing of variously-pitched bells. Nearly a century would pass before sounds were produced more routinely by electrical means. Hans Christian Oersted's theorization of the relationship between electricity and magnetism in 1820 led to further research on electromagnetism by Michael Faraday and others. By the early

1830s, William Sturgeon, Faraday, and Joseph Henry had developed the first electromagnet, electrical transformers and motors. Soon after, several explorations in electromagnetism advanced techniques for the electrical generation of sound.

In 1837, Charles Grafton Page discovered the basic principle of the electric bell by producing audible clicks when a battery made or broke contact with a coil and permanent magnet. Page published a letter on his discovery of "galvanic music" in an issue of *The American Journal of Science and Arts*, but does not seem to have developed it any further (Page 1837). In 1838, Charles Delezenne built the first rotating tone wheel to produce a sustained tone from an oscillating electrical current. Around the same time, other experimenters developed hammers affixed to springs which would oscillate in an electromagnetic circuit and produce a sustained tone. Further investigations of these ideas were carried out by scientists in several countries. By the mid-1800s, electromagnets were used to simplify the action of pipe organs and other keyboard instruments, and electricity was used to operate player pianos. In 1884, Robert Kirk Boyle in England took out the first patent for a specifically musical application of electricity in generating sustained tones, for a system that activated strings by electromagnets (Davies 1984a, 667-69).

Research on telegraphy and telephony over the course of the nineteenth century produced various techniques for the electrical generation of sound. Many inventors who worked on electrical communications also developed musical devices. Charles Wheatstone, a physicist and inventor who designed an electric telegraph in 1837, also created the concertina (a hand-held, bellows-driven, chromatic instrument similar to an accordion) and a speaking machine. In 1874, Elisha Gray introduced a "musical telegraph" to communicate messages in Morse code using a differently tuned pair of reeds, whose vibrations were amplified and transmitted to a single loudspeaker. Alexander Graham Bell proposed a similar system, called an "electric harp," for speech transmission.

Tone wheels represented an important interim technological stage between electrically amplified acoustic vibrations and fully electronic oscillators (Davies 1984a, 669). These were in use by 1882, when Emile Berliner patented one for electrical telegraph and telephone systems; Ernest Mercadier in France devised a photoelectric tone-wheel system for telegraphy in 1888 (Davies 1984a, 668). An electronic oscillator was first introduced by radio experimenter William Du Bois Duddell around 1899. Duddell investigated the high-pitched whistle produced by electric arc-lamps used in street lighting during this period, and developed a "singing arc" device to control the whistle's pitch with an oscillator. Pierre Janet and Valdemar Poulsen developed variations on this device in 1902 and 1903 that expanded its frequency range and contributed to strategies for long-distance radio transmissions (Davies 1984a, 669).

Thaddeus Cahill received the first patent for an electronic musical instrument in the U.S. in 1897, entitled "Art of and Apparatus for Generating and Distributing Music Electrically." Cahill's project was the most ambitious electronic musical device up to that point, and encompassed both the electronic generation of music and its distribution over telephone lines to restaurants, hotels, and private homes. The sounds of the Telharmonium resulted from sine waves generated by electrical dynamos, which produced alternating currents of different frequencies; several waves could be combined through a complex switching system, and these were amplified by a series of acoustic horns fitted to telephone receivers. The Telharmonium (also called a Dynamophone in an early incarnation) weighed about two hundred tons and was approximately sixty feet in length (Chadabe 1997, 4; Manning 1985, 1). Cahill promoted his instrument as a new tool for expanding sonic possibilities, which could "produce the notes and chords of a musical composition with any timbre desired out of their electrical elements" (cited in Manning 1985, 1).

As Cahill was perfecting the Telharmonium, advances in vacuum tube design soon rendered his designs obsolete, and his company failed shortly before the outbreak of World War I (Manning 1985, 2). The new vacuum tubes had roots in the incandescent light bulb first introduced by Thomas Edison in the 1870s. Around 1904, John Ambrose Fleming, an employee of the British Edison Electric Light Company, modified Edison's design and patented the diode tube (also called the radio valve or Fleming valve) for regulating current in wireless transmissions. In 1906, Lee de Forest in New York refashioned the Fleming valve into a triode tube (or audion), adding a small wire grid that enabled the tube to amplify electrical signals. This device was improved enough to be commercially viable by the mid-1910s ("Light makes music" 1915; "Men of science" 1915; Thompson

2002, 93; Deutsch 1976, 14; Davies 1984a, 669).

Several advances in wireless transmission, electronic amplification and sound generation took place during this period in rapid succession. The first wireless transmission of speech and music took place in Massachusetts in 1906, de Forest produced the first valve amplifier in 1911, and W. Burstyn developed an electronic oscillator the same year. Similar oscillators and amplifiers were devised by several experimenters between 1912 and 1915 (Davies 1984a, 669-70). For one example, around 1913, Irving Crandall and collaborators at AT&T, whose research focused on improving the quality of telephone communications, developed the thermophone, a tool for acoustic research that converted an oscillating electrical signal into sound (Thompson 2002, 93). Military broadcasting began around 1917, and the following year, a private transmission system led to the establishment of one of the first permanent radio stations (KDKA) in Pittsburgh (Davies 1984a, 670).

From the outbreak of World War I through the 1920s, electronic instrument research and design made use of these new developments in radio broadcasting and the electronic production of sound. The Audion piano, de Forest's prototype keyboard instrument, was the first musical application of his vacuum tube design; it demonstrated that the new electronic oscillators could produce sounds at a fraction of the size and cost of Cahill's dynamos. His related patent of 1915, entitled "Electrical Means for Producing Musical Notes," proposed the concepts of a beat-frequency oscillator and hand capacitance, both of which would be implemented in the design of the most successful electronic instrument of the following decade, the Theremin (Chadabe 1997, 8; Davies 1984a, 670).

This history of experiments, materials, and devices form part of the ground from which modern synthesizers would emerge. From automata to the experiments with electrical generations of sound as early as the 1830s, it is clear that modern synthesizers manifest long-standing desires to imitate sounds of nature and harness electrical forces for expressive practices.

Musical Modernism, The Science of Sound, and the Promise of Electricity

The evolution of synthesized sound, and electronic music technologies and practices more generally, also shaped and were shaped by various trends in musical modernism. There was a certain "'technologization' of musical aesthetics" in the late nineteenth and early twentieth centuries (Braun 2002, 9). Across modernist art practices, "Technologies affected not only the artistic means of production and reproduction. They were also a new aesthetic stimulus in terms of the subject matter of art" (Born 1995, 41). Like cubist and futurist abstractions that converted the forms and movements of machines into new visual aesthetics, new electronic sounds made techniques of scientific analysis audible, and musical aesthetics were increasingly understood in terms of these constituent, quantifiable elements of sound. Composers drew inspiration from new scientific theories, became conversant in the scientific properties of sound, and advocated the development of new electronic musical instruments as a means of controlling all aspects of sound (Deutsch 1976, 4).

The influence of modernist scientism in art practices emerged as early as the 1880s and formed part of the cultural context for the emergence of synthesized sound. The painters Georges Seurat and Paul Cézanne were influenced by scientific studies of perception and theories of color vision (Born 1995, 41, 346n. 4). Composer Claude Debussy also experimented with the musical relationship of shifting tone colors to moods, and in one historian's analysis, "'played' his orchestration in much the same way as today's composer 'plays' a synthesizer—by choosing the instrumentation according to overtones, fundamental tones, and the possibilities of color combinations" (Deutsch 1976, 3). Helmholtz's theories of harmonics and partials contributed to new understandings of consonance and dissonance, and informed a reassessment of tonal systems by modernist composers (Holmes 2002, 14).

Thaddeus Cahill's work was an important bridge between nineteenth-century science and twentieth-century musical aesthetics. Cahill cited Helmholtz's analysis of the components of sound as a significant influence on his approach to designing the Telharmonium (Holmes 2002, 14). In turn, Cahill's work drew the attention of composer Ferruccio Busoni (a mentor to Edgard Varèse) who, in his 1907 essay *Sketch of a New Aesthetic of Music*, promoted Cahill's instrument as a powerful tool for new compositional techniques in the manipulation of harmonics (Manning 1985, 2; Holmes 2002, 14).

The major advance of modernism in music is marked by the breakdown of the system of tonality that had organized Western music for over three hundred years, and formed the underlying structure of baroque, classical, and romantic music. There was a period of experimentation in atonality around the turn of the twentieth century, during which several composers deliberately broke from tonal and thematic conventions (Born 1995, 47-48). Around the same time, Italian Futurists applied scientific techniques to the sorting of sounds into discrete categories for purposes of developing rational systems of music composition (Holmes 2002, 14). Balilla Pretella's *Technical Manifesto of Futurist Music* (1911) imagined the orchestra to be "integrated by an effective fusion of all its constituent parts" and mobilized composers to make music that reflected "all forces of nature tamed by man through his continued scientific discoveries." This included "the musical soul of crowds, of great industrial plants, of trains, of transatlantic liners, of armoured warships, of automobiles, of aeroplanes" (cited in Manning 1985, 4). Likewise, Luigi Russolo aimed to expand the conventional sonic palette through the control of traditionally nonmusical sounds, as outlined in his 1913 manifesto, *The Art of Noises*. With painter Ugo Piatti, Russolo devised mechanical noise-producing instruments (*intonarumori*, or "noise-intoners") to produce "families" of sounds: roars, whistles, whispers, screeches, percussive noises, and voices of animals and humans (Holmes 2002, 40; Manning 1985, 4). These categories reflected the pervasiveness of the metaphor of sounds as individuals by that point, and the associated practices of classifying sounds by aesthetic attributes, which I have argued arose with a broad range of social and scientific practices over the nineteenth century.

In the early 1920s in Austria, Arnold Schoenberg and his students Anton Webern and Alban Berg developed the new compositional technique of serialism. Serialism initially focused on the organization of pitches into a manipulable twelve-tone series; for several decades, it remained a dominant philosophy of musical modernism (Born 1995, 48). A new generation of composers in the 1950s added more complex elements of rationalism to earlier forms of serialism. Milton Babbitt, an early adopter of the RCA Mark II Synthesizer at the Columbia-Princeton studios in the late 1950s, promoted mathematical rigor in compositional techniques. Composer Iannis Xenakis incorporated laws of statistics, probability, and calculus into his practice. Stockhausen "brought together serialism, scientism, and electronics with the aim of total control of timbre" (Born 1995, 51-52).

Other avant-garde compositional strategies emerged in the inter-war period. Beginning in the 1920s, French composer Edgard Varèse called for new sounds and compositional techniques; his work both prefigured and catalyzed the development of electronic musical instruments (Born 1995, 51). He developed compositional techniques that would become standard procedure in electronic sound synthesis and processing. These techniques included changing the attack characteristics of instrumental sounds and conducting pioneering experimentations with timbre, using instruments "as component building-blocks for sound masses of varying quality, density, and volume" (Manning 1985, 6). Varèse introduced several scientific terms into musical theory and practice, including “research,” “experimentation,” and “laboratory” (Born 1995, 51). He also advocated new professional collaborations among those with specialized knowledge in music and science. In a 1922 interview in *Christian Science Monitor*, he made an appeal for the development of new instruments: “What we want is an instrument that will give us continuous sound at any pitch. The composer and electrician will have to labor together to get it... Speed and synthesis are characteristic of our own epoch” (cited in Manning 1985, 6). For Varèse, synthesis was a metaphor that connoted both the experimental combinations of “building-blocks” of sound, and the joining of creative forces among previously more disparate professions of music and science.

Varèse continued to seek (somewhat unsuccessfully) and imagine productive collaborations among composers and engineers. In the late 1920s he sought access to Bell Telephone Laboratories for further development of the Dynamophone, an instrument designed by René Bertrand in 1927-28 (not to be confused with the device by Cahill with the same name), but the Guggenheim Foundation denied his grant (Manning 1985, 9-10). In a 1939 lecture, Varèse heralded the musical possibilities of optically-based methods of sound generation, again emphasizing professional collaborations: “It will work something like this: after a composer has set down his score on paper by means of a new graphic, similar in principle to a seismographic or oscillographic notation, he will then, with the collaboration of a sound engineer, transfer the score directly to his electric machine” (cited in Manning 1985, 14). Like James Jeans’ 1937 on sound-curves, which emphasized that all sounds and other physical phenomena like barometric pressure could be expressed similarly through graphical methods, Varèse recognized the creative potential for artists as designers of curves or "workers of the line" (Jeans 1937, 11-12, 20; Brain 2002, 170).

Another early promoter of music-science collaborations, especially with the goal of new instrument design, was physicist and acoustician D. C. Miller. Miller, who became president of the new Acoustic Society of America in the early 1930s (Thompson 2002, 60), anticipated that "The science of sound should be of inestimable benefit in the design and construction of musical instruments... When the artist, the artisan, and the scientist shall all work together in the unity of purposes and resources, then unsuspected developments and perfections will be realized" (Miller 1937, 263-64). Miller also promoted a division of labor among collaborators: "Musical instruments are used for artistic purposes and their selection is ultimately determined by the aesthetic taste of an artist. When an instrument has been artistically approved, the physicist can describe its tonal characteristics and select other instruments possessing the same qualities" (Miller 1937, 211). This division of labor reflected the logic of synthesis, which was about separating tasks into distinct parts to achieve a unified goal.

Other composers soon took up the cause of promoting music and science collaborations, often specifically referencing the musical and social promise of electricity as a liberating force. Russian composer Joseph Schillinger, who came to America in 1928, collaborated with Leon Theremin on the design of his electronic musical instrument. Schillinger celebrated the application of science to musical ends in his 1931 article in *Modern Music*, “Electricity, A Musical Liberator” (Manning 1985, 7). Mexican composer Carlos Chavez echoed this theme in his 1937 treatise, *Toward a New Music: Music and Electricity*. Chavez had been commissioned by the Secretary of Public Education in Mexico to report on developments in electronic communication and sound generation in the U.S., and his findings became the basis of *Music and Electricity* (Chavez 1937, 8). Chavez wrote: “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” (Chavez 1937, 16).

To Chavez, the electronic production of sounds represented the most significant development in musical instruments in seven thousand years: “We received our present sound-material complete from pre-history. Electric instruments of sound production offer the first case in history of a new musical instrument. They contain (a) a new sound-agent, (b) a new manner of vibrating agent, and (c) a new means of controlling that vibration—in frequency (pitch), amplitude (intensity), and form (timbre)” (Chavez 1937, 140).

The conductor of contemporary music Leopold Stokowski was invited to deliver an address to the Acoustical Society of America in 1932, which he titled “New Horizons in Music.” He likewise promoted sustained dialogue between musicians and scientists in an increasingly technological society, discussed artistic implications of new sound reproduction and communication technologies like the phonograph and radio, and advocated further development of synthesized sound technologies for music composition. “One can see coming ahead a time when the musician who is a creator can create directly into TONE, and not on paper. This is quite within the realm of possibility... Any frequency, and duration, any intensity he wants... anything can be done by [technological] means and will be done” (cited in Manning 1985, 11).

In a lecture to the Seattle Arts Society in 1937, John Cage similarly advocated the development of new electronic instruments and their application toward the control of discrete components of sound. Cage heralded progress toward “a music produced through the aid of electrical instruments... which will make available for musical purposes any and all sounds that can be heard... The special function of electrical instruments will be to provide complete control of the overtone structures of tones... and to make these tones available in any frequency, amplitude and duration” (cited in Manning 1985, 13). This rhetoric recalls the desire in E. T. A. Hoffmann’s 1814 story for automata to be built from the knowledge of all tones, and to be designed so that these sounds may be called forth at will.

In his 1937 speech, Cage referred to “the synthetic production of music” and specified timbre (or “overtone structure”), frequency, amplitude, and duration as the four basic components of sounds. By 1957, he added a fifth component, “morphology,” or envelope, which he described as “how the sound begins, goes on, and dies away” (cited in Holmes 2002, 13-14). This is an example of the ongoing transfer of knowledge between composers and engineers during these decades—through direct visits or collaborations, public lectures, or published texts. At the time of Cage's 1937 speech, the four basic components of sound that he identified had yet to become standard features in electronic musical instruments. By 1957, after the development of the RCA Electronic Music Synthesizer, these four features as well as the fifth (envelope) had been incorporated, and Cage seemed to revise his theory to accommodate new developments in synthesized sound technologies. Cage in fact visited the RCA Laboratories with his associates David Tudor, Earle Brown, and Louis Stevenson in April 1955. Harry Olson demonstrated the synthesizer for them and reported that "They appeared to be highly impressed and pleased" (Olson 1955b).

One of Cage's most significant contributions to musical modernism was to reframe the relationship of music and sound. His insights helped to facilitate what composer and historian Joel Chadabe has called "the great opening up of music to all sounds": the widespread incorporation of traditionally nonmusical sounds and noises into Western music (Chadabe 1997, 21). Cage suggested that if all music was comprised of sounds, and all sounds were comprised of the same fundamental components, then all sounds could qualify as musical (Holmes 2002, 15). This was, in effect, a clever reformulation of the logic of synthesis designed to upend Western musical conventions: the whole is defined by its parts, and parts in turn constitute the whole. For Cage as for Varèse, synthesis technologies and techniques were not only compositional tools, but also potentially useful metaphors for modernist creative practices.

Synthesizer Instruments

Synthesized sound, as discussed throughout this project, refers to sound that is generated electronically by analysis and synthesis of its constituent elements. The term *synthesizer* refers to various musical instruments designed to generate and process a wide range of synthesized sounds. Synthesizers were developed initially as tools for composition for electronic music studios. These included the RCA Mark I and II Electronic Music Synthesizers of the 1950s, which used a punched paper tape system to control oscillators, noise generators, and signal processors; early prototype electronic instruments developed by Hugh Le Caine in the 1940s and '50s; and a modular signal processor developed by Harald Bode in 1959-60 (Olson and Belar 1955; Bode 1984; Young 1989).

Robert Moog, Don Buchla, and Paolo Ketoff developed voltage-controlled synthesizers in the mid-1960s, independently of each other; these made use of new, more affordable semiconductor technologies. These early voltage-controlled synthesizers were oriented toward studio composition rather than live performance, and employed a modular structure that enabled several individual devices to be interconnected by patch cords in a variety of configurations. These analog synthesizers used continuously varying voltages to model and transform sound waves; they were modular in structure, consisting of "an assembly of electronic devices that may be interconnected in a variety of patterns to generate and modify sounds through the agency of interacting voltages. The combination of devices available, the manner in which they are connected, and the way in which the user controls their operation may differ widely from one model to another" (Davies 1984b, 484-85). The principle of voltage control enabled automatic and complex manipulation of all specified properties of sound, including frequency, envelope, amplitude, and timbre (Moog 1964; Strange 1972). Voltage control made the process of synthesizing sound and composing electronic music more efficient than previous methods. It supplanted the previous, more laborious studio practices of tape splicing and punch card composition. However, setting up patches still took time, and early synthesizers tended to be limited to producing one note at a time (Davies 1984b, 485).

A new generation of synthesizers in the 1970s were designed for live performance; these were generally smaller and incorporated fewer component devices than their predecessors. Previous patching systems were replaced by hard-wired configurations. This made for simpler and more reliable execution of sounds, but embedded more standards into a synthesizer's design, restricting the performer's ability to interconnect components and reconfigure the organization of the instrument. Polyphonic synthesizers were introduced in the mid-1970s, and around the same time digital components were increasingly incorporated into synthesizers to control analog processes. Digital synthesizers tended to have a more fixed design structure than analog modular synths (Davies 1984b, 484-85).

Fully digital synthesizers were introduced by the early 1980s, and the Musical Instrument Digital Interface (MIDI) protocol was adopted by a consortium of manufacturers to ensure compatibility between instruments (Théberge 1997, 89). The use of general-purpose microprocessors in synthesizers represented a new kind of design constraint in that many different synthesizers shared common microchips with similar technical features. Additionally, the predominance of microchips in synthesizer design tied technological developments in synthesized sound more tightly to the agendas and vagaries of the computer industry (Théberge 1997, 60).

This chapter has outlined a prehistory of these modern synthesizers by reviewing cultural notions of synthesis and the synthetic, a history of analytic tools and material devices that prefigured modern synthesis techniques and synthesizers, and the formation of social and professional networks in music composition, audio engineering, and electronics tinkering. When modern synthesizers emerged in the twentieth century, they were intelligible to their inventors, users, and cultural observers through metaphors in audio-technical discourse such as those outlined in previous chapters. The concluding chapter examines how, despite the long view of synthesis history presented in this study, historical accounts often start with Bob Moog's contribution to the popularization of synthesizers in the 1960s and after. I suggest that it is the operation of gender in audio-technical discourse that frames Moog synthesizers as a revolutionary break in the history of synthesized sound, rather than as technologies that inherit many overlapping historical currents.

6. CONCLUSION: TINKERING WITH HISTORY: GENDER AND THE POLITICS OF PERIODIZATION

> After listening to your recent recording of synthetic music, I have become very interested... I am very curious to know and understand the principle of this machine.
> – Shirley Stroffolino, letter to RCA (1956)

There are many ways to construct a history of synthesized sound and associated musical instruments; a key question of method involves the discernment of originary moments and significant periods. Given the long and winding history of ideas and machines outlined in the previous chapter, which is "at once too much and too little" to adequately represent the history of synthesized sound (Foucault 2001, 227-28), why do existing histories tend to begin with Robert Moog's contributions?

Moog's development of popular and portable synthesizer instruments in the 1960s were certainly greeted with widespread enthusiasm; already in 1969, the *New York Times* announced that "The Moog music synthesizer... is coming to stand in the public's mind for all music synthesizers" (Henehan 1969). The Moog company sought to brand themselves with this kind of universal recognition, evidenced in a 1979 advertisement in *Contemporary Keyboard* magazine. A photo of the Minimoog was accompanied by neither the company's nor the instrument's name, only the caption: "You know what this is... because you hear it everywhere" (Moog Minimoog 1979). Even more in retrospect, Moog's innovations have been heralded as a revolutionary moment in the history of musical instruments and a foundational moment of the contemporary electronic soundscape, as in this account by the science and technology scholar Trevor Pinch:

> Something remarkable happened between 1960 and today. The world back in 1960 was a lot quieter... Today, however, we are saturated with electronic sound... The origins of this electronic soundscape can be traced to one engineer, Robert Moog (known affectionately by everyone in the field as Bob Moog) and his invention of the synthesizer... Much of the technology for making new electronic sounds is descended from this first commercial device for making electronic music, the Moog synthesizer (Pinch 2008, 470; see also Pinch and Trocco 2002b, 67).

In their important study of the invention and impact of the Moog synthesizer, Pinch and Frank Trocco emphasize how the popularization of synthesizers formed part of a "revolution in sound" in the 1960s. The authors suggest that when Moog was building his prototype synthesizer in 1964, "working with synthesizers was seen strictly as a weird and marginal activity" carried out by esoteric, avant-garde composers, and "it was not at all clear that the synthesizer would appeal to a mass market" (Pinch and Trocco 2002a, 6, 52). Elsewhere, the authors assert that "the advent of the synthesizer is one of those rarest moments in our musical culture, when something genuinely new comes into being" (Pinch and Trocco 2002a, 6).

These narratives bear a striking resemblance to the version of history that has long been promoted by the Moog company. The advertising copy for the Minimoog, the portable synthesizer introduced in 1969, reads:

> R.A. Moog, Inc. built its first synthesizer components in 1964. At that time, the electronic music synthesizer was a cumbersome laboratory curiosity, virtually unknown to the listening public. Today, the Moog synthesizer has proven its indispensability through its widespread acceptance. Moog synthesizers are in use in hundreds of studios... throughout the world... The basic synthesizer

> concept as developed by R.A. Moog, Inc., as well as a large number of technological innovations, have literally revolutionized the contemporary musical scene, and have been instrumental in bringing electronic music into the mainstream of popular listening (cited in Dunn 1992, 21).

Here again, Moog's work is promoted as revolutionary and visionary.

These claims that synthesizers were "virtually unknown to the listening public" or seen as "weird and marginal" before the mid-1960s are challenged by archival materials on synthesizers developed by RCA in the 1950s, which document the widespread appeal of synthesized sound at least a decade before Moog built his prototypes. The engineers Harry F. Olson and Herbert Belar developed two versions of the Electronic Music Synthesizer as part of their work at the RCA Acoustic Research Laboratory, which Olson directed from 1934 until his retirement in 1967 ("Biography" 1982, n.d.). The second synthesizer (the Mark II, or "Victor" Synthesizer) was installed in the Columbia-Princeton Electronic Music Studio by the end of the 1950s and used by music composers and students who were affiliated there. The uses of the RCA Electronic Music Synthesizer in avant-garde and experimental compositions by Milton Babbitt, Otto Luening and others is well-known and documented (Chadabe 1997, 15-18, 45-47; Peyser 1970). However, a case can be made that the RCA synthesizer—that "cumbersome laboratory curiosity" called out in the Minimoog advertisement, and likewise dismissed as "a massive and very expensive brute that sat in the... laboratory" by a *New York Times* article celebrating the arrival of the portable Moog (Schonberg 1969)—was in fact a popular instrument that reached receptive audiences far beyond the avant-garde. Rather than marking the "end of the era of the early electronic instruments," as the electronic music historian Joel Chadabe suggests (Chadabe 1997, 18), the RCA synthesizer did much to consolidate a market of listeners who were interested in synthesized sound and curious about the technicalities of its production.

Although it was never mass produced and remained unseen in person by most Americans, the circulation of the RCA synthesizer's sounds on recordings, RCA's efforts to teach the public about the instrument, and prominent media coverage of its demonstrations consolidated a new market of listeners and consumers who embraced synthesized sound as a useful element in music and an acceptable medium of new musical instruments. RCA, anticipating and catering to popular reception of the synthesizer's sounds, crafted a careful mix of familiar musical selections on the synthesizer's 1955 demonstration record to appeal to a wide range of listeners (Olson 1955a; "The synthesis of music" 1955, n.d.). The liner notes to the album contained detailed information on synthesis terms and techniques, including sections on "The Physical Properties of Musical Tones" and "Synthesis and the Musician" (*The Sounds and Music*... 1955). The record was released as an LP as well as in 45 RPM format, so that it could be played in jukeboxes; the LP version sold about 6500 copies and the 45 several hundred more ("Synthesizer records sold" 1957, n.d.). The synthesizer was also featured in local and national news reports ("Electronic synthesizer" 1955; Plumb 1955a and 1955b).

By the mid-1950s, many Americans had heard electronic sounds before and were beginning to hear them more often and in diverse contexts. To name a few examples: numerous experimental and popular electronic musical instruments were accounted for in a journal article by the inventor Benjamin Meissner in the 1930s (Meissner 1936); the Theremin was featured in film soundtracks and space age pop music by the 1950s; Louis and Bebe Barron used their own custom-built analog circuits for the soundtrack to *Forbidden Planet* (1956); and Raymond Scott's electronic instruments were heard in numerous commercial jingles by the early-1960s (Taylor 2001, 72-95; Wierzbicki 2005; Winner and Chusid 2000). Before the 1950s, several electronic instruments used oscillators but not techniques of synthesis. As I have noted, there was also much fluctuation in terminology for what is now referred to as "electronic music"; terms like "electric" or "synthetic" were more commonly used before 1950. Through instructional content on the demonstration record, and popular and professional publications on its design, RCA did much to register the terms "electronic music" and "synthesizer" in the public imagination, terms that are commonly used today (and associated with Moog's contributions to the field).

Americans were curious to understand how the RCA synthesizer worked —and many of those who showed interest were women. Soon after a demonstration of the synthesizer was reviewed on the front page of the *New York Times* in 1955, and recordings of its sounds were distributed on the demonstration record through RCA's catalogue, letters of praise and interest poured in from around the United States to Olson, the synthesizer's lead developer (Plumb 1955b; Fisher, Tucker, and Whiteley 1956). He received several letters from women in high school and college expressing interest in and requesting technical information about the synthesizer, indicating that young women represented an early and eager market for these instruments. Women and girls' contributions to American popular music, especially in the late-'50s and '60s, are often recognized in areas of fan cultures and vocal performance in girl groups (Douglas 1995, 83-98, 113-21; Gaar 2002, 31-62). Their interest in the RCA synthesizer is part of another, lesser known, historical trajectory: of women and girls interested in audio technologies, electronics tinkering, and music production (Taylor 2001, 80-81; Pease 1978; Sandstrom 2000; Rodgers 2010).

In 1956, Olson received letters of inquiry from Doris Dailey, a high school senior who would win accolades for her presentation on the RCA synthesizer at the Ohio State Science Day, and Shirley Stroffolino, another student requesting information about the new "synthetic" music. "I am very curious," Stroffolino wrote, "to know and understand the principle of this machine." Florence Perrella, who studied the RCA synthesizer for her undergraduate thesis in 1956, wrote to Olson: "Electronic research has brought unimagined resources to music." She pressed him to reconsider the machine's purpose: "Since any conceivable sound can be dialed in, how come the synthesizer is used to imitate existing instruments? I had hoped to hear new sounds" (Dailey 1956; Stroffolino 1956; Perrella 1956). Olson responded to these letters with equanimity: he tended to send everyone—

from music historians to fellow inventors to women in high school and college—a reprint of his 1955 article on the synthesizer, coauthored with Herbert Belar in the *Journal of the Acoustical Society of America*, with an accompanying personal note.

Yet, at the same time that letters were arriving from young women around the country, Olson recommended to RCA's marketers that they place advertisements about the synthesizer and its recordings in magazines about hi-fi audio and electronics engineering, which was perhaps a move to direct the emerging market for synthesizers toward men who were technical experts and hobbyists (Olson 1956; Keightley 1996; Taylor 2001, 78-81). For Olson, this was likely an unreflexive expression of the homosocial engineering cultures and gendered divisions of labor in offices of which he was a part. While younger women were indicating enthusiasm and a burgeoning knowledge of electronics in their letters to Olson, women were not, or were rarely, among the audio engineers he would have encountered in the RCA laboratories and professional societies. For example, in a typed document from 1955 detailing the necessary equipment and personnel for installing the RCA synthesizer at a new studio, the one "female operator" responsible for administrative duties was crossed out by hand, determined by Olson or one of his colleagues to be dispensable, while other (unmarked and presumably male) workers in supervisory or technical roles remained (Lynn 1955). Historians have documented well the extent to which audio engineering and hi-fi cultures in the 1950s were predominantly a male preserve (Keightley 1996), but the RCA archives indicate that men were not the only ones reading these magazines. A student named Sonja Carlson sent a letter to RCA in 1956, requesting more information about the synthesizer for a physics project: "I recently read in a Hi-Fidelity Magazine that RCA has developed an Electronic Music Synthesizer," she wrote. "The article stated that it has an unlimited capacity for duplicating sounds... and creating new sounds to order." Carlson was interested in obtaining more details about the machine's development as well as "its place in society" (Carlson 1956).

Women could have been a logical market for the RCA synthesizer in the 1950s in that the technology and associated techniques of the synthesizer "patch," the configuration of wires that assembled component elements of a sound into one signal, was inherited from telephone operating. Telephone operators, of course, were often women; they were also a cyborg figuration, as partially-human and partially-technologized nodes in a network:

> The telephone operator antedates the cyborg, a plastically gendered creature formed of electrical wiring and the organic body... The female body hidden at the heart of a national communications network... is an archetypal figure. In popular culture the operator was often treated as a heroine who, knowing everyone's habits, could bring people together in emergencies: the operator as matchmaker, lifeguard, or angel of mercy. (Peters 1999, 196).

Twenty-four telephone operators were chosen from among three hundred applicants to demonstrate the Voder, a machine for synthesizing speech developed at Bell Laboratories, at the 1939 World's Fair—a testimony to the prominence of telephone operators in popular culture, and to the articulation of telephone and synthesis technologies. Many (and perhaps all) of these operators at the World's Fair were women; they were directed, like players in an orchestra, by an engineer from Bell Labs ("the man with the microphone," according to a newspaper account) who sought to attract crowds (Davies 1939). This gendered performance dynamic at the fair suggests that while telephone operating demanded significant technical expertise, it was still dismissed as a backgrounded, administrative task compared to the expertise of male engineers.

Indeed, despite the presence of women in these analog technocultures, synthesizer histories tend to locate origins and revolutions in electronic music within male homosocial audio engineering and electronics tinkering cultures (Pinch and Trocco 2002; Pinch 2008, 471). The letters from women in the RCA archives, and the technical continuities between telephone operating and analog synthesis methods, suggest that there were other possibilities for an earlier broad-based market for synthesizers, and certainly for the foundation of an audio-technical culture that was more inclusive of women as composers, musicians, and engineers.

Why are Moog-centered narratives so compelling that academic and journalistic histories substantially reproduce the promotional copy of the Moog company about Moog's "impact"? As the composer and inventor Daphne Oram concluded regarding histories of technology: "I wonder why we want so much to see one man as the hero of the occasion" (Oram 1972, 111; see also Paterson 2010). Moog himself was a reluctant subject of history, reflecting in the final years of his life on his success by suggesting that, given all the contingencies of technological invention and development, he just as well may have gotten where he was by "slipping backwards on a banana peel" (Fjellestad 2005). There is a clear affection among historians and other cultural observers for the humble hobbyist and tinkerer—"known affectionately... as Bob" (Pinch 2008, 470)—"quietly beginning a revolution" (Holmes 2002, 61) in contemporary music.

As an "impulse to rearrange technological details" through do-it-yourself projects and technological enthusiasm, tinkering was a way for white, middle-class men to carve space for themselves in what they perceived to be an increasingly feminized and isolated space of mid-century, American suburban homes (Waksman 2004, 675, 677-78). With its emphases on non-teleological technological explorations and the detailed craft of the handmade, tinkering appropriated values of hobbies and handwork typically associated with women (Rodgers 2010, 147). The notion in histories of synthesized sound that an everyman-as-tinkerer could become a great man of history reflects a certain hopefulness and desire that the genius of male invention and innovation may not require formalized training or even intent, but just "mucking around" at the workbench with an eagerness for exploration and discovery. Metaphorically speaking, we might translate this as a desire to be tossed by the waves, and overcome their unpredictabilities with clever navigation and demonstrations of mastery. Under this logic, what otherwise might be considered to be technological ineptitude or failure, or mere accidents of the overlapping waves of history, can be recuperated as male innovation and/as cultural revolution (Rodgers 2010, 7-8, 249).

As Ruth Oldenziel has written, “technology is a narrative production and plot of our own myth making” (Oldenziel 1999, 18). The term *technology* itself was defined more broadly in the nineteenth century, encompassing a broad range of material practices and social actors. Only in the 1930s did the term become widely used to designate “the useful application of scientific knowledge,” with white, middle-class, male engineers as the primary bearers of that knowledge. Its formation as such a neutral-sounding term was in fact a social process, highly contested along lines of gender, race, and class (Oldenziel 1999, 14, 51-52).

The history of synthesized sound is likewise a narrative production and myth-making process. Traditionally, feminist historiography of technology has entailed recovering the experiences and cultural contributions of women, and I have carried out this work elsewhere through ethnographic research with women who are electronic musicians and sound artists. Throughout this project, I have argued for the need to also address the politics of representation in audio-technical discourse. Doing so enables us to understand how epistemologies of electronic sound have worked to normalize white men as the subjects of history and culture. It also reveals how social differences such as those of gender and race are built in to common technical terms and technological forms that are perceived to be objective or neutral. I have shown how metaphors of electronic sounds as waves and as individuals have been a site for the production of identity and difference, and a condensation of social worlds and relations, in the realm of sound. I have also argued that there are spaces within audio-technical discourse, including certain inflections of wave and synthesis metaphors, from which feminists may imagine, through situated perspectives, novel portrayals of worlds and possibilities for their improvement. Finally, I have focused on the multiple and overlapping prehistories or historical "waves" that inform contemporary ideas and machines of synthesized sound in order to foreground the contingencies of received truths in audio-technical discourse, and resist the linear and coherent progress narratives that often characterize histories of technology and new media.

My inquiry remains grounded by my own speculations and experiences in electronic music and sound art practice, and those of the artists I interviewed in *Pink Noises.* The performer and sound artist Laetitia Sonami recalled the first time she heard a Putney VCS3 synthesizer as a student in the 1970s: "I was like, Wow, what is that?... There was this whole sense of magic, of electricity producing sounds in ways I could not fathom" (Rodgers 2010, 227). Wonder can be a starting point for critical consciousness and politicized movement, as Sara Ahmed has implied in her work on the cultural politics of emotion: "The surprise of wonder is crucial to how it moves bodies... wonder involves the radicalisation of our relation to the past, which is transformed into that which lives and breathes in the present" (Ahmed 2004, 180). Sonami, for example, was motivated to design and build an instrument that respects how technology is "a projection of our dreams, illusions, desires" rather than one that reduces it to an expression of “macho” control (Rodgers 2010, 231). This dissertation is likewise motivated by a certain wonder at the potential for audio-technical discourse and synthesis technologies to represent worlds, and represent them in better ways. Alfred North Whitehead cautions that philosophical understanding will indeed pierce the blindness and the transcendent functions of the activity in question, yet: “Philosophy begins in wonder. And, at the end, when philosophical thought has done its best, the wonder remains” (Whitehead 1968, 168).

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