JONATHAN STERNE and TARA RODGERS

The Poetics of Signal Processing

An electronic musician sits onstage, amid a maze of small boxes and cables, and twists knobs as the sound coming out of the speakers slowly morphs and changes. A sound artist hunches over her laptop, working intently with custom software objects. As she clicks a slider on the interface, the sound is transformed. Elsewhere, an automated switch system connects two wireless phone calls. A hard-of-hearing caller puts the mobile phone to his ear and experiences distracting static as it interacts with his hearing aid. At a house party, someone plugs a karaoke machine into a home stereo; it removes the vocal track so that partiers can sing along with backing tracks. The next day, the same system will decode a 5.1 format DVD for listening through stereo speakers. A forensic specialist "cleans up" an audio recording for a trial by removing some background sounds and highlighting others. A radio station compresses a song so that drivers will hear their broadcast as if it were louder than their competitors when flipping through the dial. Some of those drivers now have noise-cancellation systems in their cars that help eliminate the

Volume 22, Numbers 2 and 3 DOI 10.1215/10407391-1428834

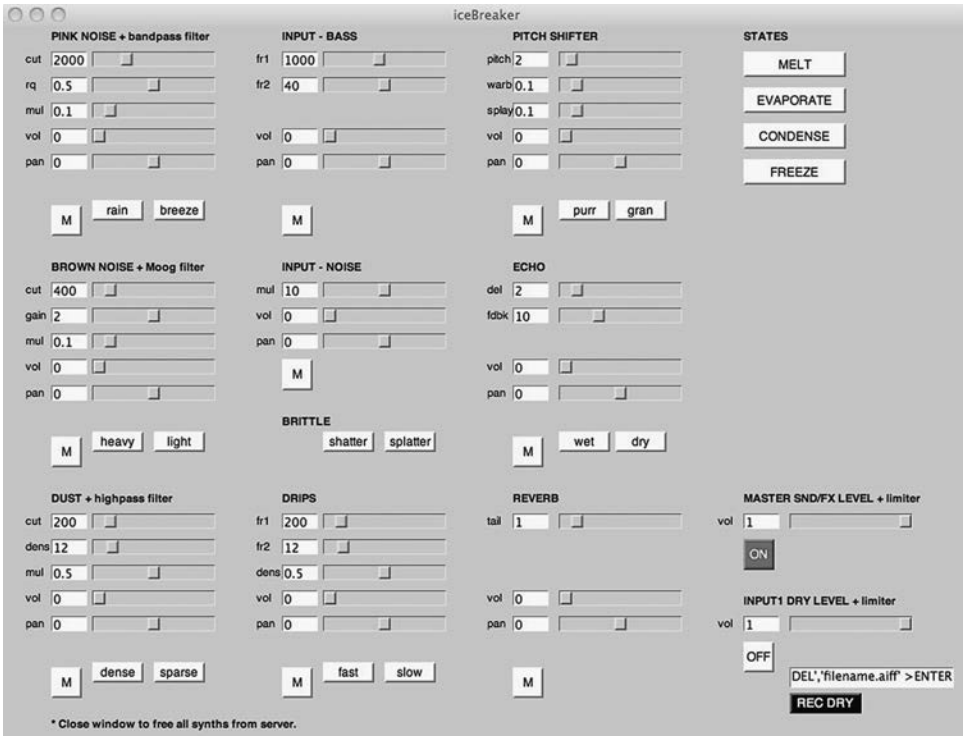

Figure 1
The Poetics of Signal Processing
A sound synthesis and processing interface in the open-source environment SuperCollider, designed by Tara Rodgers for Owen Chapman's *Icebreaker* project in 2009. Ice and water sounds are processed with noises and effects that evoke associated state changes: melting, evaporating, condensing, and freezing. http://icebreaker.opositive.ca/

drone of road noise, similar to the kinds found in headphones worn on flights across the world.

Each of these scenarios involves signal processing, perhaps one of the most important and understudied dimensions of contemporary sound culture, and electronic and digital media technologies more generally. In electrical engineering, signal processing involves the mathematical modeling of signals over time and through circuits, which then allows for their modification. Sometimes there is a person actively doing the modifying. Sometimes the process is automated. Along with Georgina Born and Mara Mills, we have argued for the centrality of sound technologies in the history of twentieth-century signal processing and, conversely, the centrality of signal processing in the history of sound (Born; Mills, "Deaf" and "Hearing"; Rodgers, *Synthesizing*; Sterne). Scholars in science and technology studies and related fields have also considered signal processing—not always by name—as central to the story of cybernetics and to knowledge construction more generally in the twentieth century (e.g., Edwards; Galison; Hayles; Mindell). But our goal in this essay is not historical—it is interpretive.

Signal processing is itself a term with a complex and politically loaded history. Mills's essay in this issue offers a nice account of the relationship between signs and signals in engineering discourse. In conventional professional usage, signal processing presupposes a distinction between an electrical, electronic, or digital signal that is manipulated, and the meaning and content of the signal (see Nebeker). Thus the signal has a certain materiality to it—it takes up space in a channel or in a storage medium, and it is an object that can be manipulated in various ways. Although cybernetically inflected thinkers have sought to subsume all of communication and social action under the rubric of information and signals, we would follow writers like Tiziana Terranova who resist this impulse. For us, signal processing involves actually manipulating sound in a transduced state—when it exists in electrical or digital form, in a moment before it is heard, or as part of the process of hearing. Signal processing happens in the middle of technologized transmissions of sound. Although signal processing can involve interpretation, it is not itself the same thing as interpretation, nor is interpretation reducible to signal processing.

In the following pages, we consider two different metaphorical frames commonly applied to signal processing in the everyday language of users and makers—cooking and travel. If we had more space, we could consider other common metaphors of signal processing, like games and play; as an advertisement for a new Moog iPhone and iPad app declares: "Filtatron is not a toy, but go ahead and play with it anyway." Each metaphor elucidates, figures, or for that matter "processes" a different aspect of what is at stake in audio signal processing. Each might nudge us in productive or problematic directions when thinking about the relationship of sound and media, or otherwise advance various agendas in sound scholarship. Our argument is grounded in the sonic register and its various electrical and digital transductions, but even if it is rarely named in some registers, signal processing is equally crucial to the experience of visual, olfactory, tactile, and culinary technologies (e.g., Belasco; Bud; Hillis; MacKenzie; Marks; Mudry; Parisi; Rodowick). Chapters on the cultural dimensions of signal processing could be important additions to histories of almost any modern media technology, including technologies like cars and thermostats that have mediatic dimensions but are not themselves "media" in any conventional sense. We hope those tales will be told in coming years.

Signal processing touches almost every sound or image that reaches subjects' senses through an electronic medium, whether analog or digital. In the sonic register, signal processing happens in sound

recording, editing and mixing, artistic creation, wired or wireless transmission, musical performance, radio broadcast, everyday conversation, playback, and listening. It is in computers, telephones, radios, CD players, home and car stereos, portable audio players, mobile phones, baby monitors, televisions, movie theaters, video game consoles, and children's toys. It is one of the most ubiquitous aspects of modern sound culture, a veritable obsession among the people who make sound technologies, whether hardware or software, and one of the burgeoning fields of inquiry in academic music and speech pathology departments. It is also one of the core metaphors through which psychologists explain the process of hearing itself. Brian C. J. Moore's standard textbook discusses, among other things, "impedance-matching" in the middle ear (51), which metaphorizes it as an electrical circuit. Moore in turn draws on work including Peter Lindsay and Donald Norman's *Human Information Processing*, which explicitly connects cybernetic theory, computer processing, and human consciousness (10–11).

Yet with some notable exceptions that we discuss in this essay, signal processing has garnered scant attention in sound studies in the humanities and interpretive social sciences. The reasons for this lack of attention appear to be a result of fairly ordinary conditions of the disciplines. The centrality of signal processing has thus far been oblique to sound studies in part because of the social distance between the humanities and interpretive social sciences and the fields where signal processing is most important—even in many music departments, where the possibilities from crossover exist, but in practice composers and musicologists can be worlds apart. Signal processing is, for instance, a major topic in electrical engineering and computer science. Besides its presence in core curricula in those fields, it can also be a point of pride. One of our colleagues whose office is in a university engineering building works across the hall from a giant "Fifty Years of Signal Processing" banner. But how many people outside engineering and the sciences will ever see that banner? Although the role of media and other technologies is widely acknowledged in sound studies, scholars are still more likely to emphasize the *fact* of mediation (in contrast to unmediated sound) over its consistency, and they are likely to use models like the circuit of culture, which separate the moments of production, circulation, and consumption and thereby obfuscate something like signal processing that is in the middle of all three moments. Thus when signal processing does appear in sound studies, it tends to appear in other forms.

Signal processing happens in the middle of media. Signal processing is not exactly the domain of musician, playback technology, or listener but rather exists within all three and in the interstices between them. For a vocalist in a recording session who asks the sound engineer to add reverberation effects to her headphone monitor as she is laying down a track, her sense of her voice reverberating in a processed space is integral to her performance. When signal processing modulates recorded sound or music—as in the cases of an equalization technology that subtly boosts the bass frequencies of a single kick drum in a mix or a spatialization algorithm on a home speaker system that makes the entire playlist on an iPod sound like it is being projected in a concert hall—the effects tend to be heard as inseparable from the sound and music itself. It is this very embedded aspect of signal processing in all stages of contemporary sound production, reproduction, and reception that makes it an elusive subject of critique.

In referring to the *poetics* of signal processing, we mean to invoke three senses of the term: 1) signal processing itself as a type of figuration, 2) the use of metaphor to represent signal processing (which is the main focus of our essay), and 3) the places where the intersections between these two forms intersect with some political effect. Thus, while we follow Albin Zak in gesturing toward Aristotle's broad sense of poetics as "making," we do not begin from mimesis or imitation (Aristotle and Butcher 147a, 147b). In the first instance, signal processing deals with life in a *transduced state*, a transformation of sound into something—electricity, digits, states on a hard drive—that can be manipulated for the purposes of expression, figuration, or representation. We begin from the proposition that others have already specified components and meaningful dimensions of signal processing, and by analyzing these components as themselves carrying metaphorical and rhetorical weight, we can better understand the kind of stories and meanings that get built into our technologies. Like cooking food, processing signals carries with it a basic set of cultural meanings (Zak xv–xvi).

"The poetics of signal processing" thus refers to the figural dimensions of the process itself as well as the modes through which the process is represented in audio-technical discourse. In the term *audio-technical discourse*, *discourse* references "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 34). The modifier *audio-technical*

encompasses the 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 and engineering, and electronics hobbyist cultures. In the rest of the essay, we consider two metaphoric constructs of signal processing to get at the phenomenon on two different levels. Our consideration of the prevalence of rawness metaphors aims at how everyday engineering talk represents the work of signal processing and elevates it as a kind of culturing process, a readying for the consumption of sound by others. In the subsequent section, we turn to spatialized representations of signal processing as a voyage, where its elements are represented as points on a map. We can subject these spatial representations to the same kinds of interpretive frames one finds in the critical analysis of landscapes, maps, or travel narratives. Taken together, we hope our explorations inspire others to ask after the status of signal processing in broader circuits of media culture and communication and to further subject actual techniques of signal processing to the critique of representation.

A Sonorous Cuisine: The Raw and the Processed

The language of cooking is everywhere in audio-technical discourse. In audio, rawness is not a form of purity but a relative condition, a readiness to hand, an availability for subsequent processing. Musicians and engineers will describe the "raw" tracks for an album, which may be made up of recordings of individual instruments or even parts of or perspectives on particular instruments, as when an engineer puts ten microphones on a drum set or two on an acoustic guitar, with each going to its own individual track on a tape machine or comprising a separate sound file inside a folder on a hard drive. Raw tracks are for mixing, for processing, and for transforming. Musicians and audio engineers talk of "slicing" and "dicing" sound samples in creative ways (Iced Audio; Kelly). Recording artists post "raw tracks" on the Internet so fans can remix them in new ways: "For years, [Trent] Reznor has been releasing music via the web—first offering his work in bonus formats (so fans could remix the raw tracks), then in an ever-growing number of additional forms" (Price). "Radiohead has announced that their new single, 'Nude,' has been released—with the remixable raw tracks packaged alongside the single! [. . .] 'Nude' comes with bass, vocal, drum, guitar, and strings/effects tracks all separated for your

mixing pleasure" (Shambro). The title "Nude" is not insignificant here; like an artistic rendering of a naked figure, the parts of the song's "body" are stripped bare and isolated in the studio as objects of aural pleasure. One of our concerns in this essay is to denaturalize the subject positions produced in audio-technical discourse. To treat "raw" tracks as passive material to be "done" through technologized processes of composition, indeed, reflects a particular gendered orientation to music technology, where the process of composition is normalized as a male performance of technological mastery. As Paul Théberge has documented, music technology magazines and advertisements address a community of readers that is assumed to be largely young and male, and these publications routinely associate electronic music machines with seductive, female sexuality. They cast music technologies as vehicles for the experience of sonic pleasure and for the performance of technological control (122–25). The tendency identified by Théberge continues in many music magazines today, and it has proliferated across online fora and Web sites dedicated to music production, equipment, and software. In this cultural context, the "rawness" of stripped-down tracks can get folded into tropes of sexualized objectification, availability, and malleability; raw tracks can be cast as feminized, passive material to be actively controlled via specialized technologies and techniques of the masterful composer/producer.

The language of the raw and cooked also permeates discourses of sound synthesis, where processing again figures as an expression of creative control. An oscillator generates a sound that is called raw until it is run through filters, amplifiers, and other sound shapers. In his history of electronic and experimental music, Thom Holmes notes that all analog and digital synthesizers have the same basic components, beginning with "[t]wo or more oscillators for generating raw sound material," which then pass through filtering and amplification processes (152–53). One finds the same discussion of the raw sounds of oscillators in numerous electronic music textbooks and synthesizer manuals. A description of the RCA Electronic Music Synthesizer, a precursor of contemporary synthesizers housed at the Columbia-Princeton studios beginning in the late 1950s, reads: "Oscillators and noise generators provide the raw materials which the composer [. . .] can obtain at will with a high degree of control over pitch, timbre, and volume" (Griffiths 68).

As with the case of recorded tracks, rawness is a relative condition, a readiness for processing and not simply the presence of sound in nature or sound in the world. This is an important distinction. As Sterne

awkwardly types this sentence in the third person, he listens out the windows of his office. The whistling wind, birds chirping, and the murmuring expressway in the distance outside his window are precisely not raw. They could be meaningful in many different ways. They may, however, become either prospectively or retrospectively raw if he launches a sound recording program in his computer, captures them with the built-in microphone, and then processes them into an ambient music composition later on (http://sounds.sterneworks.org/rawandcooked). The car noises, wind, birds chirping, and mouse clicking are all potentially meaningful sounds and will offer the standard polysemic cornucopia of potential interpretations depending on who is hearing. Obviously, the sounds mean different things to passersby, traffic engineers, deer, and birds—as well as different things to different subjects within those groups. But in this example, their rawness comes from their availability for signal processing, just as raw food or raw material becomes raw by virtue of its availability for cooking or manufacture. A lettuce planted in the ground, a mushroom hidden in a forest, and the tree nearby are not raw in the same way.

This follows a more general point Martin Heidegger makes in *Being and Time* about contemplation and availability, though he does it in standard visualist language. "No matter how sharply we just *look* at the 'outward appearance' of Things in whatever form this takes, we cannot discover anything ready-to-hand. If we look at Things just 'theoretically,' we can get along without understanding readiness-to-hand. But when we deal with them by using them and manipulating them, this activity is not a blind one; it has its own kind of sight, by which our manipulation is guided and from which it acquires its specific Thingly character" (98). Raw sound is sound that is ready-to-hand, that is available to be processed. It comes not to the sonic world as it is contemplated, but rather, rawness emerges from a relationship to the sonic world where sounds are used and manipulated (the latter word containing within its etymology a reference to the hands and to bundling up). Heidegger's examples from this part of *Being and Time* are decidedly not high tech, and our application here may be something of a stretch given that our examples so far have involved specialists. But although signal processing is a specialized term, we would be wrong to relegate it to something of import only to geeks in music departments and engineering schools. Media criticism has become a standard practice across the humanities. We are simply arguing for the inclusion of signal processing within that critical lexicon, for in many cases it is just as important to the meaning of mediatic sound as the notes

in a score, the choice of violins in a movie soundtrack, the words said or unsaid in a phone conversation. Signal processing is also increasingly something that nonspecialists do, from children playing with Garage Band or sound-making toys to drivers and airplane passengers switching on noise-cancellation devices. Heidegger might have objected to the entire proposition of signal processing, but it played a conditioning role in his experience every time he picked up a phone, saw a film, or turned on the radio or television.

As with rawness, one finds a language of decay and rot with respect to sound. Over the course of the twentieth century, the "decay" of a sound from its peak volume to silence became a common signal processing effect to be manipulated electronically (Bode). Even sonic "rot," an extreme form of distortion, is now available in the form of at least two guitar effects: pedals and boutique synthesizers (Dwarfcraft; Pro Tone). The treatment of sounds as materials to be processed and preserved for future use emerged in the late nineteenth century alongside techniques for canning and preserving food (Sterne, *Audible* 292–93; see also Josephson; Koehn). Techniques for processing and preserving food guarded against premature rot and decay and made fruits and vegetables available year-round rather than in a limited season. The fading of the human voice signified the fleeting qualities of organic life and was understood to be "a distinguishing mark of human temporality and finitude" (Peters 177). Electronic processing techniques were a means by which relatively ephemeral acoustic sounds gained extended shelf lives, so to speak, through the possibilities of electronically mediated repeatability and aesthetic transformation. These examples suggest that both processed foods and processed sounds have been shaped by desires to technologically prolong and control organic life—whereby "raw" or unprocessed sounds (like their counterparts in the realm of food) are typically articulated to the organic or natural and contrasted to their technologically mediated or "artificial" instantiations.

The many references to rawness, rottenness, and cooking recall Claude Lévi-Strauss's classic *The Raw and the Cooked*, which directly addresses the relations among these terms (and their semiotic relatives) at great length and in much technical detail. Often cited and often criticized, *The Raw and the Cooked* used the triad of raw-cooked-rotten as the basis of an attempt to demonstrate the power of structuralism to explain the workings of diverse cultures. Less often remembered is that *The Raw and the Cooked* is full of musical and sonic metaphors. The entire book is organized around terms derived from the Western concert tradition—for

example, *theme and variations*, *sonata*, *fugue*, *symphony* (vii–viii)—and Lévi-Strauss frequently resorts to references to sound, silence, and noise (e.g., 147–50, 286–89, 327–29). Our interest in semantic connections between talk about sound and talk about food mutates connections he made long ago.

Lévi-Strauss argues that "native thought" conceives of "culinary operations as mediatory activities between heaven and earth, life and death, nature and society" (64–65). In Lévi-Strauss's analysis of indigenous myths, there is a "double contrast: on the one hand, between what is raw and what is cooked, and on the other, between the fresh and the decayed. The raw/cooked axis is characteristic of culture; the fresh/decayed one of nature, since cooking brings about the cultural transformation of the raw, just as putrefaction is its natural transformation" (142). As with Heidegger, we only want to sample a morsel from this text, rather than digesting the entire argument in one sitting. His claims about the transcultural workings of myth, the structuring power of language through binary operations, and the relationship of indigenous and industrial societies are a little too rich for us. We take Stephen Mennel's point that despite the ambitions of structuralists to disclose the deep structures that lie below all of society, they offer no grounds for predicting the unfolding of hitherto unknown social structures and instead "offer mainly a classificatory scheme and not an explanation" (13; see also Bourdieu; Goody; Ross). Following Norbert Elias, Mennell argues for a more "sociogenetic" sociological approach that does not "look behind flow and process for something which is static and constant" (13, 15). But we are precisely after the analysis of classificatory schemes, not as a generative explanation (for which we would refer the reader to the signal processing histories referenced above) or as the basis of stable universals. We simply seek some reference points for thinking about what happens to sounds as they are signal processed and how people talk about the meaning of those processes. It is not that music bloggers and textbook authors are working with the same deep structure as Lévi-Strauss's Bororo in Brazil. We offer the much less demanding proposition that Lévi-Strauss's language bears some morphological resemblance to that used by our bloggers and textbook authors.

Therefore, pace Lévi-Strauss, let us consider rawness as one not necessarily (or, more precisely, serially, situationally, and transitively) fixed pole in a system of meanings attached to recorded or fabricated sounds that are available for and sometimes subject to signal processing. In a way, we have simply extended his point about musical sound to sound

as such. In discussing the arbitrary nature of scales, he points out that although sounds exist in nature, it is only "retroactively [. . .] that music recognizes physical properties in sound and selects certain of these properties with which to build its hierarchical structures" (22). To be sure, Lévi-Strauss would not "go there." His model of music was clearly rooted in the Western concert tradition, and he was not comfortable with the aesthetic or theoretical propositions of the avant-gardes of his time. He rejected the arrangement of recordings of nonmusical sounds in *musique concrète* as "floundering in non-significance," even though "it is in immediate communion with the given phenomena of nature" (23–24). Similarly, he attacked serialist composers, who exploded the Western tonal system in attempts to construct completely new ones, as "like a sailless ship, driven out to sea by its captain, who has grown tired of its being used only as a pontoon, and who is privately convinced that by subjecting life aboard to the rules of an elaborate protocol, he will prevent the crew from thinking nostalgically either of their home port or of their ultimate destination. [For the serialists,] the journey alone is real, not the landfall, and sea routes are replaced by the rules of navigation" (25). *The Raw and the Cooked* is worth a careful read by sound theorists because it is an effort to think culture sonically, but we need not accept Lévi-Strauss's theoretical commitments to systems or his universe of sonic aesthetics to do so.[1] Where Lévi-Strauss hears meaninglessness in the tape compositions of *musique concrète* and the abstract compositions of Pierre Boulez, we suspect there is a great deal of meaning to be found in the talking navigation devices in cars, mobile phones that reproduce only a fraction of the human voice, hip-hop singles that top the charts with a mixture of singing and found sounds, television shows and movies that use synthetic timbres instead of melodic figures as leitmotifs for characters, situations, or even products, and on and on. We live in a world of meaningful processed sound that is significant and also represents the kind of semiotic groundedness that, for Lévi-Strauss, was so lacking in serialist compositions.

Having established our differences, let us now return to Lévi-Strauss's founding binary. If sounds are thus rendered raw through human action—and do not simply exist in a raw state out in the world—what does it mean for audio to be "cooked"? And what do we make of the cooking process itself? Here we find some guidance in Lévi-Strauss's discussions of fire. He introduces a binary opposition between two kinds of fire in the myths he interprets: "one celestial and destructive, the other terrestrial and creative, that is, fire for cooking purposes" (188). This fire

has a "mediatory dimension" that is necessary for maintaining relations between sun or sky and earth. Total conjunction is excess, "a burned world." Total disjunction is lack, a "world of rottenness" (298). Cooking fire mediates between these two conditions by facilitating the conditions for conjunction and disjunction. Mediating fire is the basis of social and cultural order and stability.

We are used to discourses of the raw and the cooked in media theory, in both its academic and vernacular versions. Crusty critics complain of the disproportionately processed nature of our mediatic reality, while savants of the new age celebrate the possibilities of sensory plasticity (Cooley; Gitlin; Hansen; Heidegger, *Question*; Meyerowitz; Plant). The available positions can be easily anticipated: we live in a world with too much cooking; or, cooking has greatly enhanced what was once the raw world. An essay such as ours could easily begin by paraphrasing Walter Benjamin and announcing that the sound of "immediate reality is an orchid in the land of technology" (232–33). But doing so would too quickly concede one of the most special and fascinating dimensions of contemporary sound culture. In everyday life, heavily processed sound coexists with totally unprocessed sound. The hearing among us are used to hearing human voices emanating from real people every day, yet if we were to play a recorded song or transmit a speech that did not include the standard compression and equalization of the voice to the point that it differs vastly from a voice in a room, it would sound strange and unnatural to most listeners. The phone processes too, reducing the dynamic range of speech such that weak voices can sound strong and vice versa. As the sound and multimedia artist Christina Kubisch, who explores this distinction between what we hear as "natural" and "artificial" in her work, points out: "Please ask yourself how many things you know by real experience and how many by digital information. When did you smell a humid forest ground the last time, or when did you observe a sunset or a real bird in the sky for a long time? I use these very commonplace examples because they are not common originally as an experience, but instead by their transmitted image or sound" (Rodgers, *Pink* 112). James Carey has made a similar point about mediatic experience more generally: most common culture comes to us via the media we use and not direct personal or collective experience. If much of culture is indeed "processed" through media, how do particular metaphors provide the contours of these experiences? We now turn our attention to the metaphor of travel and how it has informed designs and uses of particular audio technologies and techniques.

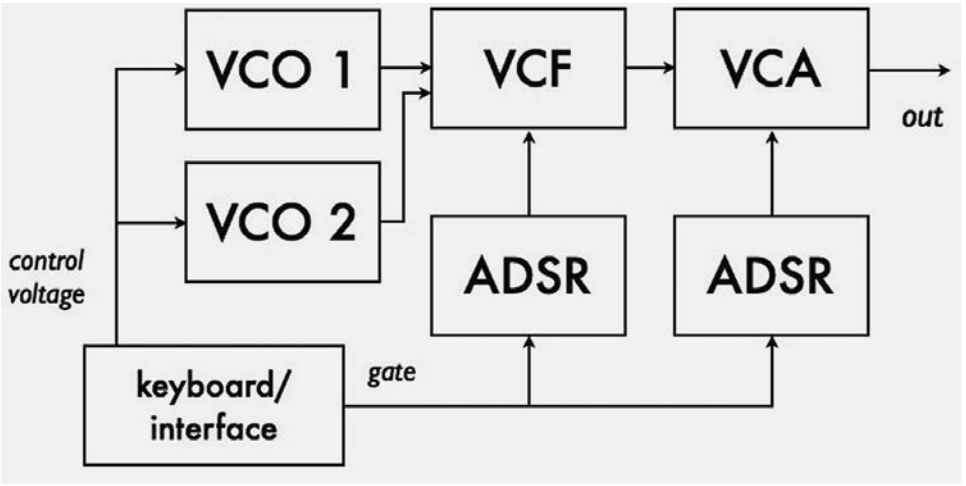

Figure 2
Signal Processing as Voyage
Illustration of signal flow from oscillator (VCO) to filter (VCF) to amplifier (VCA). Adapted from Kent H. Lundberg, block diagram of modular analog synth. *So you want to build an analog synthesizer?* 14 Nov. 2002, http://web.mit.edu/klund/www/weblatex/node2.html

Signal Processing as Voyage

The image in Figure 2 is a fairly pedestrian signal flow diagram for an analog synthesizer. The lines represent paths; the shapes represent electrical elements that do different things to the signal. Electricity flows from left to right in time. In this circuit, an oscillator creates a simple or complex pitched waveform, which more or less corresponds to an audible waveform. That sound is then modified by a filter, which removes the upper harmonics or partials of the signal, and then an amplifier, which adjusts the volume. The electrical signal then goes out of the synthesizer through the "audio out" and is turned into sound through a transducer like a speaker or headphones. This is a standard design for pretty much all popular analog synthesizers and is often imitated in the software realm. If you ask a synthesist what the essential components of a synthesizer are, she would likely say "oscillator, filter, amplifier."

In this image, the synthesizer circuit is configured as a space, and the metaphor is not simply visual. Circuit designers refer to circuits as having their own *topologies*. In electronics, *topology* has come to refer to "the way constituent parts are interrelated or arranged." However, the term has a much longer history, referring to mathematical operations, the art of assisting memory by associating ideas with particular places or things, and topographic anatomy (*OED*, "topology"). But one other meaning is of particular interest for us from this list: "the scientific study of a particular locality," listing among its examples the proposition that one can "draw deductions" about the history of a place from geographical facts.

What history of sound can we deduce from the most basic topology of an analog synthesizer?

The fundamental building blocks of the synthesizer correspond to Hermann von Helmholtz's ideas about the fundamental building blocks of sound. In the 1860s, Helmholtz theorized that loudness, pitch, and timbre corresponded to the primary properties of color: brightness, hue, and saturation (18–19; Lenoir 198–99). 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 183). Our most basic characterization of sound, and one of the most basic technologies for shaping sound today, emerges from specific historical ideas about perception and the relations of the senses.

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 [synthesizer designers] couldn't really figure it out" (Rodgers, *Pink* 147). Rylan's suggestion that the fundamental parameters of sound may have "nothing to do with anything" invites us to reconsider technical concepts that are usually taken as self-evident and universal. Rylan 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" (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.

Implicit in Rylan's critique of Helmholtz is a debate about what sound is. For Helmholtz, it is a thing in the world, a material with definite qualities. The analog synthesizer circuit animates this legacy and takes it literally. If we can analyze sound and break it down into its fundamental components, we can also create it. Rylan offers a more experiential basis

for understanding what sound is. In her model, nature exists externally, but sound exists in the hearer's experience. Perception and temporality are the central concerns here: her description of rain conjures its memory, and it is meant to evoke rather than to measure. Both her synthesizer circuits and the generic analog circuit are still mimetic in their approach to sound-making, but at two totally different levels. The Helmholtzian approach creates sound by breaking it into components and imitating and manipulating them. The Rylanian approach begins from an experience of sound and undertakes synthesis to approach and modulate it. Rylan is critical of how the "top-down" approach in the Helmholtzian tradition has been built into synthesizer designs and techniques, producing a normative logic and teleological progression of the signal ("This output goes to this input") that limits the range of possible sounds (Rodgers, *Pink* 147). Some of her design techniques are informed by circuit-bending techniques and other variations on such a "weird kind of black-magic strategy that's counterintuitive"—in other words, there are ways to route the signal in nonstandard ways through the circuit to produce more chaotic and unpredictable sounds and patterns (145).

It is not just the shape of topology that interests us but the very idea that sound travels through a circuit (or rather that electricity does to become sound). This most basic scheme, so central to almost all representations of signal processing, itself has roots in ideas about travel and voyage that inflect Western epistemologies of sound more broadly. 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, sound was defined as fluid disturbances that initiate sensory pleasures and affects. It was also figured as a journey of vibrating particles that voyage back and forth, outward and home again (Rodgers, *Synthesizing* 55–90). Ideas for the generation and control of electronic sound waves by synthesis techniques emerged at the turn of the twentieth century in a Euro-American cultural context in which wave metaphors and fascinations with the sea abounded (Helmreich 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 34, 61, 96). By the 1920s, it was popularly understood

that waves, and particles in wave motion, comprised all phenomena in the universe (Beer 298).

Themes of sound as fluid disturbance and maritime journey were imagined in the exterior world, often represented as an "ocean of air" (Hunt 1). They were 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. 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 82). Structures within the ear (solids, fluids, and membranes) were depicted as a terrain of interconnected parts through which vibrations "travel" (Barton 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 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.

Even the technological possibility of synthesizing and processing electronic 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 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 Thaddeus Cahill's Telharmonium in the 1890s. Wave metaphors and maritime themes also infiltrate the ways that analog circuits have been imagined and designed. 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" (RCA 3). Synthesizer historians Trevor Pinch and Frank Trocco refer to analog filters as analogous to technologies for the control of flowing water, like "a gate in a stream" (65).

In a similar spirit to Rylan's critique that the fundamental parameters of sound are historically contingent and have structured synthesizer designs in limiting ways, we suggest that these wave metaphors and themes of maritime travel typically privilege a particular subject position that stands in as universal. In the tropes of audio-technical discourse, white, Western, male subjects were initially figured as the proper navigators of synthetic sound waves, for whom the generation and control of electronic sound entails the pleasure and danger of taming unruly waves. This is evident in numerous accounts of the physical properties and affective experiences of sound, which are characterized by the voyage of displaced particles outward and back, and the analogous and corollary transportation of this archetypal male subject to a pleasurable, sensory experience and back to a state of rest (Helmholtz 251; Tyndall 81–82, 254).

We can interpret the narrative logics of wave motion and signal flow as we would a piece of music or other cultural text. As Susan McClary has demonstrated, the tonal organization and compositional structures of Western music represent narratives of heterosexual male desire and sexual fulfillment. These narratives are often resolved by a tonal journey through, and figurative conquest of, "other" musical areas; colonialist paradigms are thus encoded in familiar musical structures (McClary 7–19, 155–56). There are similar stakes in the ways that themes of maritime travel are mobilized in audio-technical discourse. The physical properties of sound, its affective qualities, and its mapping onto the forms of electronic circuits and musical instruments are often rendered through a masculinist and colonial rhetoric that promotes the bold traversal and technological mastery of turbulent waves and maritime frontiers. We do not wish to promote a simplistic or essentialist relationship of these normative subject positions produced in discourse and their various negotiations in audio-technical practice. In our conversations with audio engineers and musicians, we have found a plurality of perspectives and experiences. But we take technologies to be crystallizations and ongoing productions of social worlds, and thus the language and metaphors used to represent technical processes merit sustained consideration and

critique, especially as paths into their historical development and default assumptions.

Conclusion: For a Political Topology

In this essay, we have considered the metaphors applied to signal processing itself and the language used to describe and figure the work of signal processing and the people who do it, or who are supposed to be doing it. Cooking and travel as metaphors for signal processing mark cultural locations much as they do in broader social contexts. "Cooking" with sound can be figured as a creative, expressive act or as a labor or service. Signal flow as a travel narrative emerges from presumptions of freedom of mobility rather than from experiences of disability or of being surveilled and stopped (Ahmed 139). As such, metaphors that circulate in audio-technical discourse as neutral and instrumental ("it's just how we talk about it") are inflected with particular subject positions that are gendered, raced, classed, and otherwise culturally situated. As Tom Porcello and Louise Meintjes have written of talk in the studio, the figurative language can be challenged, overcome, or negotiated, but it sets the initial tone of the conversation.

Our focus on the metaphors of cooking and travel in signal processing also illustrates that, for as much as technical cultures may be constituted by "expert" language (Marvin; Porcello), this language is also metaphoric and full of tacit understandings (Horning; Théberge). Audio-technical discourse is infused with common signifiers of things people do and therefore is not purely "technical" at all—unless our understanding of technical expertise is expanded and demystified to account for its reliance on broad and familiar terms.

One of the classic questions of communication theory can thus be recast as a question of signal labor: who treats what for whom, with what process, and to what end? In their study of disabled mobile phone users, Gerard Goggin and Christopher Newell explain how it was discovered in the 1990s that then-new second-generation mobile phones interacted poorly with hearing aids. The phones generated a great deal of electromagnetic interference, which could cause a loud buzzing sound in hearing aids. "What was intriguing here," they write, "was that for quite some time hearing aids *rather* than mobiles were conceptualized as the principal problem by providers of mobile telephony. Attention was directed to the need for hearing aids to cope with higher levels of electromagnetic

emission, something that was seen as important given the wide range of technologies emitting such signals—not just mobile phones. A European standard was introduced in 1990 requiring hearing aids to be immune to emission from mobile phones" (158). At its most basic, this story seems to be about the politics of standards and use of the electromagnetic spectrum. But as Goggin and Newell so nicely point out, this really was about the politics of which assistive technologies were more fundamental. The implied normalism in the proposition that it was the hearing aids that were the problem spoke volumes. Despite the fact that the telephone is itself a technology to hear for people, phones were conceived as being for the normally hearing first and for the disabled second.

We should ask the same questions of the language of signal processing technologies. If we find that audio-technical discourse renders signal processing in terms of masculinist languages of mastery and domination of nature, can we help but wonder after its broader social implications? Does it not also suggest a gendered set of relations to these technologies (McCartney)? Is it any wonder that we still find the design, implementation, marketing, and use of audio signal processing technologies to be male-dominated fields? Overcoming this state of affairs is not simply a matter of inviting more women into various clubs—though certainly some invitations have been made and more are needed. It will require fundamentally rethinking how we model, describe, interact, and sound with signal processing technologies.

The authors thank each other, Rey Chow, Denise Davis, James Steintrager, and Mara Mills for helpful comments on and discussions of this piece. Jonathan Sterne also thanks the Center for Advanced Study in the Behavioral Sciences, where he worked on this essay.

JONATHAN STERNE teaches in the Department of Art History and Communication Studies and the History and Philosophy of Science Program at McGill University. He is author of *The Audible Past: Cultural Origins of Sound Reproduction* (Duke University Press, 2003) and numerous articles on media, technologies, and the politics of culture. His next book, *MP3: The Meaning of a Format*, is forthcoming from Duke University Press in 2012, and he is editing *The Sound Studies Reader* (Routledge, 2012). He also makes sound. Visit his Web site at http://sterneworks.org.

TARA RODGERS teaches in the Women's Studies Department at the University of Maryland, where she also works with the Program in Digital Cultures and Creativity and the Maryland Institute for Technology in the Humanities (MITH). Her book *Pink Noises: Women on Electronic Music and Sound* was published by Duke University Press in 2010. Her current project is a history of synthesized sound that traces metaphors in audio-technical discourse as representations of identity and difference. She also produces music and sound art in various forms and contexts: http://www.pinknoises.com.

Note

1 For all the complaints about the visualism (or denigration thereof) in social and cultural theory, there is clearly a long tradition of thinking problems sonically, of which Lévi-Strauss is but one representative.

Works Cited

Ahmed, Sara. *Queer Phenomenology: Orientations, Objects, Others*. Durham: Duke UP, 2006.

Aristotle. *Poetics*. Trans. S. H. Butcher. New York: Hill and Wang, 1961.

Barton, Edwin Henry. *A Text-Book on Sound*. London: Macmillan, 1926.

Bayton, Mavis. "Women and the Electric Guitar." *Sexing the Groove*. Ed. Sheila Whitely. New York: Routledge, 1997. 37–49.

Beer, Gillian. *Open Fields: Science in Cultural Encounter*. New York: Oxford UP, 1996.

Belasco, Warren. *Meals to Come: A History of the Future of Food*. Berkeley: U of California P, 2006.

Benjamin, Walter. *Illuminations*. Trans. Harry Zohn. New York: Schocken, 1968.

Bode, Harald. "History of Electronic Sound Modification." *Journal of the Audio Engineering Society* 32.10 (1984): 730–39.

Born, Georgina. *Rationalizing Culture: Ircam, Boulez, and the Institutionalization of the Musical Avant-Garde*. Berkeley: U of California P, 1995.

Bourdieu, Pierre. *Distinction: A Social Critique of the Judgement of Taste*. Trans. Richard Nice. Cambridge, MA: Harvard UP, 1984.

Bud, Robert. *The Uses of Life: A History of Biotechnology*. Cambridge: Cambridge UP, 1994.

Carey, James. *Communication as Culture*. Boston: Unwin Hyman, 1988.

Cooley, Charles H. *Social Organization: A Study of the Larger Mind*. Glencoe: Free Press, 1909.

Dwarfcraft Devices. "Dwarfcraft Devices Rot Yr Brain Pedal." http://www.themadape.com/Dwarfcraft_Devices_Rot_Yr_Brain_Pedal_p/dd-rotyrbrain.htm (accessed 18 Nov. 2010).

Edwards, Paul N. *The Closed World: Computers and the Politics of Discourse in Cold War America*. Cambridge, MA: MIT P, 1996. Inside Technology.

Elias, Norbert. *What Is Sociology?* London: Hutchinson, 1978.

Galison, Peter. "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision." *Critical Inquiry* 21.2 (1994): 228–66.

Gitlin, Todd. *Media Unlimited: How the Torrent of Images and Sounds Overwhelms Our Lives*. New York: Metropolitan, 2001.

Goggin, Gerard, and Christopher Newell. "Disabling Cell Phones." *The Cell Phone Reader*. Ed. Anandam Kavoori and Noah Arceneaux. New York: Peter Lang, 2006. 155–72.

Goody, Jack. *Cooking, Cuisine, and Class*. Cambridge: Cambridge UP, 1982.

Griffiths, Paul. *Modern Music and After*. New York: Oxford UP, 1995.

Hansen, Mark B. N. *Bodies in Code: Interfaces with Digital Media*. New York: Routledge, 2006.

Haraway, Donna Jeanne. *Modest_Witness@Second_Millennium.Femaleman_Meets_Oncomouse: Feminism and Technoscience*. New York: Routledge, 1997.

Hayles, N. Katherine. *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. Chicago: U of Chicago P, 1999.

Heidegger, Martin. *Being and Time*. New York: Harper and Row, 1962.

———. *The Question Concerning Technology and Other Essays*. Trans. William Lovitt. New York: Harper and Row, 1977.

Helmholtz, Hermann von. *On the Sensations of Tone as a Physiological Basis for the Theory of Music*. 2nd ed. Trans. Alexander John Ellis. New York: Dover, 1954.

Helmreich, Stefan. *Alien Ocean: Anthropological Voyages in Microbial Seas*. Berkeley: U of California P, 2009.

Hillis, Ken. *Digital Sensations: Space, Identity, and Embodiment in Virtual Reality*. Minneapolis: U of Minnesota P, 1999.

Holmes, Thomas B. *Electronic and Experimental Music: Pioneers in Technology and Composition*. 2nd ed. New York: Routledge, 2002.

Hornbostel, Erich M. von, and Curt Sachs. "A Classification of Musical Instruments." *Galpin Society Journal* 14 (1961): 3–29.

Horning, Susan Schmidt. "Engineering the Performance: Recording Engineers, Tacit Knowledge, and the Art of Controlling Sound." *Social Studies of Science* 34.5 (2004): 703–31.

Hunt, Frederick V. *Origins in Acoustics: The Science of Sound from Antiquity to the Age of Newton*. New Haven: Yale UP, 1978.

Iced Audio. "AudioFinder: Audio Library and Production Base Station." http://www.icedaudio.com (accessed 8 May 2011).

Josephson, Paul R. "The Ocean's Hot Dog: The Development of the Fish Stick." *Technology and Culture* 49.1 (2008): 41–61.

Kelly, Dean. "Make a Crazy Drum and Bass Breakbeat by Slicing and Dicing in Fl Studio." 14 Aug. 2008. http://audio.tutsplus.com/tutorials/production/make-a-crazy-drum-and-bass-breakbeat-by-slicing-and-dicing.

Koehn, Nancy F. "Henry Heinz and Brand Creation in the Late Nineteenth Century: Making Markets for Processed Food." *Business History Review* 73.3 (1999): 349–93.

Lenoir, Timothy. "Helmholtz and the Materialities of Communication." *Osiris* 9 (1994): 185–207.

Lévi-Strauss, Claude. *The Raw and the Cooked*. Trans. John and Doreen Weightman. Chicago: U of Chicago P, 1969.

Lindsay, Peter, and Donald Norman. *Human Information Processing: An Introduction to Psychology*. New York: Harcourt, 1977.

MacKenzie, Adrian. "Codec." *Software Studies*. Ed. Matthew Fuller. Cambridge, MA: MIT P, 2008. 48–54.

Marks, Laura U. "Thinking Multisensory Culture." *Paragraph* 31.2 (2008): 123–37.

Marvin, Carolyn. *When Old Technologies Were New: Thinking about Electric Communication in the Late Nineteenth Century*. New York: Oxford UP, 1988.

McCartney, Andra. "Inventing Images: Constructing and Contesting Gender in Thinking about Electronic Music." *Leonardo Music Journal* 5 (1995): 57–66.

McClary, Susan. *Feminine Endings: Music, Gender, and Sexuality*. Minneapolis: U of Minnesota P, 1991.

Meintjes, Louise. *Sound of Africa! Making Music Zulu in a South African Studio*. Durham: Duke UP, 2003.

Mennell, Stephen. *All Manners of Food: Eating and Taste in England and France from the Middle Ages to the Present*. 2nd ed. Urbana: U of Illinois P, 1996.

Meyerowitz, Joshua. *No Sense of Place: The Impact of Electronic Media on Social Behavior*. New York: Oxford UP, 1985.

Miller, Dayton Clarence. *The Science of Musical Sounds*. 2nd ed. New York: Macmillan, 1937.

Mills, Mara. "Deaf Jam: From Inscription to Reproduction to Information." *Social Text* 28.1 (2010): 35–58.

———. "Hearing Aids and the History of Electronics Miniaturization." *IEEE Annals of the History of Computing* 33.2 (April–June 2011): 24–45.

Mindell, David. *Between Human and Machine: Feedback, Control, and Computing before Cybernetics*. Baltimore: Johns Hopkins UP, 2002.

Moore, Brian C. J. *An Introduction to the Psychology of Hearing*. New York: Academic, 2003.

Mudry, Jessica. *Measured Meals: Nutrition in America*. Albany: SUNY P, 2009.

Nebeker, Frederik. *Signal Processing: The Emergence of a Discipline*. New York: IEEE P, 1998.

Parisi, David P. "Touch Machines: An Archaeology of Haptic Interfacing." PhD diss. New York University, 2008.

Peters, John Durham. "Helmholtz, Edison, and Sound History." *Memory Bytes: History, Technology, and Digital Culture*. Ed. Lauren Rabinovitz and Abraham Geil. Durham: Duke UP, 2004. 177–98.

Pinch, Trevor J., and Frank Trocco. *Analog Days: The Invention and Impact of the Moog Synthesizer*. Cambridge, MA: Harvard UP, 2002.

Plant, Sadie. *Zeros and Ones: Digital Women and the New Technoculture*. New York: Fourth Estate, 1998.

Porcello, Thomas. "Speaking of Sound: Language and the Professionalization of Sound-Recording Engineers." *Social Studies of Science* 34 (2004): 733–58.

Price, Nancy J. "Trent Reznor Digs Digg: Trent Reznor Virtually Interviewed by Digg Readers." *She Knows Entertainment* 7 Apr. 2009. http://www.sheknows.com/entertainment/articles/808484/trent-reznor-virtually-interviewed-by-digg-readers.

Pro Tone Pedals. "Pro Tone Pedals Body Rot 2 Heavy Metal Distortion Pedal." 26 Oct. 2010. http://protonepedals.blogspot.com/2010/10/pro-tone-pedals-body-rot-2–heavy-metal.html.

Radio Corporation of America (RCA). "Electronic Aid to Music Composers Is Developed by RCA Scientists." Press release. ca. 1944. Herbert Belar Collection, Princeton, New Jersey.

Rodgers, Tara S. *Pink Noises: Women on Electronic Music and Sound*. Durham: Duke UP, 2010.

———. *Synthesizing Sound: Metaphor in Audio-Technical Discourse and Synthesis History*. PhD diss. McGill University, 2010.

Rodowick, David. *The Virtual Life of Film*. Cambridge, MA: Harvard UP, 2007.

Ross, Eric B. "Food Taboos, Diet, and Hunting Strategy." *Current Anthropology* 19.1 (1978): 1–36.

Sachs, Curt. *The History of Musical Instruments*. New York: Norton, 1940.

Shambro, Joe. "Radiohead Launches Remixable Single." 2 April 2008. http://homerecording.about.com/b/2008/04/02/radiohead-launches-remixable-single.htm.

Sterne, Jonathan. *Audible Past: Cultural Origins of Sound Reproduction*. Durham: Duke UP, 2003.

———. *MP3: The Meaning of a Format*. Durham: Duke UP, 2012 (forthcoming).

Terranova, Tiziana. *Network Culture: Politics for the Information Age*. London: Pluto, 2004.

Théberge, Paul. *Any Sound You Can Imagine: Making Music/Consuming Technology*. Hanover: Wesleyan UP, 1997.

Thompson, Emily Ann. *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900–1933*. Cambridge, MA: MIT P, 2002.

Tyndall, John. *Sound: A Course of Eight Lectures Delivered at the Royal Institution of Great Britain*. 2nd ed. London: Longmans, Green, 1869.

Vico, Giambattista. *The New Science of Giambattista Vico*. Trans. Thomas Bergin and Max Fisch. Ithaca: Cornell UP, 1984.

Waksman, Steve. *Instruments of Desire: The Electric Guitar and the Shaping of Musical Experience*. Cambridge, MA: Harvard UP, 1999.

Weintraub, Andrew. *Dangdut Stories: A Social and Musical History of Indonesia's Most Popular Music*. New York: Oxford UP, 2010.

Zak, Albin J. *The Poetics of Rock: Cutting Tracks, Making Records*. Berkeley: U of California P, 2001.