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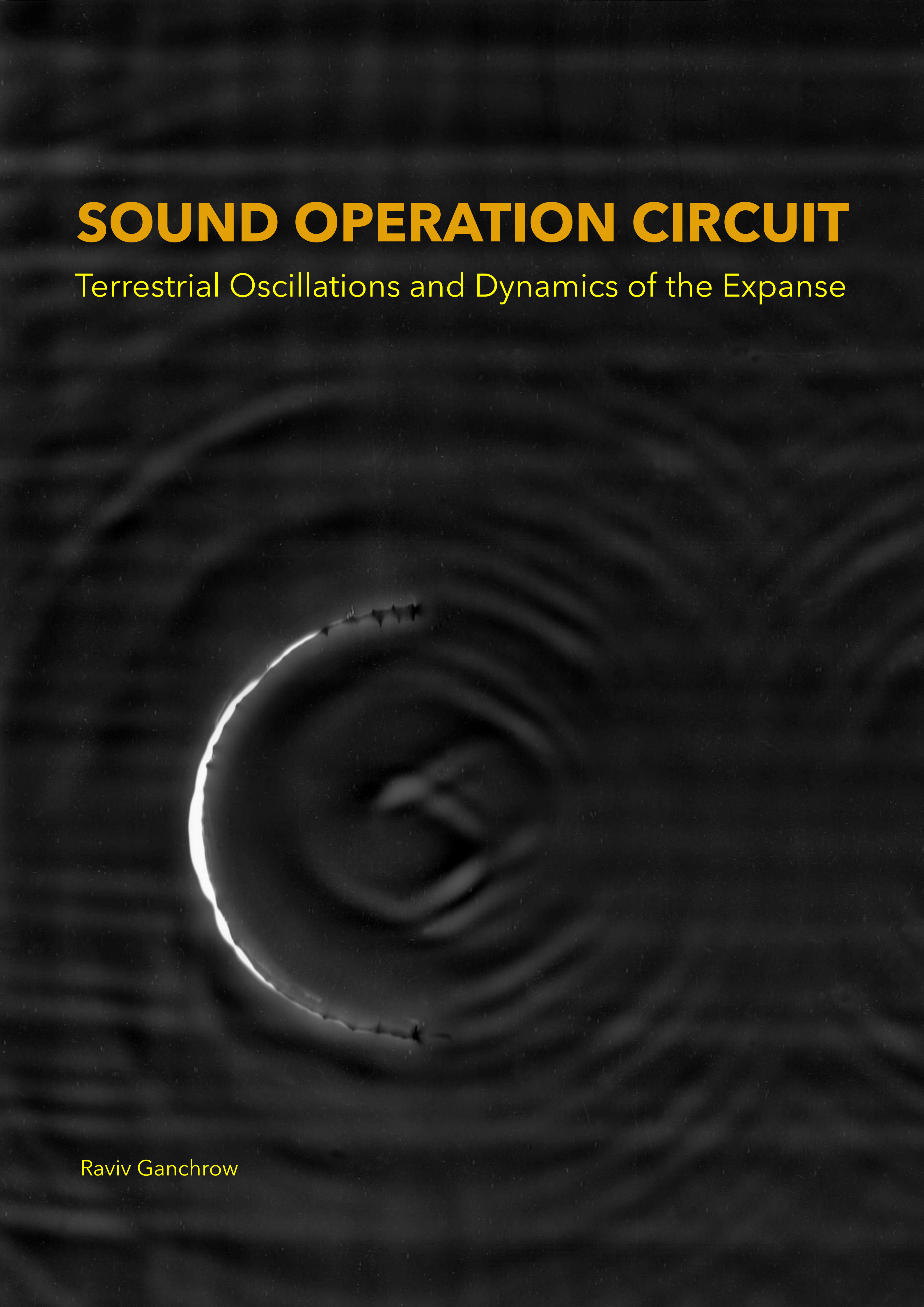
SOUND OPERATION CIRCUIT

Terrestrial Oscillations and Dynamics of the Expanse



Raviv Ganchrow

Sound Operation Circuit: Terrestrial Oscillations and Dynamics of the Expanse

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus, Prof.dr.ir. T.H.J.J. van der Hagen,
chair of the Board for Doctorates
to be defended publicly on
Wednesday, 15 May 2024 at 17.30 o'clock
by

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This dissertation has been approved by the promotors.

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Keywords:
Sound, Space, Operational Circuit Approach (OCA), Refraction-transduction, Post-acoustics, Poly-temporality, Distributed Subjectivity, Dynamics of Expanse

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Propositions

1) Sounds materialize expansive operational circuits.
This proposition pertains to this dissertation.
2) Sound manifestations are context-bound operations.
This proposition pertains to this dissertation.
3) Sound's spatial-material qualities map relational agencies.
This proposition pertains to this dissertation.
4) Observation, its techniques and devices, decisively shape sound's spatial-material qualities.
This proposition pertains to this dissertation.
5) Material definitions are always selectively biased.
6) Auditory experience performs subjectivity.
7) Listening recalibrates relations between subjects and surrounds.
8) The world is always inside the experiment.
9) Representations participate in existential dynamics.
10) The historicity of sensations and natural histories of the senses are one continuum.

These propositions are regarded as opposable and defendable, and have been approved as such by the promotors Dr.ir. M. Schoonderbeek and Prof. R. Cavell.

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Summary (NL)

Geluiden komen altijd 'ergens' voor, begiftigd met specifieke materiële 'kwaliteiten' die ook diverse actievormen aangeven. Ruimtelijk-temporele kwaliteiten van geluid, de contexten die ze omsluiten, samen met de attenties die ze vasthouden en de acties die ze omvatten, vormen samen dynamische systemen die 'circuits' worden genoemd. Dit onderzoek onderzoekt de circuits waarin geluiden zich manifesteren in diverse ruimtelijk-materieel-temporele configuraties en onderzoekt de wijzen waarop deze gesitueerde materialisaties onlosmakelijk verbonden zijn met contextuele dynamieken.

Hoe zijn geluiden verbonden met de context? Welke aspecten komen aan bod in de ruimtelijk-materiële kwaliteiten van geluid? Wat is de aard van de werking van geluid en hoe zijn de verschillende kwalitatieve verschijningsvormen van geluid verbonden met grotere aard-gebonden dynamieken? Deze dissertatie presenteert een nieuwe integratieve benadering van de gedistribueerde activiteiten van geluid, waarbij de acties van geluid worden waargenomen terwijl ze ongelijksoortige gebieden overbruggen en kennisverschillen overbruggen. Een operationele circuitbenadering (OCA) wordt toegepast als een middel om het refractief-transductieve meanderen van geluid door heterogene, poly-temporele velden te volgen. Het proefschrift benadrukt de diep genetwerkte en territoriaal actieve basis van de onuitputtelijke verschijningen van geluid. De ruimtelijk-materiële werking van geluid wordt onderzocht op een aantal locaties die geologische, technologische en zintuiglijke domeinen met elkaar verbinden. Bijzondere nadruk wordt gelegd op herconfiguraties van attentie-circuits sinds het tijdperk van de akoestiek.

De openingshoofdstukken (*Shapes of Time; Hear and There; Perspectives on Sound and Space*) gaan over de fundamentele ruimtelijke en materiële onderbouwing van geluid. De drie hoofdstukken vormen een naar buiten gaande beweging, beginnend met de ruimten van de directe ervaring, naar die van de algemene waarneming en naar de omgeving in het algemeen. In alle drie de gevallen - de plaats van de subjectieve ervaring; de plaats van het menselijk lichaam; en de plaats van de omgevingsmonitoring - worden verschillende gesitueerde praktijken van sonische observatie onderzocht in relatie tot hun overeenkomstige, uiteenlopende materialisaties van geluid. De eerste hoofdstukken laten zien dat de ruimtelijkheid van geluid onlosmakelijk verbonden is met de gesitueerde context. Hoofdstuk vier (*Phased-space*) fungeert als een crossfade naar de operationele circuitbenadering, waar categorieën van sonische materialiteit plaatsmaken voor meer indringende onderliggende circuitdynamieken, die een integratieve procesmatige uitgestrektheid vormen waar waarnemer, waargenomene, en omgeving voortdurend in elkaar grijpen.

Het uitgebreide circuit van geluid wordt ontwikkeld in de drie volgende hoofdstukken (*Earth-bound Sound; Baku Sirens; Sound Operation Circuit*) waar open verstrengelingen, op de oscillerende raakvlakken van geologie-organismen-omgevingen, de basis vormen van de levendige aardse dynamiek van geluid. In deze hoofdstukken wordt de operationele circuitbenadering gedemonstreerd in zijn nut om het binaire onderscheid tussen natuurlijk/technisch en organisch/inorganisch te verminderen, om een meer doordringend domein te betreden waar sociaal-historische, politieke, technische, biologische en geologische condities een voortdurende expansie van circuitinteracties vormen. Het hoofdstuk *Earth-bound Sound* behandelt de verspreide aardse dynamiek van geluid in verschillende geologische tijdperken, met bijzondere aandacht voor de wijzen waarop mensen hun gehoor over de horizon en onder water uitbreiden, beiden onlosmakelijk verbonden met tactische omstandigheden en technieken. *Baku Sirens* pakt de specifieke geo-historische context van Baku (Azerbeidzjan) op, aan het begin van de geïndustrialiseerde petrochemische winning, om de sociale/politieke/esthetische/economische/technologische vectoren te observeren die door de gesitueerde manieren van het horen van mechanische sirenes lopen. Ter afsluiting van dit deel van het proefschrift geeft het hoofdstuk getiteld *Sound Circuit Operation* een overzicht van de centrale componenten en mechanismen die betrokken zijn bij het operationele circuit van geluid, met bijzondere aandacht voor het ruimtelijk-materiële, alsmede de temporele en subjectieve transformaties die circuitacties met zich meebrengen.

Het proefschrift sluit af met een bespreking van de betekenis van sonische sites uit het tijdperk van de akoestiek, ten opzichte van alomtegenwoordige hedendaagse manieren van horen en waarnemen

van materialiteit, waarbij de centrale instantie en het probleem van universeel-gemaakte geluiden worden onderstreept. Het hoofdstuk biedt ook een samenvatting van de algemene kenmerken, het nut, de betekenis en de overwegingen van de operationele circuitbenadering (OCA) aan, evenals centrale onderzoeksresultaten en vooruitzichten op toekomstige circuitnavigaties.

Het onderzoek toont aan dat sonische specificiteit zelf een kwalitatief resultaat is van het operatieve circuit van geluid en dat opkomende ruimte-materiaal-temporaliteit zintuigen zijn van deze operaties. Het proefschrift legt het werkingscircuit van geluid uit en presenteert een originele, integratieve benadering voor het betrekken van de gesitueerde specificiteit van geluid. Het onderzoek biedt inzicht in de complexe dynamiek van de ruimtelijk-materiële operaties van geluid en onderzoekt de alomtegenwoordige aardgebonden werking van geluid. De operationele circuitbenadering werd bijzonder productief geacht bij het doorsnijden van heterogene kennisgebieden en het verbinden van ongelijksoortige fysieke domeinen. De circuitbenadering was ook effectief in het lokaliseren van epistemische en tactische vooroordelen die circuleren in akoestische epistemologieën en technieken, én in het identificeren van kritieke hiaten in de kennis, met name de kloof tussen de historiciteit van gewaarwording en de natuurlijke geschiedenis van zintuiglijke organen. Meer in het algemeen stelt deze dissertatie voor dat circuitstrategieën kunnen helpen bij het verduidelijken van de dynamiek van andere, tijdsgevoelige, contextueel-relationele, voorbijgaande identiteiten en kwalitatieve verschijningen die in overvloed aanwezig zijn in de omgeving.

De operationele circuitbenadering biedt een eerste stap in de richting van de ontwikkeling van complexe verklaringen voor aardse wederkerigheid die gebaseerd zijn op expansieve poly-temporele oscillaties. De dissertatie toont de complexe dynamiek van geluid aan als een voorbeeld van aardse levendigheid, waarbij de werking van circuitoperaties in het veranderen van menselijke attenties en het transformeren van tellurische milieus wordt aangetoond.

Summary (EN)

Sounds always occur 'somewhere', endowed with specific material 'qualities' that also indicate courses of action. Spatio-temporal qualities of sound, the contexts they enmesh, together with the attentions they sustain and actions they enfold, collectively constitute *dynamic systems* termed 'circuits'. This research investigates the *circuits* through which sounds manifest in diverse spatial-material-temporal configurations, and probes the manners in which those situated materializations are inextricably bound to contextual dynamics.

How are sounds linked to context? What aspects do the spatial-material qualities of sound address? What is the nature of sound's operations and how do sound's diverse qualitative appearances tie into larger earth-bound dynamics? The thesis presents a novel integrative approach to sound's distributed operations, where sound's actions are observed bridging disparate realms and spanning knowledge divides. An operational circuit approach (OCA) is adopted as a means of *following* sound's refractive-transductive meandering through heterogeneous, poly-temporal fields. The thesis highlights the deeply networked and territorially active basis of sound's inexhaustible appearances. Sound's spatio-material agency is examined across a range of *sites* interlinking geological, technological and sensory domains. Particular emphasis is placed on reconfigurations of attention circuits since the age of acoustics.

The opening chapters (*Shapes of Time, Hear and There, Perspectives on Sound and Space*) contend with the fundamental spatial and material underpinnings of sound. The three chapters constituted an outward movement beginning with the spaces of immediate experience, to that of generalized perception, and onto the environment at large. In all three instances — the site of subjective experience; the site of the human body; and the site of environmental monitoring — differing situated practices of sonic observation are probed in relation with their correspondingly divergent materializations of sound. The initial chapters demonstrate that sound's spatiality is inextricably tied to its situated contexts. Chapter four (*Phased-space*) functions as a crossfade into the operational circuit approach where categories of sonic materiality give way to more pervasive underlying *circuit dynamics,* forming an integrative processual expanse where observer/observed/environment perpetually interleave.

Sound's expansive circuitry is developed in the three subsequent chapters (*Earth-bound Sound, Baku Sirens, Sound Operation Circuit*) where open-ended entanglements, at the oscillating interfaces of geology-organisms-environments, form the basis of sound's vibrant terrestrial dynamics. In these chapters, the operational circuit approach is demonstrated in its utility of diminishing binary distinctions between natural/technical and organic/inorganic in order to engage a more pervasive domain where social-historical, political, technical, biological and geological conditions constitute a continual expanse of circuitry interactions. The chapter *Earth-bound Sound* addresses sound's distributed terrestrial dynamics, across various geological epochs, with particular attention the ways in which humans extend their hearing over the horizon and underwater, both inextricably tied to tactical circumstances and techniques. *Baku Sirens* picks up the specific geo-historical context of Baku, Azerbaijan, at the dawn of industrialized petrochemical extraction, in order to observe the social/political/aesthetic/economic/technological vectors passing though situated modes of hearing mechanical sirens. Concluding that sections of the thesis, the chapter titled *Sound Circuit Operation* the provides an overview of the central components and mechanisms involved in sound's operational circuitry with particular attention to the spatial-material, as well as temporal and subjective, transformations circuit actions entail.

The thesis closes with a discussion of the significance of sonic sites from the age of acoustics, vis-à-vis pervasive contemporary modes of hearing and sensing materiality, underscoring the central agency, and problematic, of universalized sounds. The section also provides a summary of the general features, utility, significance and considerations involved in the operational circuit approach (OCA), as well as central research findings and prospects for future circuit navigations.

The research demonstrates that sonic specificity itself is a qualitative outcome of sound's operative circuitry and that emergent space-material-temporality are senses of those operations. The thesis exposes sound's circuit operations and presents an original integrative approach for engaging sound's situated speci-

ficity. The research provides insights into the complex dynamics of sound's spatial-material operations and examines sound's pervasive earth-bound agency. The operational circuit approach was deemed particularly productive in cutting across heterogeneous fields of knowledge and interlinking disparate physical domains. The circuit approach was also effective in locating epistemic and tactical biases circulating in acoustical epistemologies and techniques as well as identifying critical gaps in knowledge, notably the gap between the historicity of sensation and natural history of sensory organs. More generally, the thesis proposes that circuit strategies could help clarify the dynamic of other, time-sensitive, contextual-relational, transient identities and qualitative appearances abundant in the surrounds.

The operational circuit approach provides an initial step towards the development of complex accounts for terrestrial reciprocity keyed on expansive poly-temporal oscillations. The thesis exposes sound's complex dynamics as exemplary of terrestrial vibrancy, demonstrating the agency of circuit operations in altering human attentions as well as transforming telluric milieus.

Introduction

This thesis probes spatio-material agency of sound by way of its dynamically shifting, contextually distributed and predominantly earth-bound circuitry. It questions the 20th century remedial paradigm of architectural acoustics by examining the substantiality of sound as a qualifier of space in its own right and not merely as a by-product of architectural construction. In doing so it proposes to consider the early 20th century remedial narrative of architecture's audibility itself to be a particular spatial-material manifestation and understanding of both architecture and sound, circulating within confined historical and technological circuits. Observational tropes of *acoustics,* with dedicated epistemologies, ontologies and technologies of listening and sounding are central ballasts of those circuits, demanding carful contextual unpacking across various locations, historical moments and operational domains. The full breadth of spatial sonority, transitioning from acoustics into geological, technological and sensorial domains is picked up and examined over the course of the following chapters.

This dissertation builds on a central thesis that sounds reflect contextual interactions, mutually patched through dynamic agencies that are termed 'circuits'[1]. Conversely, sonic specificity, reflecting those diverse agencies, can be traced back through their interlinked dynamics[2] across discontinuous territories of the extant, revealing constituent operational contexts sustaining material-spatial-temporal specificities while at the same time interlinking disparate domains. Paramount for this approach is recasting the locational/geographical, social/historical as well as the technological/physical not as inert anecdotal backdrops, but instead, as active conduits in expansive circuitries of the manifest. Epistemologies and ontologies of sound — such as registered acoustics and waveforms — are observed as active components in the extant, partaking in complex terrestrial dynamics that cannot be grasped from within a single framework of knowledge.

Instead, chapters of the thesis *follow* and *trace* various agencies of airborne and waterborne oscillations, culled from selected sites from the age of acoustics, interspersed and juxtaposed with recent sound-related discoveries in the natural sciences as well as deep-time sonic remnants. Throughout the expose, particular attention is placed on anthropic auditory circuits, related *sonic attentions* and the manners in which sound dynamics, activate contexts, territorialize domains and *produce* qualitative discrepancies as well as situated interdependencies. The approach opens into sound's contextual dynamics, first through human attentive domains that are then broadened into a more general sense of sound's operational circuits and their role in transforming terrestrial milieus.

The core of the thesis probes materio-spatial agency of sound by way of its dynamically distributed circuitry. It shows how sound operates within heterogeneous yet interconnected milieus such as geology, sociology, physiology and technology and attempts to track down manners in which materializations are indicative of contextual interactions, transducing and refracting *across* the various domains.

It is important to mention that the writing builds on observations and experiences gleaned from nearly three decades of the author's sonic practice and research into situated spatial-material dimensions of sound. In other words the thoughts and approaches developed over the course of the thesis are steeped in substances, tethered to techniques and deeply indebted to ongoing, intensive negotiations on-site. The sonic thinking is inseparable from my installations, radio works and technical sound research, however there is not direct engagement with my projects in the thesis (besides a brief intersection with my involvement in Wave Field Synthesis phased array techniques, covered in chapter four, *Phased-Space*). This is partially for practical reasons of scope, but also for theoretical clarity in trying to identify an operational dimension in material understandings of sound — especially those tied to ontologies of modern acoustics — that are more

1 Please refer to the glossary for a concise description of this and other key terms applied in the operational circuit approach.

2 Throughout the text, the plural 'dynamics' is used to highlight the diverse relational interactions that give rise to a variety of dynamic categories associated with qualities of the extant. The singular 'dynamic' implies a single overriding principle, which is not the case in mechanisms of the manifest. Instead, the text argues that the diverse formations of sounds occur in the draw of contextual constraints, exhibiting a variety of arrangements with differing dynamic traits.

readily traceable in residues of the natural and applied sciences as well as modern industrial techniques. For such purposes scholarly tools are particularly effective and hopefully this thesis demonstrates that to a certain extent. Conversely, the thesis itself is an important material artifact of ongoing sonic preoccupations and praxis. Text provides a means for navigating the complexities, a vehicle for traversing vast swaths of data, histories, ideas and senses of locales. Writing has the capacity of taking you, the reader, along for the ride.

Introduction to Sound's Situated Circuitry

This thesis hones in on spatial-material aspects of sound, observing sounds in their plural formations as *situated contextual circuits,* where hearing is deemed a particular category in a broader field of *attention circuits* bridging human/non-human and organic/inorganic divides. In this approach spatial-material and poly-temporal ontologies of sound reflect *operations* of the extant.[3] The approach demonstrates how specificities of sonic formations reflect relations in contextual operations.

Sound is examined as attributes of *circuits in action*. Sound's multifarious appearances, forms, textures, territories and perceived boundaries are descriptive qualities of operating circuits, involving inexhaustible components and interactions. The aim throughout the thesis is to highlight the terrestrially networked and territorially active basis of sound's qualitative appearances. Especially qualities linked with shifting sensations, altering attentions and transitioning identities. Attending to sound's meandering agencies has hatched the operational circuit approach (OCA), a strategy for accessing sound's complex situated dynamics that is discussed in detail in the concluding chapter. OCA follows sound's practical participations, revealing underlying *functional* characteristics in *all* manifest sounds. Sound's qualitative functions can be observed in the *actions* they perform across various domains, blurring distinctions between nature/culture/technique/physiology, subsuming sonic attentions into geological processes and further afield towards broader dynamics of the expanse. OCA examines sound as a pervasive *environmental force* occupying superimposed spaces and enduring differing times, revealing dimensions in contemporary sounds that are established long before the emergence of anthropic electro-acoustic techniques.

A vantage into sound's practicality reassesses sonic qualities seemingly constrained to physical limits, or cordoned off in social and subjective spaces, instead, in terms of their deeply enmeshed, expansive dynamism. In this wide-ranging approach (explicitly demonstrated in chapters 05, 06 & 07), *every* manifestation of sound is understood to participate — and importantly contribute — to behaviours of the expanse.[4] Even seemingly inert mathematical equations or incidental sonic descriptions take on pronounced effect when observed in terms of their material participations and the influence they exert upon conditions of the extant. The circuit approach demonstrates that supposedly inert, objective, universalized descriptions of sound in fact entail immense practical coordination, through distributed infrastructures, with dedicated approaches and standardized techniques, the sum total of which impart equally significant *movements* and *pressures* back into their milieus.

Observed spaces of action and material confines in sound correspond with context-specific relations. As such every manifest sound is already a *condition* that interlinks circumstances of extant (qualitative materializations) with dynamics of the expanse (extended movements intermingling). Recurring qualities of sound accumulate conditions that consolidate in notable *sites,* indicating predominant attentions and modes of hearing. However those sites are not confined to the places in which they appear. Their features distribute elsewhere, reappearing in multiple overlapping sites, at times vastly distributed in space and time. Material, spatial and temporal qualities of sound provide access to dynamic linkages of intermingling con-

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3 The term 'extant' aims to provide a synonym for existence emphasizing the dynamics *in* presence, hence the noun-ing of the adjective. Please refer to the glossary for an overview of nomenclature.

4 The term 'expanse' denotes the full reach of intermixed movements in processual actuality, with emphasis on an expanded dynamic state that incorporates emergent spatiotemporal properties of the extant. Expanse and extant are closely related terms. The former emphasizes an expanded dynamic state of ongoing interactions while the latter underscores materializations of processes.

texts. The diversity of sonic spatialeties and qualities reflect equally diverse contexts at play. OCA examines this diversity through their dedicated sites of sonic attention.

Dynamic Circuits of the Extant

What does the making and unmaking of sounds tell us about contextual dynamics and the circuits of sonic attention? How does sonic attention distribute auditory subjects (hearers and sounders) and reveal both the extents of its subjects and their spaces of operation? Experiences of sound exist in a networked domain of dynamically shifting circuits patched through fluctuant contexts of organic-inorganic amalgamations afloat on heterogeneous times. Manifest sounds are sites that can be accessed through specificities of their circulated attentions. Sound's polytemporal, distributed heterogeneity, nevertheless is also responsible for establishing sound's discrete tangible presence and locality. Sonic particularity is a gateway to undulating contextual domains where auditory subjects (both hearers and things) synch with altering environmental agencies.

To better understand sounds, one should ask what sound *does*, not what it *is*. Sounds are in, and of, actuality. Representational, symbolic, communicational or idiosyncratic subjective reports sounds may provide, indicate the manners in which sounds participate in the upkeep of perceived realities by patching and transducing through differing portions of the extant. Moreover, the contextual networks of sensory circuits and the realities they sustain, are patterned portions of a much larger dynamic of the extant. Senses of the real, the subjects they sustain and spaces and temporalities they provide are tendencies in expansive dynamic relations. Existence itself is teeming with transient entities, quasi-stable identity-things, lasting as long as circulations sustain and attentions preside.

This writing plunges into the curiously *ornate textures and surfaces of the real*, examining observed qualities — sound's diverse materializations — in order to partially reveal the peculiar activities through which qualities come into being. The following pages navigate sound's thickened surfaces through the actions in which they partake, but also following the twists and turns of context and the slippage of appearances and meanings sounds endure en rout. The dynamics reveals an ontological richness of sonic presences that are diverse, elegant, contradictory, subtle, and at times brutal or just maddeningly sublime.

Acoustic Milieus

When pressured for answers, sounds seem to default to their own pressurized milieu of acoustics, because sounds are, after all, vibrations. Or are they? Well yes and no. Sounds are vibrations to the extent that they can be observed as such. Traced through their oscillations in waveforms, wavering canyons of vinyl grooves or monitored on computer screen and oscilloscopes. But for the longest time sound's inherent dimensions of molecular movements were obstructed from human observation and its socially circulated ontologies were other. In most cases, their oscillations were more implied than materially accessible. And their physical movements were dampened by alternate meanings tethered to vibrancy. Their operations were also elsewhere, aligning with other motions and agencies of the surrounds. Sounds of the past — from other places and other times — are sounds nevertheless, but sounds that were markedly different.

The science of acoustics changed all that with its standardized measurements, replicable, mathematically modeled, impressions and materializations of sound: sounds appearing as patterns, as waveforms, as spectrums, as standardized numerical equations. Sound's seemingly objective, universalized encapsulated guise echoed positivist epistemologies of sound directly put to work in tactical (trench and U-boat warfare) as well as grand musical ambitions (standardization of pitch) of the early 20th century. Universalized sound was poised to become a predominant mode of hearing, amplified through commercial audio technologies and its effectiveness in modern technology-laden warfare.

The broad-ranging utility of sound *transduced* into wide-spread attentions through the domestication of electricity, finding its voice tethered to telegraph and telephone lines, springing from aerials and spinning phonographs, tape reels, and later cycling though digital buffers or streaming over earbud playback.

By 1956 an estimated 40 million carbon microphones were busy relaying voices over telephone lines. (Hunt, 1954, p. 37) In 2021 alone, an estimated 548 million headphones were sold. In 2022 an additional 580 million shipped worldwide, a marked rise from previous years attributed to an increase in demand due to COVID-19 lockdowns. (*Futuresource Consumer Headphones Market*, 2022; *How Many Headphones Can You Sell?*, 2022)

If anything, pandemic lockdowns demonstrate an overwhelming global reliance on transmissive electronic infrastructures of sound (and image), only set to increase with further integrations of telepresence across of range of social practices. In the past two years, earbuds designed for immersive spatial sound, have become tailored to user physiognomy, delivering even more convincing spatial sound experiences to consumer audio.[5] Add to that the integration of transducers into everyday environments such as public address systems and intercoms, together with the deployment of high-speed fiber optic infrastructures and satellite-based Internet streaming, to get an impression of the sheer scope of the audio infrastructural patchwork currently underway. The result is an increased hybridization and integration of air-based hearing through algorithmically networked electronic circuitries with global reach. Today it is quite likely that the total sum of transducers (microphones, loudspeakers and sensors) currently in operation outnumbers the collective number of human mouths and ears on the globe. That abundance and sensory repatching of hearing and sounding is also notably transforming manners of listening through terrestrial air. This simple material fact warrants an investigation into audio agency in general and electro-acoustic circuits in particular to better qualify the effects and attentions current audio infrastructures collectively enmesh.

Telltale Sounds

The age of acoustics has its historicity, one that possibly requires an urgent revisit in contemporary times to unearth the continuities, but also bring up for discussion biases that may still be silently circulating in the attention circuits that acoustic modalities sustain.

The cover illustration of Major William Henry Bragg's book on acoustics (also Sir William Bragg and Professor William Bragg) sums up that historical moment of universalized sounds in technologically ballasted acoustic materiality. Traits of acoustic materiality emerge from coalescing developments in physics, industrialized audio manufacturing, experiences of mechanized warfare and state power consolidations of scientific knowledge, becoming especially pronounced over the course of the 20th century. The cover of Bragg's 1920 book titled *The World of Sound* (based on a series of lectures delivered at Britain's Royal Institute in 1919) depicts a speeding locomotive binding the heaves to the oceans, with human technique at the center of a world teaming with sonorous activities. Implicit in the steam rising from the engine are the periodic whistles of the train and prevalent mechanized railway sounds carrying across the early modern landscape. Aloft on the engine steam is a piping angel, seated on a brass horn, in a flurry of leaves and wind chimes, evoking frescos in the European tradition where cupola angels often appear musically inclined. In the ocean below are the implicit sounds of crashing waves, two fish and a conch (Bragg, 1920).

The chapter listing clarifies a genealogy of sounds, categorized in a specific lineage of post-industrial anthropic attentions, concluding with tactical concerns. The chapter title are as follows: What is Sound?; Sound in Music; Sounds of the Town; Sounds of the Country; Sounds of the Sea; Sounds in War. The final chapter covers latest developments in underwater monitoring (hydrophone designs with which William Bragg was intimately familiar due to involvement in early developments of submarine detection) and electronic and optical registration techniques of airborne shockwaves (gun sound ranging).

Bragg received the Nobel Prize in physics (1915) for work X-ray crystallography stemming from ear-

5 As of October 2022, Apple AirPods integrated a so-called 'Personalized Spatial Audio' feature that requires 3D scanning of the users pinna via the iPhone's inbuilt TrueDepth camera to create 'a personal profile for Spatial Audio that delivers a listening experience tuned just for you.' https://support.apple.com/en-us/HT213318, accessed June 01, 2023.

lier wireless communication research. He shared the prize with his son Lieutenant (later Major) William Lawrence Bragg who had just been appointed by the War Office (1914) to head the British (gun) sound ranging efforts, crucial for the introduction of electro-acoustic microphone techniques into battlefield explosion monitoring that were also applied as electronic detectors in the design of long-range acoustic surveillance sound mirrors constructed along Britain's southeastern coast.[6]

Ironically, or maybe fittingly, finances for the prize they received traces back to wealth acquired by the Nobel's innovations in chemical explosives and hydrocarbon extraction, namely assets from the invention of dynamite, numerous ammunition factories and the Baku oil cartel Nobel Brothers Petroleum Company. Both contexts — gun-sound ranging and blast-assisted extraction — convey a particularly prominent category of anthropic-percussive sounds interspersed throughout the thesis.[7]

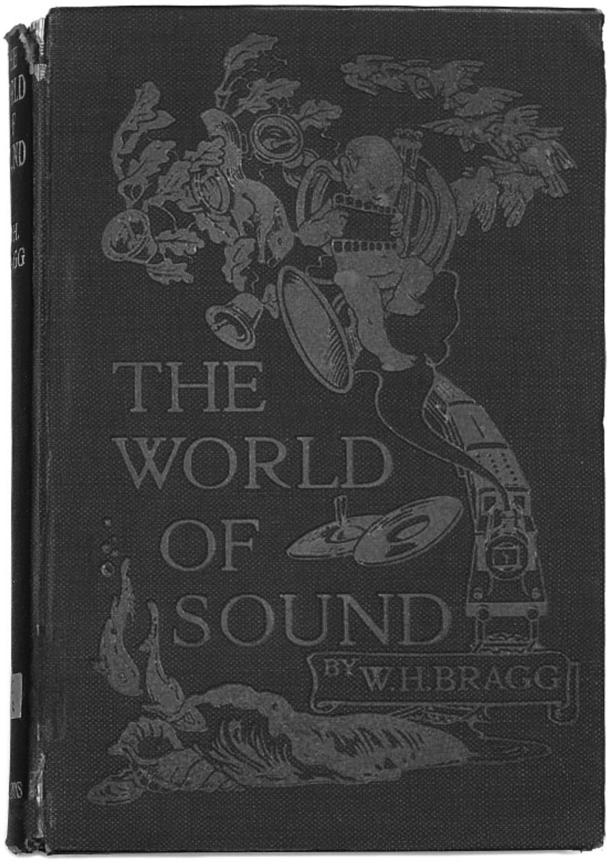

Figure 1.1 The World of Sound, William Bragg (1920)

Acoustic attentions to sounds divorced of their sounding milieus, suspended in ahistorical vibrational schematics is an immense, multi-faceted site. It includes technically-laden, often closed-loop, circuits through which modern sounds materialize, especially through observational techniques where tactical and political agendas end up becoming embedded along signal pathways, through circuit relays and algorithmic functions. Parallel trends are observed in civilian entertainment and communication domains where sound circuits become increasingly standardized and streamlined for public consumption.

Stated succulently: the materiality of acoustics cannot serve as a neutral lens for general inquiries into sound. A more *situated* model for sound is required, that can account for the myriad of sonic appearances, spanning the gaps between vibration and appearances. A model that also attends to sound's ongoing

6 William S. Tucker, inventor of the Tucker Microphone — a resonator-based transducer tuned to pickup battlefield artillery infrasound — was part of Lawrence Bragg's team.

7 Contexts of Nobel dynamite and oil receive pronounced playback in the chapter titled *Baku's Sirens*. Genealogies of attentions to explosive localizations and long-distance sound surveillance are covered in the chapters *Earth-bound Sound* and *Perspectives on Sound and Space*.

transformations. This text proposes OCA as a strategy for apprehending sound in its perpetual, processual, mediation and remediation.[8] In other words sounds understood in terms of their *functional* and *perfomative* reciprocities, in their constructive participation (at times inadvertently) in socially shared realities. Sounds with no outsides, where observation, location and oscillations are one continual field of operations. Where mappings, impressions and narratives linked to manifestations of sound not only provide access to itineraries of those sounds but also subtly alter their courses and subsequent pathways through the extant, at time giving rise to new appearances and altered attentions.

Observer-participation in shared sustained attentions implies a responsibility or ethical dimension to qualitative observations. Both in terms of the specific *kinds* of experiences socially coordinated hearing can provide, but also, by extension, in the modes of descriptive analysis that ballast or intensify such consensus and by doing so diminish or exclude other possible hearing. The words and phrases populating this thesis take heed of such eventualities. What's at stake with sonic attention reiterated through language and to what ends? What are the contextual extents and circuit bounds of predominant modes of hearing? What sounds remain unheard or intentionally suppressed within a given circuit-logic? What does 'hearing otherwise' entail? Although this thesis does not directly engage these questions, the chosen sites of sound are understood as critical thresholds, or moments, in prevailing modern sonic tropes (the science of acoustics, sonic surveillance, hearing ontologies of the siren etc.) offering some critical insights onto their inner workings. As well as potentially providing remedial roadmaps and alternative pathways to navigate the legacies.

Refractive-Transductive Listening

When attempting to qualify conditions of hearing, refractive-transductive listening is employed as a method for grappling with the immensity and discontinuities encountered when sounds skip from one context to the next.

In sounds, qualities express operation, hence the emphasis throughout the writing on sound's emergent spatial-material-temporal tendencies. Attention to oscillations produces distinctive sonic materializations. The flicker of spaces, positions, extents and times, attributed to any given sound, correspond to configurations in a sound's contextual circuitry. Throughout the various chapters there is a pronounced emphasis on *physical configuration* and *attentive formations* of sound. Those aspects are not so much the author's bias as much as they understood to be crucial indicators of sonic operation. Manifestations of sound appear with pronounced spatial, material and temporal qualities. Those qualities are indicative of contexts in action; their particularities are endowed with directional orientations, operative tendencies and relational agencies that in turn facilitate physical arrangements and condition perceptions.

The writing explores the dynamics of sonic agency through concrete examples where the circuits of sound are charted through tangible contexts, exposing sound's operations. It also employs refractive-transduction strategies for circuit sounding, accessing sound's contextually bound circuitry, as well as formulating a situated model of ever-changing sonic specificity, centered on attention-action configurations of the milieu.

Attention is an environmental circuit in which sound plays a determinant role in shaping observer-environment reciprocities. Sound's overt temporality and evanescence, that is none the less bound to its located circumstances, provides the basis for the contextual, relational approach, underscoring sound's networked and interlinked agency. The sonic circuit answers these multifaceted, situated, specificities while at the same time attending to the broader complexities interleaving its presence.

The following chapters are devoted to context-bound operational circuits, providing insights into sonic attention that pattern the manifest at cardinal sites of modern hearing. Sonic agency is examined through sites, exemplifying formative manifestations of sound, examined through their expansive social/historical and technological/material locales and formations. In many cases the sites have been engaged in

8 For a broad-ranging discussion of remediation dynamics in relational ontologies of media and technique see R. Cavell's book *Remediating McLuhan* (Cavell, 2016).

parallel through the authors active sonic practice, involving the construction of in-situ environmental circuits (*Fray, Agora Circuit, Westhafen Ground Electric, Lighting Ellipse, Building Telluric*)[9], explorations in radio-phonic hearing, in collaboration with national broadcasters (*Radio Plays Itself* [ORF], *Forecast for Shipping* [BBC], *Knallfunken* [DfK])[10] or critical historical re-enactments in anechoic chambers such as the experiments in 'retroactive hearing' conducted at TU Delft's anechoic facility and the Max Planck Institute for the History of Science, Berlin.[11] The nature of the dynamics, and corresponding contextual extents, circulated in sonic attentions demonstrates corresponding transformations in its appearances. A detailed survey of the components and mechanisms involved in sound circuits is explored in chapter 07 (titled *Sound Operation Circuit*).

Sonic attentions, the circuits they maintain and materialeties they sustain are understood to be part of a larger set of dynamic interactions of the extant. In that sense the mapping of sonic materialities can be taken as a strategy for rethinking other spatial manifestations (such as agencies of architecturally-produced space)[12] or temporally-bound identities, and by doing so, open vistas onto dynamics of the manifest (ontological flux), the comings-and-goings of meaning (morphing epistemologies) and attentions, and other pluralistic, poly-temporal, processual multiplicities of the extant.

Understatedly, the observations of sound's spatial agencies, set in measure with a broader scope of material interactions, can also serve as a preliminary corrective to the long-standing geometric bias in architecture, by observing the primacy of *relational interactions* (many of which escape geometric representations) at the *basis* of spatial manifestations. The thesis exposes the flowing tectonics of *vibrant relationality*, enmeshing substances, contexts, attentions, social conventions, politics and histories all at once. Examining the tectonics of temporal configurations in ongoing spatial-material emanations.

Chapter Overview

The opening chapters (*Shapes of Time, Hear and There, Perspectives on Sound and Space*) contend with fundamental spatial and material underpinnings of sound. The three chapters constitute an outward movement beginning with the spaces of immediate experience, to that of perception, and onto the environment at large. In all three instances – the site of subjective experience; the site of the human body; and the site of environmental monitoring – differing situated practices of sonic observation are gauged in relation with their correspondingly divergent materializations of sound. The initial chapters demonstrate that sound's spatiality is inextricably tied to its situated circumstantial contexts.

Chapter four (*Phased-space*) functions as a crossfade into the operational circuit approach (OCA) where the distinction of sonic materiality gives way to more pervasive underlying *circuit dynamic,* forming an integrative domain of processes where observer/observed/environment perpetually interleave.

Sound's expansive circuitry is developed in the three subsequent chapters (*Earth-bound Sound, Baku Sirens, Sound Operation Circuit*) where open-ended entanglements, at the oscillating interfaces of geology-organisms-environments, form the basis of sound's vibrant terrestrial dynamics. The operational circuit

9 For more information on site-specific circuits see (Ganchrow, 2013) as well as the following links for *Agora Circuit*, *Westhafen Ground Electric*, *Lighting Ellipse*:
https://www.tunedcity.net/?page_id=5349
https://www.zku-berlin.org/timeline/westhafen-ground-electric-1/
https://ravivganchrow.com/page/ltg-lps.html

10 For more information on *Radio Plays Itself*, *Forecast for Shipping* and *Knallfunken* see:
https://www.kunstradio.at/2013B/29_09_13.html
https://www.researchcatalogue.net/view/106497/335248
https://ravivganchrow.com/page/spark-gap/knallfunken-text.html

11 For more information on the anechoic experiments in retroactive hearing see:
https://www.mpiwg-berlin.mpg.de/research/projects/padded-sounds-latent-aurality-anechoic-chambers

12 Architecture's long-standing commitment to narratives of space has deemed the discipline custodian of the spatial discourse. Spatial epistemologies are intimately linked with histories and theories of architecture. However the current thesis proposes that space is a more general property of contextual dynamics. Although architecture is an exemplary spatial practice, the spatiality discernable in sound can also serve as a model for rethinking relations between atmosphere-context-tectonics in the production of architectural space.

approach diminishes binary distinctions such as natural/technical and organic/inorganic, engaging a more pervasive domain where social-historical, political, technical, biological and geological conditions constitute a continual expanse of circuit interactions. The chapter *Earth-bound Sound* addresses sounds expansive terrestrial dynamics, by way of human extensions of hearing over the horizon and underwater. *Baku Sirens* observes social/political/aesthetic/economic/technological vectors passing though historical modes of hearing mechanical sirens. The chapters conclude with an overview of the central components and mechanisms involved in sound's operational circuitry, in a section titled *Sound Operation Circuit*.

The thesis closes with a conclusions section reflecting on the research, findings and future investigations.

Chapter 01: ***Shapes of Time: an Experiential Account of Sonic Spatiality***

The centrality of spatial-material characteristic of *all* manifest sounds, sustained throughout the thesis, is picked up in the first chapter titled '*Shapes of Time: an experiential account of sonic spatiality*'. This brief text, written from the position of a listener, begins with a discussion of the emplacement phenomena native to sonic experience, emphasizing that any materialization of sound into palpable qualities *necessarily* manifests a corresponding spatial framework within which it, and other material properties are seen to reside.

The emphasis is on space as an emergent property linked to the contexts of observation, where inbuilt sensory-oscillatory transformations sustain *spatial paradoxes* that question the seemingly unproblematic nature of rudimentary spatial sound perceptions.

By comparing two seemingly contrasting categories of sonic experience, 'reverberation' (a quintessential *spatial* attribute) and 'pitch' (an exemplary *quality*), the text suggests that distinction between 'qualities' and 'spatialities' in sound are superficial, proposing instead that space is a *quality* among other qualities sounds possess (or conversely that qualities are unfamiliar spaces), contingent to contexts and manners of observation. If space, tone and timbre are different in degree but not in kind, commonalities are discernable in the compounded relational continuities they express and *operational affordances* they provide.

The text also describes divergent spatial ontologies (such as the space of acoustic waves and the space of localized sounds) emanating from the same vibrational expanse, when differing contexts of observation are patched in. No observed space is deemed more primary than another, concluding that several spaces can overlap, coincide, or even coexist at the same locale.

Chapter 02: ***Hear and There: Notes on the Materiality of Sound***

The discussion proceeds to the site of early experimental psychology, investigating the material context of sonic observation in the late 19th century, demonstrating the role of *techniques* and *sonic media* in hatching the outside/inside dichotomy of modern acoustics and psychoacoustics respectively. At that site, the role of waveform transcriptions, acoustic visualization and laboratory milieus become paramount.

The chapter includes a brief survey of sound registration techniques in the late 19th and early 20th century (namely in the work of the Hermann von Helmholtz' early psychophysics experiments, Wallace Sabine's acoustic schlieren photography and spatial amplitude mappings and Édouard-Léon Scott›s phonautograph) to demonstrate how each example manifests divergent spatiotemporal configuration of sound. The discussion demonstrates that enumerating the dimensions involves discerning the various *modalities* within which materialities of sound are seen to take shape.

Materialities of sound are observed in the transformations they endure while passing through various technological influences, each time taking on distinctive contours, that in turn also give rise to alternate modes of sonic attention, each within its own distinctive context of operations.

These latent, and for the most part unintentional, materialities ascribed to sound get amplified by way of their social utility. In particular, the instances where sound is seen to come in contact with the architectural floor plan, evident in the acoustic research of Wallace Sabine and the shadowgraph photographic techniques, employed in early experiments of architectural acoustic modeling. But also in the less apparent examples, such as the material agency of the waveform, whose spatiality is more abstruse, yet it succeeds in carrying-over into countless consumer audio applications, not to mention squeezing its way into nearly every chapter of this thesis.

Chapter 03: ***Perspectives on Sound-Space: The Story of Acoustic Defense***

Once the site of acoustic waves is established, its territories become key protagonists in tactical operations above and below the waterline, particularly after the introduction of high explosives, aviation and submarines to combat.

Proliferation of sound-based geo-spatial observation techniques on land intensified through trench warfare in World War I, centering on the bandwidth of infrasound at the intersection of explosive shock-waves and weather monitoring. Tactical underpinning of sonic knowledge amassed in that period expresses acute sensitizations to human (and technical) abilities for binaural *sound localization*. The proliferation of acoustic techniques and artifacts such as tactical binaural listening devices (above and below the waterline) culminate in the development of ocean-wide sound monitoring networks (SOSUS) as well as the construction of architectural sound mirrors on England's coast.

The materiality of tactical airborne acoustics is examined in the design and construction of experimental acoustic defense fortifications along England's southeastern coast. Sound mirrors are exemplary experimental listening devices incorporating state-of-the-art of acoustic knowledge, developed for purposes of long-range surveillance. The late 1920's yielded the development and construction of several large-scale coastal concrete acoustic 'mirrors' aimed at apprehending sounds of approaching aircraft outside the visual range.

A central mode in the design of these long-range listening devices is the sonic paradigm where frequencies correspond to physical sizes and aircraft engine sounds are mapped for their *signature spectrum*. This chapter examines the sound mirrors as a formative moment within the broader reconfiguration of listening habits (picked up in broader context in chapter five, *Earth-bound Sound,* as well as in the conclusions), and attempts to locate a shift in the grasp of space that occurs when an optic model of viewing is replaced with an acoustic model of listening, exposing a paradoxical condition where the close-at-hand and the far-off momentarily coincide.

Chapter 04: ***Phased-space***

In this chapter, the emphasis on sonic materiality gives way to more pervasive underlying *circuit dynamics,* crossfading into the operational circuit approach (OCA). The discussions focuses on the physicist Ernst Mach's unorthodox model of sensation (the realm of 'elements' at the interplay between observer/observed), juxtaposed with modern techniques of Wave Field Synthesis (WFS), a spatial audio rendering method allied with geophysical phased-array monitoring techniques. Common to both is the conditions of phased-space, a domain where observer/observed/environment perpetually enmesh.

From advanced imaging devices to emerging spatial acoustic systems, developments in contemporary technology display a hybridization of sonic and optical attributes. Underpinning these various techniques are complex understandings of spatialized fluid dynamics. The Phased-space chapter traces implicit interdependencies emerging from within the confines of phased-space, interleaving statements from Mach's research, with reflections on WFS.

Mach's proto-spatial definition of 'elements', a position is examined whereby both the 'thing' and the discreet 'ego' are viewed as alternating pattern-bundles composed of common blocks. The emphasized intertwining of observer and observed along with a broadened definition of 'sensation' is then shown to manifest in Mach's empirical research as a radical re-thinking of the epistemic purpose ascribed to the photographic plate, reimagined as inanimate version of 'sensation taking hold'.

The theme of interdependent tactility and fluctuant spatiality is then applied to a reading of the wave field synthesis techniques that extends the sensation-substance modality into the audio spectrum by implementing a bounded acoustic expanse, constructed as a vibrational tapestry, within which a spatialized hearing occurs divorced from all source resonating 'objects'.

The phased-array technique implemented in wave field synthesis, borrows its methods from tomographic monitoring techniques linked to oil and gas exploration, an observational context that feeds into the subsequent chapter *Earth-bound Sound*, where tactical underwater surveillance hatches a version of wave field synthesis seven decades before the technology was officially 'invented'.

Notably, phased-array techniques are imagined within a paradigm of geophysical 'sensing' and spatialized modalities of time (spatialized time-delayed wave fronts), where space is understood in terms of *fractured temporality*.

Chapter 05: ***Earth-bound Sound: Oscillations of Hearing Ocean and Air***

This chapter is a clear demonstration of the OCA. It opens into a much broader field of interactions, following the open-ended entanglements at the interfaces of sounds-organisms-environments through the knotted interrelations of situational, terrestrially-bound, contingencies especially relating to hearing and sounding abilities of various organisms on land and in water. At the same time it attempts to qualify complexities introduced to materializations of sounds passing through specific historically situated techniques of empirical observation on land and in water, laden with carry-over biases from communication theory, electrical engineering and optics.

In the case of humans listening to air, this mostly manifests in technically mediated listening to atmosphere at the intersections of warfare, weather and early experimental psychology. Technically enhanced methods of binaural hearing in the battlefield, above and below the waterline, since World War I, prove a critical catalyst for ontologies of environmental sound propagations, gaining momentum during the era of nuclear proliferation, briefly intersecting with the contexts of meteorology and seismology.

The chapter is structured as an oscillation rather than a history or chronology. Anecdotes pass from one to another by way of mutual points of contact, similar in behavior to energy transferring across incongruent domains, activating additional motions and unforeseen unfolding. The purpose of this chapter is to open up a vast array of interconnections and contexts that are potentially at play in earth-bound sounds. Oscillating narratives afford a polyvalent portal into eventfulness. At the same time they can never provides an 'overview' as every traced movement is already also fundamentally a reduction. To amend this gap, the writing incorporates open ends and incomplete trajectories pointing towards onward convergences and conductivities.

Chapter 06: ***Baku Sirens: Circuits of Industrious Attention***

This chapter sounds the operational circuits of mechanical sirens. The histories and contexts entangling sonic entities often defy rationale and cannot be grasped from within any singular logic or domain. A prime example for this is the polyphony of shifting meanings heard through trills of the mechanical siren. Originating in the 19th-century psychoacoustic laboratory (a demonstration device linking perception of tone height and corresponding pulses of air), migrating into civic and industrial infrastructures (emergency vehicles and factories), onto concert hall stages, and more recently establishing itself as a central ballast of national alarm systems.

Arseny Avraamov's city-wide performance *Symphony of Sirens* (Sinfoniya Gudkov), that took place in Baku, Azerbaijan in 1922, is particularly instructive of siren transformations linked to corresponding transitions in society and industry. Contrasting agencies of siren sounds emerge when refracted-transduced back into Baku's context, through a tangle of petroleum infrastructures, political turmoil, revolutionary agitations, evolutionary and utopian musical imaginations and techniques of geo-spatial sound localization, providing access to coinciding attention circuits inhabiting the performance.

Four distinctive modes of hearing are discerned overlapping on site: hearing urban hubbub *as* music; hearing *social progress* in sirens; hearing *synchronization* through blasts; and hearing metropolis as *metabolism*. None of these modes are native to Baku. They distribute elsewhere, coming into prominence over the first half of the 20th century in a variety of historical contexts momentarily coinciding in Azerbaijan's capitol. Listening to complexities of Baku's sirens partially makes audible a myriad of transformations that were underway in spatial-sensory attentions at the time, notably a dynamics of attention linked to fluid ontologies of media, participating in expansive infrastructures, revolutionary politics and turbulent events. The chapter also revisits and curiously recalibrates materialist epistemologies of Ernst Mach.

Chapter 07: *Sound Circuit Operation*

The closing chapter provides and overview of the central components and mechanisms involved in sound's operational circuitry. Including a survey of sound's functional underpinnings and its emergent spatial-temporal-material properties, and contextual dynamics. It discusses the particular sensory and observational circuitries through which sounds tend to manifest and the qualitative configurations their circuits sustain. Sound circuits are gauged in relation with their fluctuant contexts and through the temporal and territorial scaling they endure.

The chapter follows-up with a discussion of implicit redistributions of subjects (observer/observed) linked to attention circuit dynamics as well as related observations on the physicality of sensation. The chapter concludes with a summery of sound's processual, situated operations tethered to conductive terrestrial-circuits. The operational circuit approach along with the circuit model of attention, recalibrates notions of site-specificity, in-situ attentions, towards a general *tectonics of interactions*. Sound's complex dynamics are shown to be exemplary tendencies of terrestrial vibrancy where qualities are relational, contexts are reciprocal, and identities are always in process.

Chapter 08: *Conclusions*

The thesis concludes with a brief statement on 'post-acoustics' followed by a chapter overview and summary of the operational circuit approach. Discussions continue with a concise sequence of reflections on the thesis findings, research process and format, covering the affordances and limitations of the sound circuit model and operational circuit approach, its contributions to the spatial discourse and potential utility as a more general approach for probing the extant. The chapter reflects on the challenge of contextual navigations and applications of refractive-transductive listening as method of inquiry as well as some preliminary comments on methodological challenges and shortcomings as well as potential future research.

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Chapter 01

Shapes of Time: an Experiential Account of Sonic Spatiality[1]

The following text suggests that the qualities of experienced space in sound are inherent to, but not measurably part of, an acoustic domain. Furthermore, audible spatiality is not mimetically representative of, or restricted to, corresponding visual frameworks of space. This is not to say that audible spatiality has an independent existence – quite the contrary, it is linked to concrete events. On the other hand heard spaces have no other existence than that to which our experience attests. At the same time audible spatiality cannot be reduced to a phantom effect. Audible space is ontologically 'real' if not merely for the fact that it is tied to a physical locale (even when that locale is recorded), then at least in terms of a status it maintains within intersubjective categories of experience. Yet the specific characteristics and qualities of an audibly 'real' spatiality, I propose, depend on radically subjective-relational transformations. The suggestion is that any noticeable space in sound is an *emergent property* formed by interactions between listeners and contexts of sound; and that audible spatial qualities are indicative of expanded, resounding, contexts. As a result, the terms through which sound-space appears are essentially observer-centric, producing a range of discernable spatial presences. In addition, the variety of sonic presence experienced by a group of listeners at a common location do *not* relate back to a presupposed, objective, 'acoustic event' but rather indicate a form of *aggregate-realism* where the collected *experiences themselves* form multifaceted yet concrete appearances, characteristically ambiguous and at times contradictory in temperament.

My attempt is to broach common-sense notions of audibility by adopting an operative mode of hearing that suggests a polyphonic approach to spatiality. To arrive at an expanded understanding of sonic spatiality, I will compare two perceptual categories, namely hearing 'reverberation' and listening for 'pitch'. Admittedly these two examples do not sufficiently conclude, nor amply explain the broader implications suggested in the introduction. None the less the choice of these examples has to do with the seemingly unproblematic and clearly defined categories they maintain within common-sense notions of hearing: on the one hand hearing a 'space' *within* which a sound is understood to be *contained* (reverberation) and on the other hand hearing an *inerrant* 'characteristic' of sound (pitch). My hope is that by taking two disparate positions in auditory sensation, that these examples may indicate other, less defined, categories of hearing that in turn can be considered in a similar vein.

This analysis is indebted to an idea of 'immediate experience' as the primary condition from which 'space' (and its corresponding qualities) are seen to arise as secondary attributes. In that sense 'heard spaces', necessary include within them sensory encounters with lived-time that suggest embedded attitudes towards perceptual experience (attitudes that can be both intentional as well as unconscious or absentminded). Hearing space involves a particular kind of kinesthetic: namely the specific experiences generated from the friction between 'listeners' and a 'locale'. The degree to which spatial attributes in sound are an *outcome* of situated perceptual interactions becomes apparent when examining our capacity to localize sound. From the physical (as well as the physiological) standpoint, sound is a tactile event, entering the body from the surface of the eardrum. Nonetheless, sound is rarely perceived to be occurring at that position on the body. Instead, sounds are projected unconsciously into *external* locations from where they *seem* to be emanating. The process of perceptual localization is a complex matter, but suffice to say that when hearing is considered from the position of physical acoustics certain asymmetries arise between the position of stimulus waves and the perceived location of sound sources.

The domain of acoustic propagations itself could be considered the primary space of sound. Acoustic space, or what could be called 'phased space', is that territory where tangled vibrations travel every which

1 Ganchrow, R. "Shapes of Time: an experiential account of sonic spatiality." In *Music, Space and Architecture*, edited by Maarten Kloos, Machiel Spaan, and Klaas de Jong, 141–45. Research—Reflections—Projects 05. Amsterdam: Architectura & Natura, 2012.

way, oblivious to any intentions of a listener. This is also arguably the most measurable space of sound. After all, the accuracy of wave equations are indebted to this particular category of space. On the other hand, acoustic space, with its pronounced empirical access, is also the one space that cannot be entered by way of the unmediated senses. In fact we can never physiologically *hear* such a space. It is only by way of instruments and calculations (after sound has been geometricized and frequency has been spatialized) that the pronounced dimensional-voluminous character of acoustics becomes tangible.

Our ears communicate quite a different spatiality *in* sound, materialized from within continually unfolding modulations. These emergent spaces are sustained upon fluctuant interrelations within events. In the absence of listeners these spaces remain concealed potentialities, diffuse and embedded within innumerable vibrational interactions. That is not to say that the 'phased space', mentioned in the pervious paragraph, is any more or less of a 'space' than those perceived through listening, but simply that the *qualitative aspects* of a sonic space are dependent on the particular *mode of listening* that is applied (and this includes technical modes of listening such as microphone recordings and acoustic cameras). In other words I'm suggesting that no audible space is more primary than any other within a given auditory context. In fact several such spaces may seem to overlap, coincide, or even coexist at the same locale. Furthermore, the biological capacity to 'hear' space (in terms of an ability to discern particular qualities within an audible context) is considered here in terms of a 'practice' rather than a biological constant. The more one trains certain modes of listening, the more a specific set of emergent sonic qualities become noticeably present. Likewise, the more one *expects* to find space within sound, the more those spaces tend to appear.

When listening through the unmediated ear, the *dimensionality* of sound becomes an audible *spatiality* when it is folded back into experience. Sound must pass through a perceptual process of sustain and prolongation before space becomes audible. Reverberation reveals a resounding presence in architecture inverse to its degree of vacancy. But what exactly is heard in architectures confined emptiness? In the example of perceived reverberation, the impression of expansiveness depends, quite literally, on durational compounding of successive intervals. It is not the sounding of mute walls that is heard but rather an activation of *intervalic-timbral* relationships. Only a portion of sound emitted within a room arrives directly to the location of a listener, most of what is heard has already rebounded off the various walls and surfaces before arriving at the ears. These movements unravel the time of the sound source, imprinting and extending vibrations into the cavity of the room. Sound propagation travels in all directions simultaneously, such that the reflections have a mirroring effect, resulting in a rapid onset of crisscrossing sound paths, themselves recursively altered by the acoustic characteristics of the hall. A simple impulse emission, such as a handclap in a room, very quickly becomes an immensely complex acoustic situation. It takes the attendance of an active ear to take hold of the multitude of interactions, prolong their perceived presence, and provide an immediate sense of the *progressive interrelations as a whole*.

The space *in* sound manifests only when sounds are permitted to linger in the ear. It is important to stress that the perception of reverberation, itself a fundamental category of sonic spatiality, emerges from compounded continuities. The particular lingering that results in perceived 'reverberation' is achieved by collapsing rapid, successive, wave reflections into one another so that every instance of 'now' contains shadows of that which has just past from existence. In reverberation, one cannot distinguish solitary sound reflections as they are delivered to the listener at too fast a rate to contemplate individually. Instead they are comprehended all at once. This process involves taking hold of the unwinding time of the sound source (located in the patterning of propagating waves) and coiling that expanded time back around an instance of sensation. In that sense the perceived spatial quality of reverberation is not so much an 'aural impression' of the physical chamber, imparted upon the listener, as much as it is an encapsulation of all the incidental relations between body, place and event constituent of that particular instance of hearing. In other words the material and tectonic properties of the chamber only partially contribute to a much more complex set of underlying relations conveyed to the listener as a totality. Practically speaking, the sensation of an audible 'now' is comprised of an immediate past. What is heard in a present moment is a compounding of that which has just occurred, together with the tendency towards what is yet to come and made available to consciousness all-at-once. The audible present is a thickened condition, where instants of simultaneity melt into one another, forming distinct atmospheric spatialeties. These atmospheres, to a certain extent, condense and embody the central relations in an unfolding 'event'.

Another category of aural qualia that seemingly bypasses the question of space altogether is that of pitch. In the case of frequency fluctuations, the perception of discernable pitch arises from listening into continuous, periodic, oscillations. The perceived tone height of an oscillation is relative to the specific frequency, or rate of change, at which the vibration alternates. The specific architectural conditions in which a periodic oscillation is heard has very minor, if any, influence on the perceived pitch. In fact, if one was to transmit the same periodic signal directly at the ear's aperture as well as from the far end of a hall, the same pitch would still be discernable. It would seem then that pitch constitutes a distinctly separate sonic category than that of space mentioned in the example of reverberation. On the other hand when examining the process through which qualities of pitch, timbre and tone arise some striking similarities can be discerned. To begin with, in terms of relationships between stimulus and perceived outcomes, the qualities of pitch have no similarity to the intermittent waves seen in specialized photographs of sound propagation (the 'phased-space' of acoustics). Most notably, audible pitch is continuous and enveloping whereas the acoustic waves are intermittent, spatially elongated and enumerative. Secondly, the ear does not count the number of consecutive oscillations when perceiving pitch but rather compounds motions into discernable shimmers. Hearing tone height means that the entire series of consecutive oscillations are synthesized and conveyed to the listener all-at-once. Each progressing instant of hearing tone, contains within it a buildup of immediately preceding moments, thus creating the sensation of a continuous flow with sustained qualitative attributes. More importantly, the perceptual process of *compounding* seems to be a key factor in the palpable articulation of qualities suggesting that there may be more than a casual relation between what is considered 'timbral' and what is deemed 'spatial' in sound.

Distinction between 'qualities' and 'spatialities' in sound is a superficial one, stemming from social habits invested in the utility of the respective sonic definitions, and that the difference between sound spatiality and sound pitch is one of degree and not one of kind. On an operative, perceptual level, one could consider audible space as a form of 'qualitative' perception or conversely think of pitch as supporting an unusual idea of 'spatiality'. The latter definition, although somewhat counter intuitive, has in my view more significant implications. This is not merely a matter of preference, it has to do with an understanding that any materialization of sound into palpable qualities *necessarily* manifests a corresponding idea of 'space' within which such materials are seen to reside. Applying this notion to the category of audible spatiality, two points to be stated: Firstly, that degrees of perceived spatiality are an outcome of interactions between observer, event and locale. Secondly, that there is no singular sound-space but rather an open ended set of spatial territories, each containing its own logic and particularity. Reverberation, pitch and timbre can be understood as varying interpretations of the same kind of qualitative experience, namely: heterogeneous forms of audible spatiality.

From the experiential position (and this applies to sensations in general) there is no such thing as perceived qualities devoid of spatial attributes. Qualities always occur 'in', 'on', 'beside', 'behind' or 'around' something else. Returning to the example of frequency, if pitch can be contemplated in isolation, e.g. without an intervening space of emission, then this suggests the perception of pitch *itself* may be a peculiar condition of expansiveness. That is to say that listening to frequency is an attentiveness to the spacing of micro-intervallic fluctuations and hearing a discernable spectrum could be considered as an intuiting of various patterned emanations of time. Such a broad-based definition of sonic spatiality not only accounts for hybrid conditions between the so called 'concrete' and 'abstract' sonic appearances, it can also grant ontological status to more vague categories such as 'sonic social space' (as a description for an evoked audible domain of conversation). In that sense, each sound-space is also descriptive of a corresponding 'framework of action' and differences between spatialities are determined by variance in degrees of *relational complexity* inherent to corresponding frameworks of action. For instance, a pitch-space includes a reduced framework focused primarily on relations between chromatic oscillations and postures of observation. Doppler shift indicates modifications in the framework of those relationships. Whereas, reverberation includes a greater number of relational interactions.

Categories of audible space can be understood to substantially exist yet at the same time they display an inherent fragility: Once the listener is withdrawn from a sounding context, space shrinks back into the expanse of vibrational interactions. The transience, malleability and listener-centric nature of audible space calls attention to the importance of individuating audible spaces. To a certain degree, acts of naming have a structuring capacity on the realm of appearances. Names are form-giving portals through which the world tends to deliver itself back to us. Linguistic categories enforce and encapsulate constellations of perceived qualities deemed particularly useful and transport them into a broader social consciousness. Specialized acoustician nomenclature attests to the utility in naming experiential categories of sound, at least in terms of the historic implications to developments in dedicated listening halls. At the same time, the futility of a definitive 'spatial taxonomy' of sound should also be acknowledged because the conditions through which something is 'significantly heard' is perpetually adapting. Transformations in the backdrop of listening occur both on the level of individual capacities to 'tune-in' to spaces as well as within a broader context of listening itself.

The potential of an expanded spatial hearing, is not merely a matter of auditory concentration. Much of what can be heard is not reducible to a set of listening exercises. Social, historical and geographical contexts arguably play a crucial role to a variety of epistemic meanings ascribed to instances of hearing. The role of an historical constitution of the senses is not to be under-estimated, especially in terms of ascribing spatial-material meanings to sound. Hearing relies not only by the space and place within which the sounding event occurs, but also by the myriad of expectations, prior experiences and listening practices that preceded and inevitably oriented that moment of hearing. The cultures of listening are shaped by the accumulated intentional as well as absent-minded techniques and practices within which common-place hearing is embedded.

The variety of spaces derived from of an expanded sense of listening are never fully comprehendible as their potentialities reorient in the double pull between degrees of listening attention on the one hand and the context that creates such attentiveness on the other. Nonetheless, listening to the site of sound in any situated context potentially opens into a vast array of spatial murmurings.

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Chapter 02

Hear and there: Notes on the Materiality of Sound[1]

From the position of the listener there is no resemblance between the contours of experienced sounds and the shape of acoustic wave phenomena. In other words, there is no mimetic similarity between the qualities of perceived sounds and the presence of the vibrations in air from which these perceptions arise. Also, when considering the sensation of sounds, particularly with respect to the experience of tone, there are instances when audible sounds cannot be traced back to a corresponding source of vibration.[2] This notable gap between 'sound measured' and 'sound perceived', both in terms of material forms and connective asymmetries, tends to polarize sound into 'physical' and 'psychological' acoustics.[3] In this sense any inquiry into a dimensional nature of sound seems to be foreshadowed by a contextual binarism where one is required to simultaneously inhabit adjoining chambers protruding from either side of the tympanic membrane.

Hearing space entails enduring signals. We internalize fluctuation that give depth to concrete sensations and shape to acoustic durations. Audible worlds congeal every time we lend an ear to the vast acoustic tangle in which we are immersed. For the listener, the space of hearing reveals itself to be an uninterrupted interior, where boundaries drift incessantly outwards with every step towards an edge. Within an auditory scene, sounds appear as qualitative experiences with more or less distinct characteristics. The transformation of acoustic-flux into objects of cognition is an inbuilt characteristic of perception. It is through this innate ability to grasp sensations reflexively, that innumerable acoustic fluctuations gradually appear to the listener as solitary, identifiable, events. It is also by way of this learned experiential language that the body is able to navigate an otherwise infinite field of sensations.

Concurrent to the cognitive space of apprehended sounds, a separate view can be opened into the physical life of waves. This vista delineates another kind of sound-space quite remote from the stable confines of perceptual certitude. Acoustic studies into the principles of sonic behavior including transmission, propagation as well as properties of reflection and absorption, particularly since the nineteenth century, indicate a move towards a physicalized understanding of vibration, *i.e.*, uncovering a sonic materiality quite different than the ephemeral traces impressed by audible sensations. Central to this notion is the spatiality inherent in descriptions of propagating waves in themselves. To constitute this remote space of vibrational interactions demanded relegating the sensorium outside the acoustic frame, opening instead into the broadband spectrum of physical vibrations. In this window onto phenomena, from the subtlest ultrasonic agitations to the grand seismic rumbles deep within the earth's crust, space began to quiver with implicit activity.

But in fact enumerating the dimensions of sound is not so much a matter of defining two kinds of

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1 Ganchrow, R. (2009). "Hear and There: Notes on the Materiality of Sound". Oase, 78, 70–82.

2 Two prominent conditions where phantom sounds are perceived are the examples of tinnitus and combination tones. The term 'tinnitus' describes a condition where a sound is discernable within the human ear in the absence of corresponding external source. The term 'combination tone' describes a psychoacoustic effect, where a tone is psychologically audible but has no measurable physical existence. The phenomena manifests as an audible presence of a third perceivable tone when actually only two tones of particular scalar proportions are sounded simultaneously.

3 This distinction in many ways has become a normative mode of acoustic thinking. For instance in Jens Blauert's account of spatial hearing, published in 1997, he open the discussion with the clear bifurcation of sound: "Terms such as 'sound source,' 'sound signal,' and 'sound wave' will always be used to describe physical phenomena that are characteristic of sound events. What is perceived auditorily will be denoted by the adjective 'auditory,' as in the term 'auditory object' or, preferably, 'auditory event.'" Setting up a distinct terminology is backed up later in the text with an explicit differentiation between the two aspects of sound: "More generally, the fact that a sound event does not necessarily produce an auditory event, and not every auditory event is connected with a sound event, must exclude the interpretation that one leads to the other in a causal sense…The common belief that sound events cause auditory events is, consequently, understandable, but nonetheless incorrect." J. Blauert, *Spatial Hearing: The Psychophysics of Human Sound Localization* (Blauert, 1997, pp. 2–3).

sonic spatiality as it is about discerning the various *modalities* within which materialities of sound are seen to take shape. In this sense there are no spaces connected to either side of the ear just as there is no absolute sonic-spatiality that needs to be defined but rather heterogeneous and intermittent contextually constituted materializations of sound, where each instance spawns a slightly divergent take on the spatial characteristics of vibration.

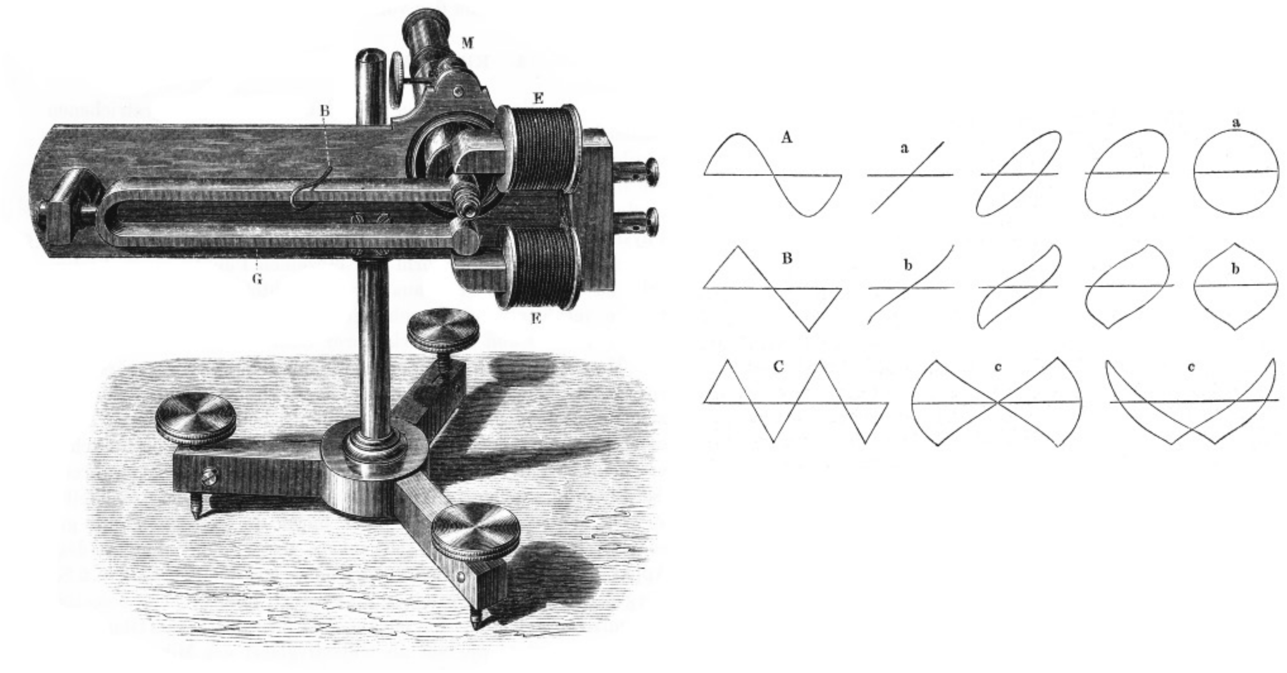

Figure 2.1 Hermann von Helmholtz's 'vibration microscope' and corresponding 'vibrational curves' observable in the microscope. Form von Helmholtz's book On the Sensations of Tone as a Physiological Basis for the Theory of Music, 1863.

To materialize sound is also to make corporeal artifacts from durational flux. Constituting any materiality from within vibrational transience will simultaneously constructs a corresponding space within which certain aspects of sound are seen to operate. In other words, every materialization of sound is already spatialized within the limits of its own comprehension; and attention to these descriptions not only gives access to the capacities (and limitations) of diverse notions of sound-space but also hints at the socio-cultural context that allows for these interpretations of sound to take shape in the first place.[4] Any account of spatial-material aspects of sound is also an account of less tangible transformations taking shape within the attitudes of listening and more generally speaking amendments to normative understandings of space, time and place. In order to grasp these shifts it is important *not* to separate between the various cultural and the scientific disciplines within which sound experimentation and production takes form but rather open into the eclectic field constellations operating on the structures of listening. Developments taking place in specialized fields of research as well as commonplace technologies of sound production are all seen to partake as diverse structuring agents, allowing certain materializations to take precedence over others. At times these spatialeties will be seen to subsume one another, while at other occasions they remain disparate and incompatible in a way where they nearly interfere with one another. The following example traces an instrumental view opened onto sound where waves take shape as independent 'objects' and briefly traces the impact of this view on developments in architectural acoustics.

Prior to the development of electro-acoustic methods, 'seeing vibration' (not only as waves) played

4 The more contours we ascribe to the psycho-physiological aspects of sound, the more distance the cognitive space will seem to take from the remote realm of physical vibrations. At the same time this drifting apart invites moves to eradicate such imagined distances by giving rise to alternative definitions and practices. Contemporary accounts of sounds contribution to the experiential dimension of architectural space might be better understood in terms of bridging this polarity. Similarly musical trends that emphasize a tactile physical abortion of sound vibrations through the body rather than the ear can be read in this light.

an important role in the historic epistemology of sound. From the enigmatic Chladni figures (revealing modes of vibration in membranes), to graphic vibrating string patterns rendered visible through the mirrors and lenses of Lissajous (later implemented in Helmholtz's 'vibration microscope'), to the bore-bristle waveform registrations of the 'phonoautograph' - the visibility of acoustics continually underlined the dimensional characteristics of sound. But it took the force of August Toepler's technical ingenuity to decisively displace the sonic ripples out from the reservoir of metaphors and into the realm of empirical tangibility.

In 1864 the German scientist August Toepler pioneered a technique he termed 'Schlieren-Beobachtung' ('striae observation') that led to the first photographic images of acoustic reflection.[5] His method makes visible the inconsistencies in air by way of a specialized photographic procedure. The innovation was to think of air as a continuous lens whose refractive properties are determined by the discrete pressure conditions over the framed zone of the image. Strictly speaking, the images produced via this method are not directly pictures of sound, but rather images of the way light bends around the pressure folds in air produced by sound. Toepler redirected photography's uncanny ability to turn light into synthetic artifacts by drawing the invisible through the sieve of optic representation. In Toepler's mechanism, sound itself is made visible by casting sonic shadows into the electromagnetic spectrum.

This particular window onto acoustics, where both the sounding object as well as the listener are intentionally muted, opens a view onto the material body of reverberation itself. Here, the receding angular lines of perspective are replaced by the interval of time-pressure zones marked out as alternating gradient patches of energy phase position. And where sound fills the optical gaps of depth perception, space itself is rendered solid. In this space sound is portrayed as expanded and immersive, suggesting an infinite field of localized affect. And contrary to the photographic snapshot that seemingly isolates a moment out of the flux of becoming, schlieren images somehow manage to preserve a *kinematics* of that space as the angle of curvature and banded spacing simultaneously implicate a past condition as much as they anticipate a future mode of transition. Schlieren photography takes a literal section through an oscillating phased-space, a space that from the position of a listener amounts to a kind of spatialized duration. Once acoustic space enters the visible realm, vibrations themselves then become optical substances that must awkwardly find their place amongst the other 'things' in the world.

In the absence of technical possibilities for measurement of absolute sound intensity, Wallace Sabine, the founding figure of architectural acoustics, turns to techniques of sound visualization in order to answer questions about room acoustics. After success at determining the hyperbolic curve charting relationships between the volume of an auditorium, the type of material surfacing within it, and a quantity of audible 'reverberation time' he went on to investigate more complex phenomena of reflection and refraction, this time aided by Toepler's photographic technique.[6] In the case of Sabine, the necessity to employ opto-sonic transcription methods were more than a matter of convenience. In order to describe the precise relations between an acoustic event and a corresponding building, Sabine had to look at architecture from the inside, while occupying a posture where frequencies are seen to correspond with distinct physical sizes. The audible frequencies, from twenty to twenty thousand cycles per second that punctuate the various pitched notches on the musical scales, are the very same frequencies that define Sabine's sonic ruler of distances. For Sabine, the scale of tones corresponded to a telescoping slide rule spanning distances between 17 millimeters to 17 meters in length.[7]

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5 Notably the American physicist R. W. Wood published a series of sequential images, utilizing Toepler's schlieren method, in which sound is seen in various states of reflection rebounding off of a variety of geometric surfaces. The purpose of these acoustic images primarily was to illustrate the behavior of optical phenomena. Wood, R. W., *Physical Optics* (Wood, 1905).

6 For a description of the historic lineage of Sabine's research in relation to the transforming contextual backdrop of the American soundscape see E. Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900–1933* (Thompson, 2002). Thompson's description is particularly revealing with respect to Sabine's work as it places his research in the company of much broader developments within auditory techniques and practices of that time in a way that suggests the impact such research had on the prevelant listening practices, building codes and eastheto-cultural understandings of sound.

7 The speed of sound in air will vary depending on climate, relative humidity and altitude conditions, yet remains

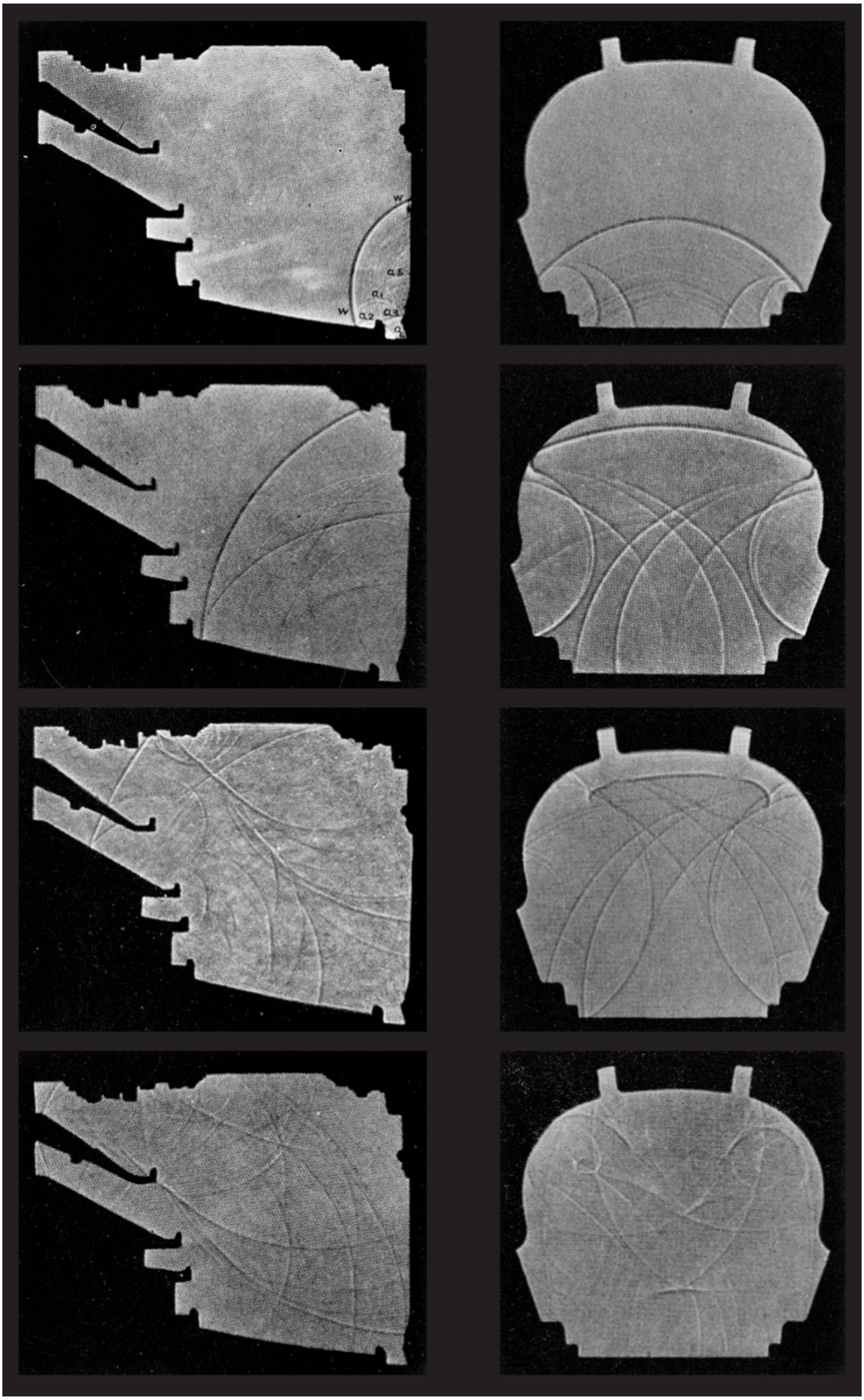

Figure 2.2 Wallace C. Sabine. Schlieren method photographic sectional studies of sound-wave propagation through scale models of the New Theatre, New York, circa 1913.

constant for all frequencies. The speed of sound in air at sea level in dry air with an ambient temperature of 20 degrees Celsius radiates at 343 meters per second. In other words the tone detected by the ear as an 'A', will have a corresponding pattern that repeats in air every 78 centimeters.

Borrowing Toepler's schlieren method proved to be effective in Sabine's task, the results of which are some of the first scale model descriptions of wave-front reflection and refraction off complex interior room geometries. In these studies, sectional plaster models (primarily based on existing concert halls and theatres) were used to chase the propagating wave fronts directly through the open model and onto a photographic plate[8]. In the images, reflecting echoes appear as sequentially shaded crescents of varying curvature – as if charting localized tensile adjustments in a progressing tremor over some gigantic membrane stretched across the architectural space. What emerges from these sectional studies is the superposition of space with its shadow: An immersion of a tectonically definitive frame onto a hazy broth of diffuse differentiation. One space is familiar, and the other remote and abstract, but somehow in the images these spaces are seen to communicate. Through the lens of sound, every chamber becomes a proposition towards an anticipated dialogue with crisscrossing pressure fronts, as if the graphic lines of the architectural section already echo with an implicit murmur.

The schlieren technique proved useful in describing the entropic permutations affecting a single wave front echoing through a modeled space. But it is in a more arcane drawing, predating the schlieren photographs, that Sabine fully comprehends the spatial structuring of frequencies in volumetric space. A drawing from 1910 charts the spatial pattern generated by a constant 248 Hz sine wave in a closed rectangular room. To achieve this map of a laboratory room at Harvard University, required the construction of an elaborate rotating pulley mechanism that could translate a horizontal spiral section of localized vibrations into a scalar registration on a linear filmstrip. The final line drawing infers the geo-spatial borders of relative loudness from the point-to-point transcription of vibration intensity registered on the filmstrip.[9] The resultant image is a topographic amplitude map tracing the peak and trough interference structure generated through the interaction of emitted and reflected sounds within a confined room. It is more than mere technical ingenuity that is reflected in this drawing, as it makes palpable, possibly for the first time, the invisible architecture of standing wave patterns that emerges when tone is taken out of the ear and placed instead into architectural space.

When sound traverses distance, it leaves a trace that unravels the time of its source. This time-pressure tapestry, in turn, extends towards all the dispersed surfaces and objects. At the same time, sound culls and preserves all of these chance encounters by imprinting slight irregularities into the chromo-weave of the progressing sound structure. The timbral characteristics as well as the environmental-spatial context inhabit this fabric as encoded possibilities. And within this tangled matrix the entire spatialized coherence is bundled up such that each singular presence interpenetrates all others. Then, to translate this vast acoustics into discrete images entails the pausing of vibration where frequency neatly aligns with geometric space and thus conforms with the traditional codes of architectural representation. Seen through Toepler's lens, energy-phase is ascribed an equivalence of gradient schemes. It would seem that to deliver sound into a world of appearances is also to give the intangible a name and a face, potentially fixing limits to a realm where there are none. Within vibrations themselves, there are no abrupt boundaries, no distinctive thresholds, only heterogeneous continuities afloat on a flux of becoming.[10]

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8 Sabine describes the procedure in *Collected Papers on Acoustics*: "The formation and propagation of echoes may be admirably studied by an adaptation of the so-called schlieren-methode device for photographing air disturbances. It is sufficient here to say that the adaptation of this method to the problem in hand consists in the construction of a model of the auditorium to be studied to proper scale, and investigating the propagation through it of a properly scaled sound-wave. To examine the formation of echoes in a vertical section, the sides of a model are taken off, and as sound is passing through it, it is illuminated instantaneously by the light from a fine and somewhat distant electrical spark. [The resultant photographs] show the sound and its echoe at different stages in their propagation through the room." W. C. Sabine, *Collected Papers on Acoustics* (W. C. Sabine, 1922, p. 236).

9 A detailed description of the setup can be found in Paul E. Sabine, *Acoustics And Architecture* (P. E. Sabine, 1932, pp. 44–46).

10 Just as the dawn of cinema threatened to relegate the idea of 'motion' to a sequence of freeze-frames, Henri Bergson proposed distinguishing between divisible trajectories and a realm of 'real movements', described at length in his book 'Time and Free Will' (Bergson, 1913). In a similar vein, it would seem that the interpherometric-space immobilized on the photographic plates of Toepler requires the contentions set forth in Ernst Mach's realm of 'elements'

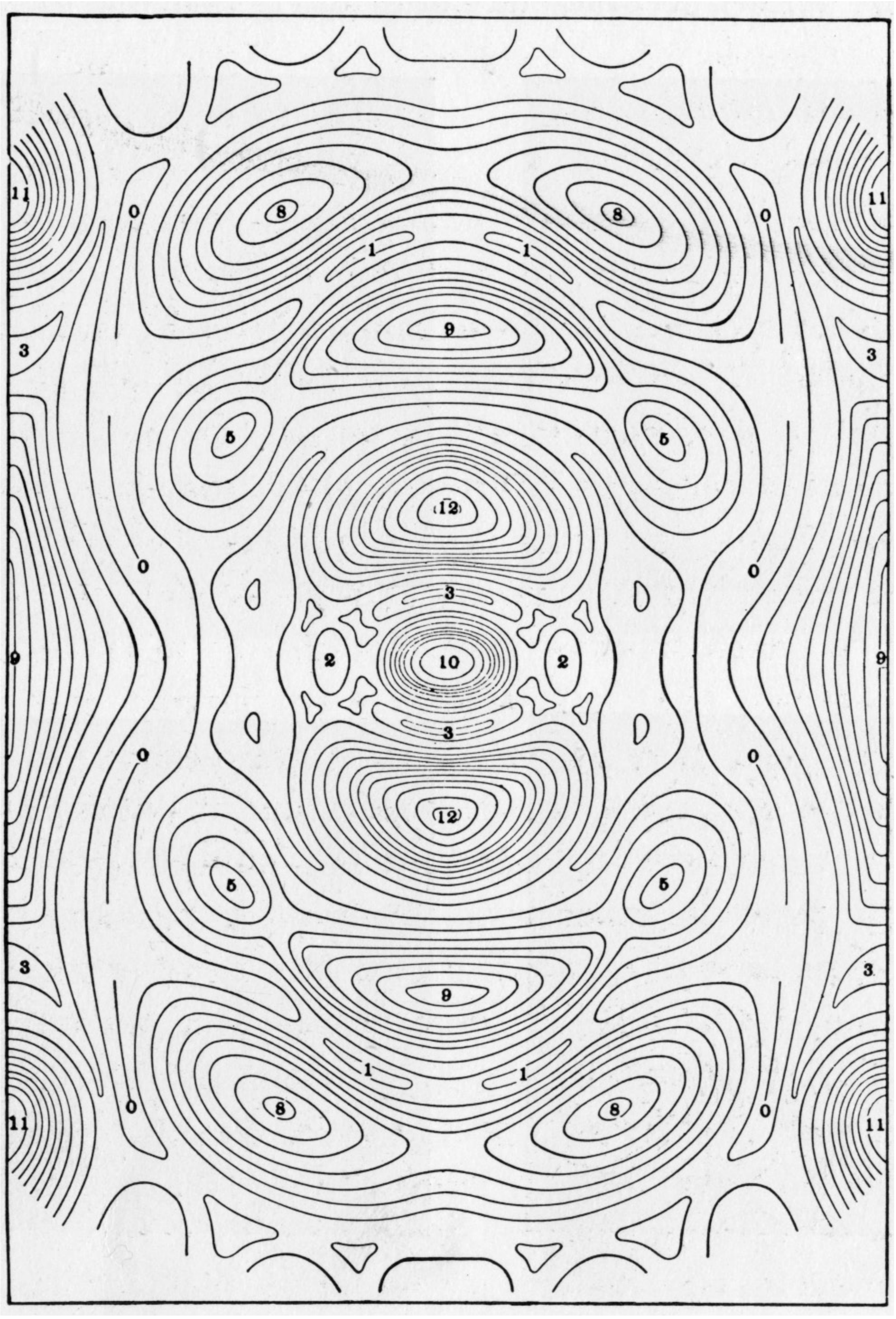

Figure 2.3 Wallace C. Sabine. Horizontal distribution of standing wave patterns from a continuous 248 Hz sound source in an enclosed rectangular room. Numbers between zero and twelve indicate the relative sound pressure at a head-level cross section through the space. Sabine derived this amplitude mapping from measurements taken in the Constant Temperature Room of the Jefferson Physical Laboratory, Harvard University, circa 1910.

(Elemente) (Mach, Ernst, 1914). It is within Mach's description of the primordial expanse of all-things-possible that the static gradient bands of Toepler's image become dislodged from the firm grip of the mind's eye and are cast back into the shivering propagation of matter.

To hear space is to derive a spatiality from a temporal event. To see sound is to wrap that same temporality in a tangible cloak. For the listener, the far unfolds from within the near by way of tactile interactions, where on the intimate surface of the ear, a sonic fragment effortlessly sets forward an impression of the whole. Though once the image of an acoustic space of interactions begins to exert its presence back into the chambers of hearing, it would seem that even the most attentive listening plumbs only one facet at a time from the vast myriad of interlocking event-structures comprising the entire field of sounds.

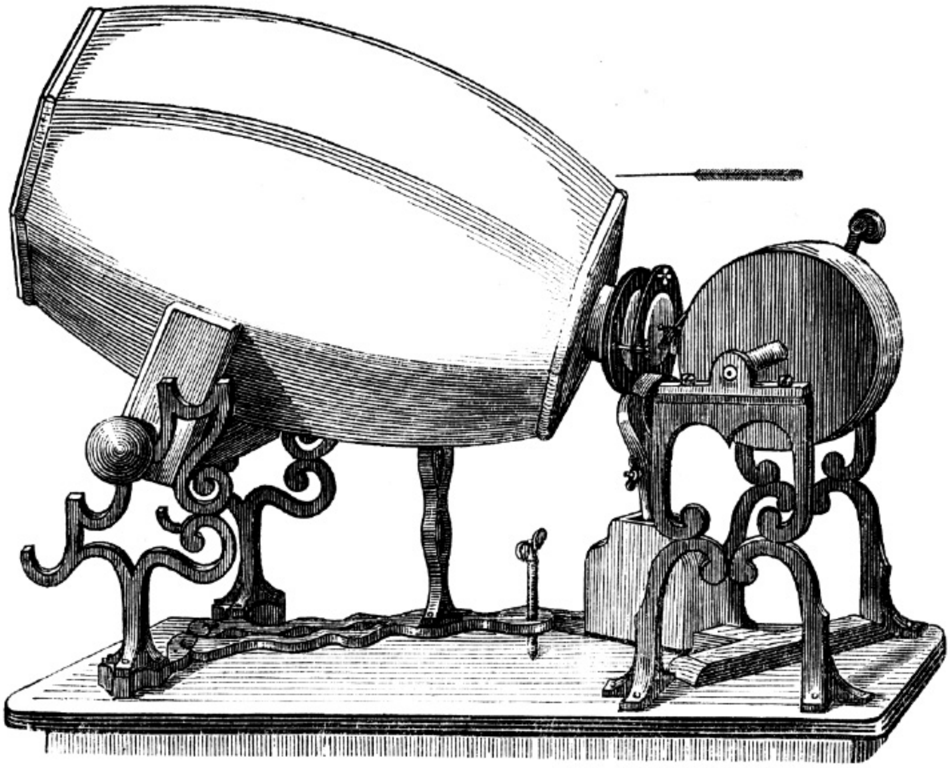

Figure 2.4 Scott-Koenig's phonoautograph and plotted waveform. This device, predating the invention of the phonograph by some twenty years, presents an early transcription method of sound into a visual medium without a corresponding means of play back.

Maybe it is in Edouard-Léon Scott's phonoautograph that one can find the most enigmatic formulation towards a materiality of sound, as the device neither describes the multitude of auditory spaces nor does it reconstruct a space of vibrations, it simply adds a distance to a one-dimensional oscillation and by doing so preserves the immensity of an auditory scene by balancing it in the thickness of a continuous line. It is this simple contour that somehow manages to chart the pulsating flutter from which to derive the full gamut of embodied sonic experience.

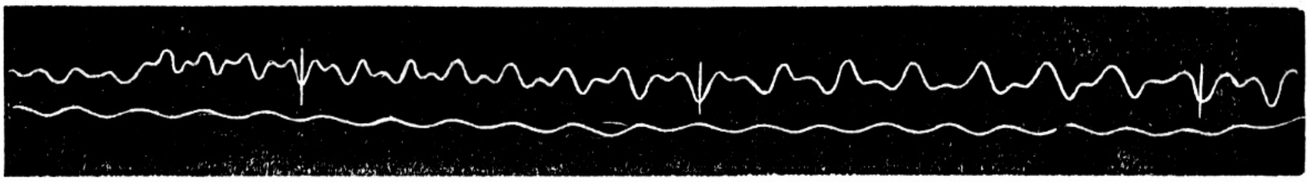

Figure 2.5 Scott-Koenig's phonoautograph plotted waveform.

The materialization of time-in-motion represented in Edouard-Léon Scott's physicalized waveform also anticipates Edison's tinfoil phonograph (a device that literally makes objects from sounds) predating it by some twenty years. The same waveform also has managed to wiggle its way into modern times by becoming the baseline interface representation in a multitude of audio related software. By avoiding the traps of mimesis the waveform turns towards the material properties of time, and instead of providing a space it summons up a curious road-map through which to navigate the material shivers of sound within a particular tremble of time.

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Chapter 03

Perspectives on Sound-Space: The Story of Acoustic Defense[1]

Armatures of Listening

Today's epistemologies of listening are not part of a premeditated advancement, but rather, results of cultural and social habits formed under immense fragmentary fields of interaction.[2] Although it can be said that the physiological capacities of the ear are for the most part determinant, the scope of 'listening' remains fundamentally vague. 'Listening' in terms of an attention-to-sounds-heard inherently expresses the categories we choose to extract from audible eventfulness. Tuning in to such categories may also reveal the meanings we tend to reversibly invest in matters of vibrations.

A history of hearing (if such a history can ever be palpable) would demonstrate the extent to which the characteristics of our audible worlds are historically and contextually constituted[3]. Attempting to decipher the contemporary armatures of listening would no doubt unfold along mellifluous and unpredictable lines, tracing the unintentional undercurrents set forth in the wake of pragmatic innovation. It is my hunch that in order to grasp such modalities of 'sonic attention' it is imperative *not* to separate the cultural and scientific fields in which sonic attitudes are formed, but rather, to open into the eclectic domain of practices, artifacts and peripheral influences operating upon the malleable structures of listening. The following account of acoustic defense provides a compelling artifact from our audible past – namely, one where particular configurations of listening are set forth in the development of long-range listening devices placed along the southeastern coast of Britain. I propose to consider this example as a solitary instance within the much broader reconfigurations of listening.

Acoustic Defense

During WWI, and in the years leading up to WWII, Britain was involved in a wide-scale project of acoustic defense.[4] The research aimed to locate enemy gunfire and aircraft movements by way of various listening devices. In this footnote to military history there is only a minor role delegated to electronic technology; instead research focused on an investigation into physical acoustics and reflective properties of rigid surfaces. Before the advent of sophisticated radar detection systems, surveillance was limited to information gathered directly by way of sight and hearing, and these initial sound-ranging devices extended the inbuilt

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1 Ganchrow, R. "Perspectives on Sound-Space: The Story of Acoustic Defense." *Leonardo Music Journal* 19 (October 28, 2009): 71–75. https://doi.org/10.1162/lmj.2009.19.71.

2 The following account, 'Acoustic Defense', is one instance in a series of formative moments of modern acoustics I have examined in terms of their implications towards what might be called 'epistemologies of sound-space' related to specific sites and practices of sound. The rather oblique case of acoustic defense has been selected for it's relative obscurity within the history of spatial acoustics as well as to support my intuition that if a space-in-sound is to be discerned, it is neither located in an absolute space of propagating waves nor in physiological capacities of hearing as much as focalized where the body and social contexts intersect and influenced by myriad peripheral aural practices extending well beyond commonly accepted borders of the 'cultural'. The story of Britain's 'Acoustic Defense Project' is based on my research undertaken at the site of the Denge mirrors in 2005 as well as some additional comments regarding the nature of hearing in relation to our techniques and practices of listening. Results from my research into the remaining sound mirrors at Denge were published in an essay titled "An improbable dimension" (Ganchrow, 2006).

3 For instance an exhaustive account of interrelations between technologies of sound, building practices and the cultures of acoustics in early 20th century America can be found in E. Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Cultures of Listening in America*, 1900 – 1933, (Cambridge: MIT Press, 2004). Such historically contextualized accounts of hearing lend compelling evidence towards the malleability of listening.

4 Military research into auditory observation techniques, leading up to Britain's acoustic defense project of the 1930's, dates back to 'gun sound ranging' experiments in the trenches of WWI. A preliminary description of these earlier developments can be found in Scarth, N. Richard, *Echoes From The Sky*, (Kent: Hythe Civic Society, 1999) pp. 4-10.

listening capacities of the human sensory apparatus, at times to the scale of buildings.

Architecture's acoustic focusing capacities were known from the examples of 'whispering galleries'. Sound transmission along curvilinear structures at times converges into focal zones due to the reflective properties curved surfaces exert upon the realm of fluid dynamics. Even a standard wall surface will reflect, on average, 96% of the incoming acoustic energy, and can be contrasted with the best, silvered mirrors whose reflection properties of light rarely exceed 90%. In the example of a dome, which approximates a sphere, any source sound that is transmitted from the center will create an echo that will refocus at the center point almost without energy loss.

Numerous examples of whispering galleries have been documented as far back as the 4th century where an 'S' shaped cavern at Syracuse, Sicily, was said to have been used as a pan-aural prison[5]. Along the apex of the cave runs a conical duct leading to a concealed room at the far end of the cavern where all the reverberating sounds of the prison could be heard. The surveillance principle echoes the more familiar example of Jeremy Bentham's panopticon prison yet is founded upon aural capacities instead of those of vision. Despite the prospects of intentionally incorporating such properties in architectural design, most examples of whispering galleries are thought to be coincidental flukes of construction rather than premeditated intentions of design. Even in the case of the 'Dionysian Ear' mentioned above, the cavern originally functioned as a quarry, and only later converted into a prison.

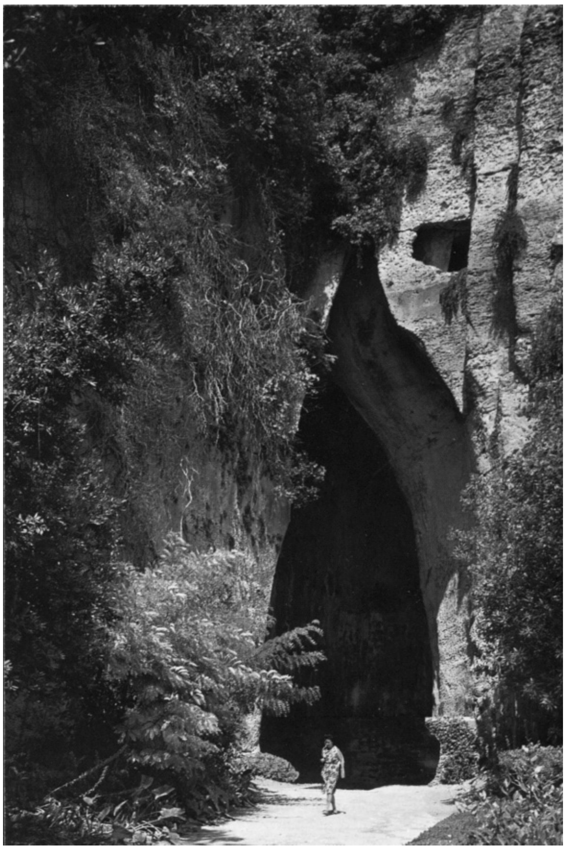

Figure 3.1 Whispering gallery at Dionysian Ear, pan-aural prison, Syracuse, Sicily (c. 4th Century BC).

In this sense, Britain's acoustic defense project is exemplary in that it constitutes a deliberate attempt to harness airborne vibrations by means of construction. In contrast to whispering galleries, the development of acoustic sound mirrors incorporated a refined understanding of sound wave propagation and reflection, oriented towards a narrowly defined subject of reception, namely, a certain range of wavelengths. Two types of listening dishes were developed over the course of the project: one, deeper with parabolic properties; the other, shallow with spherical curvature. In order to function properly, sounds had to arrive

5 A description of the so called 'Ear of Dionysius' can be found in W. C. Sabine, *Collected Papers on Acoustics*, (New York: Dover Publications, 1964) pp. 274 - 276

perpendicular to the opening of the parabolic dish, while the mirrors based on spherical sections were able to pick up sounds traveling obliquely to the surface of the dish. These defining characteristics led, on the one hand, to the development of rotating parabolic dishes, adjustable to the direction of incoming signals; and on the other, the construction of large fixed dishes called 'sound mirrors'.

Stationary sound mirrors were conceived as part of an early warning system, operating as long-range listening devices aimed at intercepting sounds of approaching aircraft outside the visual range. The problem the project sought to overcome was that of amplification: by the time distant aircraft sounds had reached the coast, the propeller and engine rumble had faded to such an extent that it was no longer audible to the naked ear. The solution was somehow to collect the incoming vibrations and refocus their energy back into audibility. This was done by means of the reflective properties of curved surfaces. Waves reflected off the concave spherical surface of the mirror form a hemispherical zone of wave enhancement midway between the mirrors center of curvature and the surface of the dish, called the 'caustic'. Any incoming signal becomes focused at a point upon the caustic that sits perpendicular to the incident angle, extending along a line that passes through the center of curvature.

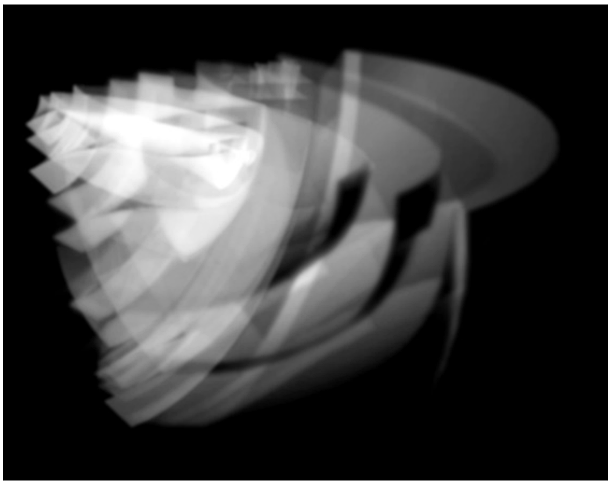

Figure 3.2 The development of a single incoming wave front superimposed in different stages of reflection off a sound mirror. Volumetric-sectional focal point study. (Illustration by author)

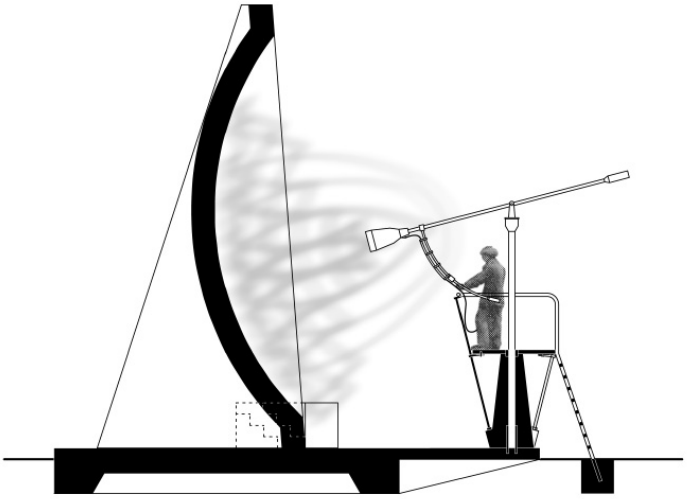

Figure 3.3 Drawing based on a photograph from 1928 of the 20 ft. sound mirror at Abbots Cliff, Kent coast. The mirror was designed to be operated by a single listener. Consulted document: The National Archive, ref. AVIA 7 / 2765. Strip mirrors 1926-1940. (Illustration by author)

Nearly all the mirrors built along the narrow stretch of Britain's coastline, from Suffolk in the north to Dungeness in the south, were based in spherical section design. Initial attempts at long-range listening began at Joss Gap, where bowl-shaped excavations were directly carved out of the chalk cliffs as early as 1918. Later efforts were focused at Hythe, Abbots Cliff and then at Denge, on the Kent coast, in what was to become the headquarters for 'The Air Defense Experimental Establishment'. In the marshlands extending towards the seaside, an assortment of freestanding cast concrete dishes were constructed and tested including a 20 ft. version and 30 ft. half-sphere 'listener', complete with a submerged listening chamber and rotating funnel. From within the chamber, personnel could scan the mirror's caustic by way of the funnel, channeling sound through an attached stethoscope.

Of primary concern for the design was the frequency components emitted by the aircraft, and the dramatic scale these concrete dishes attained is directly related to the physical size of the frequencies that the dishes attempt to detect.

> 'It has long been known that the most penetrating sounds for long distance transmission are the lowest pitched sounds with the greatest wavelength. Whereas the 30 ft. mirrors are

very efficient for waves up to 3 ft. or so, corresponding to the middle of the pianoforte scale, the sounds we wish to deal with have waves of 15 to 18 feet, and tend to become inaudible to the ear. This involves the extension of mirror surface to about 10 times that hitherto employed. The other dimensions are to be extended 10 fold […] Since for long distance listening of this type the elevation angle will be small, the vertical mirror dimensions can be reduced'[6]

In other words, the dish structures were literally tuned to the physical size of the airplane's fundamental frequencies; these being the deep rumble tones with superior transmission properties. To effectively pick up these 15 to 18 ft. long wavelengths, the equivalent of approximately 60-70 Hz[7], the most ambitious construction project was undertaken. In 1929, a 200 ft. strip sound mirror, 26 ft. high, with a double radius of curvature of 150 ft. and flanked by a sloping forecourt was erected at Denge. The surface area of this concave wall was extended to such a size that the swinging funnel collector and stethoscope used in previous constructions were replaced by a patrol of walking listeners.

Figure 3.4 Thirty-foot hemispherical sound mirror, Denge, 2005. (Photo by author)

The forecourt was divided into triangular patrol zones corresponding to a certain range of azimuths, extending out over the open sea. The focal point of incoming sounds was determined to occur along a designated arc at the front of the structure. Each quadrant was to be silently patrolled by a trained listener equipped with rubber shoes and unabrasive clothing. Additionally, a retaining wall was constructed at the front of the forecourt to reduce wind noise. One report even describes 'lateral canvas curtains' that were to

6 Dr. W. S. Tucker, a report quoted in Scarth, N. Richard, *Echoes From The Sky*, (Kent: Hythe Civic Society, 1999) p.93.
7 One document concerning the mirrors at Denge includes a chart of aircraft models analyzed and calibrated in terms of their specific acoustic-fingerprint denoted in cycles per second. The attempt was to gauge the size of the vibrations produced by the propeller's friction with air, combined with the noise from the exhaust pipes of the aircraft engine. What is important to stress here is a thinking of an acoustic vibration in terms of the physical sizes of frequencies. *Long Distance Listening with Sound Mirrors*, Document AVIA12/132, (London, October 1932), p. 14.

be placed on either side of the mirror to further reduce incidental noise. No photographic records support this claim, but one can only imagine the curious ceremonial appearance of the fully operational site.

Figure 3.5 Two-hundred-foot strip mirror at Denge, 2005. (Photo by author)

The early 1930's marked the peak of military acoustic research. After the completion of six large-scale mirrors, a proposal was drafted for an extensive early warning network, with mirrors placed at sixteen-mile increments forming a 'listening shield' extending from East Anglia in the north to Dorset in the south. But the plan was never realized. In fact, sound mirrors never developed beyond the experimental stage due to the discovery of a more powerful means of aircraft detection. In 1936, an airplane flying along the coast of Norfolk was pinpointed by means of RDF (Radio Direction Finding) at a distance that far exceeded the range attained by the mirrors. This event effectively sealed the fate of the acoustic defense project and announced the birth of radar.

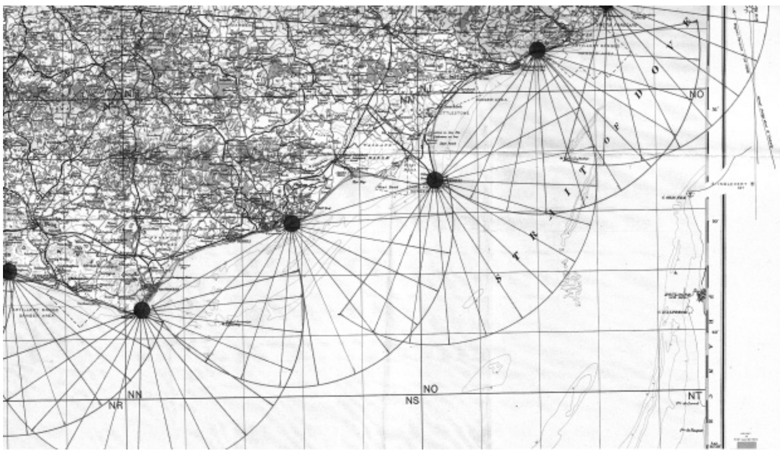

Figure 3.6 Acoustic defense 'listening wall'. Map indicating the location and listening extents of a coordinated coastal network of 200 ft. sound mirrors. (Photo: the National archive, ref. air 16/317 Sound discs and mirrors development 1934 Feb. - 1935 Nov.)

Tactile Perception

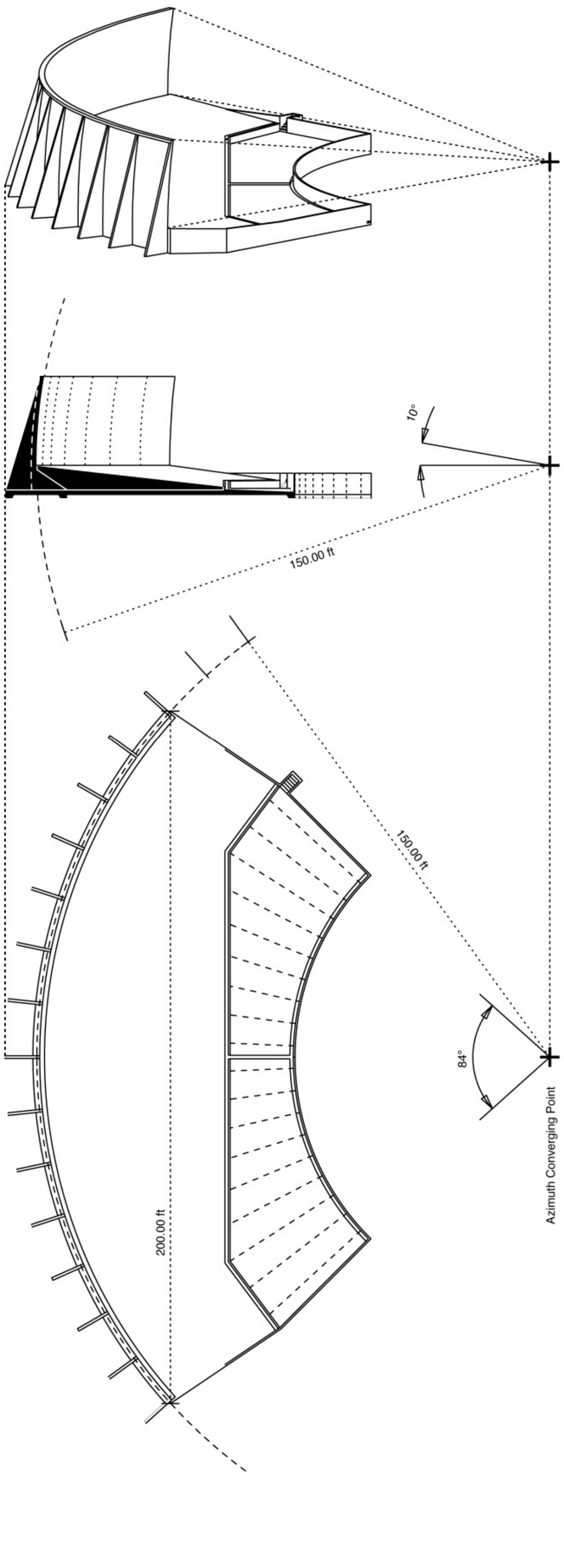

Figure 3.7 Azimuth converging point in relation to the tectonic configuration of the 200 ft. mirror. (Illustration by author)

The border occupied by the sound mirrors, between whispering galleries and advanced imaging technologies, arguably demarcates a paradigmatic shift in perceptual relations. Inherent to the anatomy of the mirrors is the shift in observational methods that move away from the optic model of the telescope (where the eye is seen to extend into a 'stable' landscape) to the radiant model of interferometry (where a point of observation becomes the anchor in an otherwise fluctuant zone of wave fronts). In the 200 ft. mirror, knowledge of a distant aircraft materializes from within the tactile registration of vibrations literally brushing up against a listener's ears. To hear a distant vibration, also means to physically collide with that same acoustic event at a specific focal point along the caustic arc designated in the forecourt of the mirror, thus conveying a location of sound that is as much 'here' as it is 'out there'. In this format of localization, an unmistakable sequencing of perception occurs - the undulating focal point of sound itself is primary, engaging the listener at point blank, while at the same time producing a secondary reference that is then conceptually (instead of reflexively) projected back over the horizon towards a yet-to-be-seen coordinate. One curious outcome of this condition is the evocation of coexistent (or superimposed) spaces where the close-at-hand and the far-off momentarily coincide.

This condition subtly violates the normative symmetry hearing maintains in relation to vision, namely that of apprehension at a distance. When confronted with sound's physicality, the listener begins to occupy a double position. The outcome is a shift between sound, temporality and perception when a 'viewer' becomes a 'listener', signaling a reorientation in the site of experience.

Importantly a 'space' that was previously deemed to be the outcome from a network of relations between dispersed objects within a visual field, is foreshadowed by the space of the *interval itself* – in other words a registration of the micro-spacing between successive fluctuations constituting an ongoing pulsation of appearances. Under the influence of the mirror, the commonsense Cartesian framework where solitary, identifiable sounds are seen to occupy coordinates within an otherwise empty, 'space', subsequently dissolve into a more primary continuum of pulsating Phased-space[8]. An understanding of sound as a pre-cognized state of crisscrossing interference patterns is embedded within the anatomy of the mirror by considering frequencies in material terms, and by imagining the peaks and troughs of vibration in terms of their corresponding physical sizes.

The idea of Phased-space effectively opens a portal into an impalpable realm of acoustic phase interactions where the patterning of abstract wave undulations perpetuate a secondary spatiality, emanating from the coordinated acts of listening, and where the 'distant' is foreshadowed by an immersive space of sonic eventfulness. The outcome suggests a loosening of the meaning-reflex through which sonic entities seemingly coincide with their opto-spatialized sources of emission.

In terms of the 'site' addressed by the structure of the mirrors, their technical functioning also serves to redefine their own architectonic extents: A case where the 'tectonic limits' are broken open to include an extensive territory of influence. In architectural terms, the 200 ft. wall extends well beyond its visible form by plumbing a malleable space between the wall and a remote resonating object. The result is a structure that relates very precisely to an expanse 84 degrees in width and approximately 128 seconds long; the territory that corresponds to the listening extent of the 200 ft. wall. Such implicit territorializing of a seemingly 'limitless' panoramic expanse is no better illustrated than in the map proposing the coordinated network of strip-mirrors along the southeastern coastline of Britain.[9]

Materiality of Frequencies

One apparent departure from prevalent sonic modalities embodied within the sound mirrors, relates to a spatial materialization of sound. The development of sound mirrors could not have been undertaken without a corresponding shift in thinking about sound's materiality outside of the way sounds are perceived. More specifically: thinking about frequencies in terms of physical sizes.

Once sound is conceived in its dimensional attributes, it also facilitates the superposition of an imagined acoustic terrain back into our observable surroundings. The materialization of frequencies into actual ocular artifacts is in fact a trend that has extensively played out over the course of the last half-century, particularly in the development of visualization apparatuses employing techniques of wave reception and radiation (such as ultrasonography, radio astronomy, and MRI). It is in this sense that the interferometric techniques may find their early antecedents with the case of the sound mirrors, a notable case where the mechanism of reception still plays out at the scale of the body, and where techniques of reception are little more than a fine-tuning of echoic principles of reflection.

Admittedly, the more recent radiant technologies no longer directly address the biological capacities of the human ear, yet nonetheless they extend the spectral boundaries of 'hearing' (at times bypassing the realm of acoustics altogether) while altering the significance of 'listening-in'. Such developments, I would suggest, exert pressures back onto our epistemologies of listening, consequently amending definitions of such categories as 'sound', 'place' and 'space'.[10]

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8 The use of the term 'Phased-space' is to assign a nomenclature to the spatial sound field seen from the position of the wave interactions themselves. It is a category that encapsulates both space and sound in a single description. Phased-space should not be confused with the term "phase space" from mathematical analysis. It is my intention to emphasize the phenomenal underpinnings of phased-space.

9 For information on the coastal mirror network project see document ref. AIR 16/317, *Sound discs and mirror development 1934 Feb. – 1935 Nov*., (The National Archive, London)

10 An article published in the journal American Scientist, titled 'The Sounds of Spacetime', describes attempts at detecting gravitatiownal waves in terms of 'listening'. Although these waves are expansions and contractions in spacetime itself, the article repeatedly utilizes the word sound to describe such vibrations. It would seem that an abundance of methods for transduction (implemented in devices that can translate magnetic or electromagnetic fluctuations into audible signals or visa versa) has thoroughly prepared the way for an expanded notion of sound as an inclusive terms covering the broadband spectrum of terrestrial vibrations. See C. J. Hogan, 'The Sounds of Spacetime', *American Scientist* Volume 94, no 6 (2006), pp. 534 - 541

Epilogue

Although in empirical terms, the realm of acoustic fluid dynamics is rather well understood, the notion of a 'space-of-sound' maintains an ambiguous status. This is particularly the case when approaching the terms of spatiality from the position of the listener. It is my current assessment that there is no singular (and certainly no 'absolute') sound-space. 'Hearing space', pertains to multiple notions of space, where each space corresponds to an alternate material understanding of sound, and furthermore that these spatialities do not necessarily subsume one another let alone correspond to each other. The same practices that enlist sound as fundamental, tend to perpetuate and sustain their latent spatialeties as byproducts of their own implementation. In that sense sound-space is as multiple as the defining characteristics we choose to discern within audible (and even inaudible) vibration. And achieving an expressive articulation of spatial sound is to my view less a matter of innovations in audio technique and more a question pertaining to various degrees of listening. Sound's spatialities are approachable by adopting attentive attitudes towards those sonic sediments already in circulation within the social-cultural environment as well as sharpening our own spatial-sonic definitions and maybe most crucially: exercising an intention to significantly 'listen to space'.

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Chapter 04

Phased-space[1]

How can the pronounced temporality of sound be understood in terms of corresponding spatialities? For the situated listener, sounds seem to surround a point of observation, giving an impression of apprehension at a distance. But sound is also a physical phenomena enveloping the listener. Sound communicates its contours by way of tactile intrusions upon the surface of the eardrum. In spatial terms sound simultaneously occupies two locations for the listener – the one situated at a distance, the other positioned strikingly close at hand. Frequency oscillations are also distances traversed, to the extent that eachcycle heard is also a spatial disposition with intervallic attributes that unfold in a space where tones can be seen to fit into a corresponding scale of physical sizes. The listener is at once immersed in such fields of fluctuating waves as well as located between discreetly oriented sounded events. An application of acoustics, considered in terms of vibrational 'matter', can be discerned in auditory practices implementing phased array loudspeaker configurations. Wave Field Synthesis pronounces one such take on a materiality of sound where localized tactile interactions between 'observer' and 'observed' are simultaneously the posture from which immense soundscapes unfold.

This text aims to highlight certain aspects of sound by coupling considerations from wave field synthesis[2] with aspects of Ernst Mach's approach to sensations. The attempt is to set up a system of resonances that intentionally exceeds both contextual frameworks: on the one hand relating Mach's principles to practices that extend beyond his original investigations; and on the other hand, applying a theoretical framework to practical techniques of spatial sound production that do not outwardly announce such theoretical pretensions. This particular coupling is focused upon an account of what might be termed 'Phased-space,'[3] a meta-perceptual domain of phenomena within which both Mach's experiments and wave field synthesis are seen to intervene. My intention is to outline the implications set forth by a materialization of 'Phased-space', particularly with respect to the bearing it has upon the relations of sound-space-listener.

Ernst Mach recounts an autobiographical experience as the foundational moment for his intuitions of material existence:

> 'I have always felt it as a stroke of special good fortune, that early in life, at about the age of fifteen; I lighted, in the library of my father, on a copy of Kant's *Prolegomena to any Future Metaphysics*. The book made at the time a powerful and ineffaceable impression upon me, the like of which I never afterwards experienced in any of my philosophical reading. Some two or three years later the superfluity of the role played by 'the thing in itself' abruptly dawned upon me. On a bright summer day in the open air, the world with my ego

1 Ganchrow, R., 'Phased Space.' In *Chrono-Topologies: Hybrid Spatialities and Multiple Temporalities*, edited by Leslie Jaye Kavanaugh, 179–93. Critical Studies, vol. 32. Amsterdam; New York: Rodopi, 2010.

2 My recent development of a wave filed synthesis system for electro-acoustic music in the Netherlands was designed to provide a 10 meter x 10 meter listening arena for acoustic rendering. The aesthetic-cultural implications of WFS as a platform for electro-acoustic music production was of primary interest in this project, particularly with regards to the social contexts and theoretical concerns of music and listening. The project, initiated by the Game of Life foundation, builds on experiments I conducted at the Institute of Sonology, Den Haag between 2002-2004. The initial algorithm (a geometric implementation of dynamic space-time mappings), has been extensively developed into a full GUI user interface by Wouter Snoei with the assistance of Jan Trützschler von Falkenstein. Generous technical support throughout the project was provided by Dr. Diemer de Vries and the Technische Natuurkunde department at TU Delft, the department in which the technique of wave field synthesis was originally pioneered.

3 The use of the term 'Phased-space' is to assign a nomenclature to the spatial sound field seen from the position of the wave interactions themselves. It is a category that encapsulates both space and sound in a single description. Phased-space should not be confused with the term 'phase space' from mathematical analysis. It is my intention to emphasize the phenomenal underpinnings of phased-space.

suddenly appeared to me as one coherent mass of sensations, only more strongly coherent in the ego. Although the actual working out of this thought did not occur until a later period, yet this moment was decisive for my whole view'.(Mach, 1914, p. 30)

As a specific sensation, sound would become an important object of investigation in working out his original intuitions. Sound provides a pertinent subject matter in which to test correlations between the observer and the observed. Sound emanates from a realm of crisscrossing vibrations, though for the listener sound never appears in the shape of its vibrations. Every sound emerges in perception as a fluctuations (re) cognized. As a result, most profoundly, audible sounds are always chronometrically articulate as well as spatially present. Indeed, a sensation of a sound cannot be perceived that is not already emanating from a discernable source. Even with the case of deep bass tones, sound seems to emerge from 'everywhere' and never from 'nowhere'. On the other hand, if we were able to peer into the expanse of vibrations, there would be little hope of identifying similarities between the spatio-temporal articulations familiar to our audible worlds when compared with the dense mass of enfolded sonic activity literally suspended in air.

The interplay between these two aspects of sound: the space of acoustic eventfulness, and the unfolding spaces of listening is the relational paradigm underlying the technique of wave field synthesis. Wave field synthesis (WFS) is a spatial audio rendering method that applies algorithmic calculations of acoustic transformations in the service of materializing unfolding fields of acoustic vibrations.[4] WFS utilizes individually amplified, sample synchronized, transducer arrays in order to dynamically shape acoustic vibrations into a choreography of spatial-sound relations. Within a four-sided array, arranged to provide a rectangular territory for listening, it becomes possible to materialize a confined field of sonic interactions cut out as it were from an enormous acoustic expanse.

Wave field rendering implements an understanding of acoustics that does *not* try to replicate hearing. It is a method that stands in sharp contrast to other electro-acoustic techniques that *simulate* the perception of localized sounds. Simulations will often employ physiological and psychological aspects of hearing (such as mapping the directional frequency characteristics of the pinna) to give an impression of sound localization in an imaginary space.[5] The result is a kind of duplication of aural functions back into sound thus imposing an 'externalized ear' onto the matter of acoustic waves. In such audio setups, the sounds we perceive have already passed through a pair idealized ears.

WFS acts upon the air itself, in the domain of physical acoustics. Its operation relies on considering sound in terms of its material manifestation, and thinking of frequencies for their corresponding lengths and sizes. Instead of measuring sound from the gauge of an ear, WFS acquires its measure from the crest to crest spacing of successive traveling spherical waves. The technique maps vibration into spatial contours, shaping

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4 These combinations of calculations describe conditions where the 'state' and 'location' of energy is determinant within a given moment in time. What is essential for the spatial implementation of these calculations are 'phase' relationships between adjacent sound rendering transducers. In acoustics, the term 'phase' designates the particular state within the cyclic periodicity of compression and expansion. It is both the 'state' and the 'time' of an acoustic condition, and when extended to a line of transducers it is also the component responsible for the properties of curvature ascribed to synthesized acoustic waves.

5 Particular techniques that implement HRTF (head-related transfer function) for binaural encoding embody the idea of a synthetic ear. Stereo, and arguably surround-sound systems, enforce another model of hearing namely a spatial paradigm fastened to an ocular analogy of space. By situating the listener in a precise relationship to two or more loudspeakers, one is able to give an impression of a soundscape that extends outwards from an apex at the ears and extends behind the loudspeakers. When properly situated, two loudspeakers construct a picture window for sounds, where distinct sound-objects are seen to interact in an imaginary ocular expanse behind the loudspeaker boxes. Even though hearing is a 360 degree affair in both the horizontal and the vertical axis, operating in all directions in every given instant, stereo decisively narrows that field in order to correspond to the frontally oriented apparatus of vision. Surround sound formats that have become commonplace in domestic settings, merely expand that frontality to include sounds-to-the-side or sounds-from-the-back. Peripheral sounds enforce the pronunciation of a distinctly axial understanding of the listening space, often culminating in a viewing screen or monitor marking the position of the 'absolute front'. The development of spatial sound technologies in concert with cinema standards (and their various domestic offshoots), underline the ocular basis of such sound models that aim to enhance or at least support the field of vision.

volumetric patterns of emission within a given confine of air. Phase-synchronized arrayed transducers imprint within the air multi-directional compression fronts, weaving in and out of one another to form a weightless tapestry of interpenetrating vibrations. The result is a time-space intervention into the pre-corporealized realm of pulsating matter. By coordinating the phase interactions on adjacently sounding loudspeaker membranes, one effectively multiplies the timbral characteristics of a sonic event with a spatial parameter thus enfolding both space-time and sonic-form into a single field of affect.

This technique impresses itself upon the Phased-space of fluid dynamics, in a mute territory of *pre-auditory* acoustic potentialities. The listener enters this remote terrain as a kind of experiential postscript. Immersed within vibrational interminglings, listening becomes an activating agent capable of unlocking the myriad of spaces enfolded within the continuum of vibrations. From the position of pulsating matter – there is no space to be discerned – the extended remains enfolded on a continuum. Any static location cast into that continuum acts as a ballast against the turbulence of acoustic flows, and every ear becomes a reference point for phases to brush up against and forms a locus through which durations take hold. It is only after consecutive phases have extended into durations that acoustics transform into the various dimensions of aural spatial sensations. In WFS sounding objects remain concealed entities until the participation of experience intervenes in the site of vibrations. As Mach writes:

> 'There is no rift between the psychical and the physical, no inside and outside, no 'sensation' to which an external 'thing', different from sensation, corresponds. There is but one kind of elements, out of which this supposed inside and outside are formed – elements that are themselves inside or outside, according to the aspect of in which, for the time being, they are viewed. The world of sense belongs both to the physical and the psychical domain alike'. (Mach, 1914, p. 310)

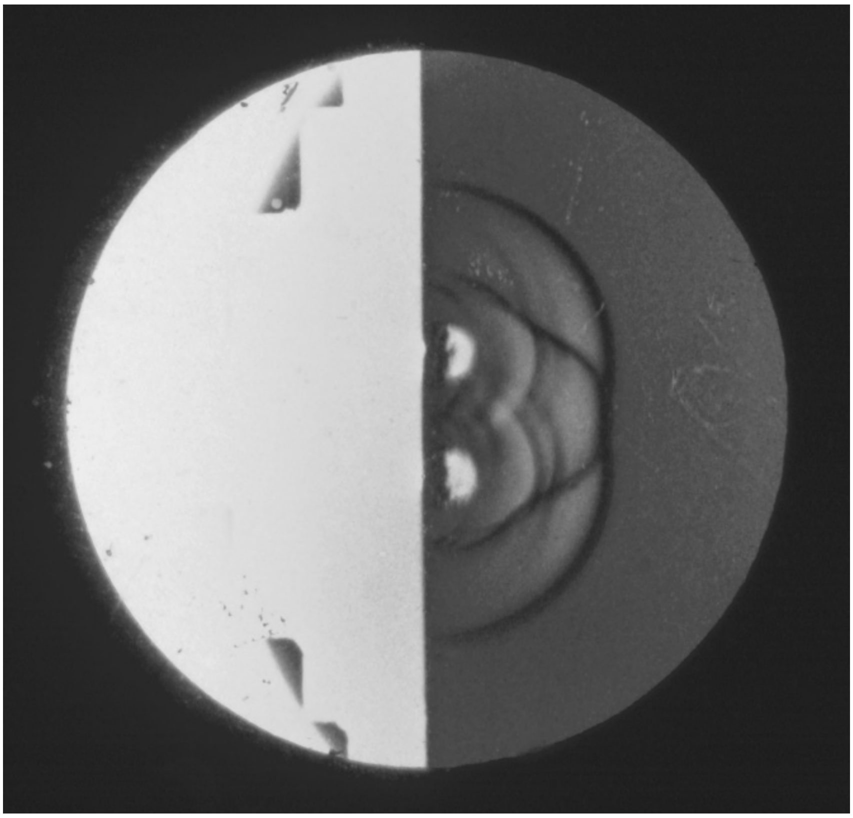

Figure 4.1 Double acoustic wave interference, Ernst Mach, circa 1892 (Photo Deutsches Museum ©)

Mach's proposed realm of 'elements' simultaneously implicates the 'perceiver' and the 'perceived' from a single referential construct where both the 'thing' and the discreet 'ego' are simply viewed as alternating pattern-bundles composed of common blocks. Elements implicate a fundamental realm that is neither physical, nor psychological, yet bridge between the two. If we were to take the elements and arrange them one way, the 'self' is denoted, pick them up and arrange them again, and the 'thing' appears. According to Mach, the dualistic illusion of separateness is an inevitable byproduct of the conscious mind, where these two arrangements can never coincide in a single image. Waking experience perpetuates a picture of existence that will always takes sides, and the terms 'I' and 'it' are simply patterns visited at a greater frequency such that they will progressively be seen to take on the characteristics of independent entities.

The Phased-space addressed in WFS, despite being invisible to corporeal sense perceptions, is accessible to instrumental observations and by extension can be seen to possess certain discernable characteristics. Such a position towards matter enforces an extended domain of 'presence' stretching beyond the windows afforded by the unaided sensorium. Phased-space (if it can be considered a space at all) might be seen as a category of manifestations that are revealed if sound (or for that matter any other wave phenomena) were to peer in on itself; and as such only becomes accessible by way of translation or transposition onto secondary mediums. This realm persists at another location within the matrix of sensations – easing away from the auditory materiality the waking body reflexively ascribes to sound.

The application of photography in Mach's experiments can be seen as such a 'secondary medium' capable of conveying an altogether different materiality of sound. Mach was among the first to produce cross-sectional images of the Phased-space of acoustics. His application of the Schlieren method of photography to airborne projectiles managed to visualize the shock waves in air enveloping bullets traveling at supersonic speed. Phase is the material component that shows up in Mach's Schlieren photographs as the alternating gradient bands of tone superimposing the frozen projectile onto a backdrop haze of energetic formations. Similarly, his experiments with acoustic reflections opened glimpses into the physical expanse of acoustic interactions. In consideration of Mach's approach to sensations, these images would seem to present a significant departure from the ocular model of photography practiced by his contemporaries; namely, a modality where the camera is understood to be either a partial replication of, or an extension to, normative ocular functions.[6]

Even though this model was not a pronounced concern in Mach's work, I would suggest that his photographic studies of fluid dynamics in general, and his acoustic imaging experiments in particular, should be understood in terms of tactile 'sensing' and not as prosthetic extensions to 'vision'. There is no eye that can be situated within acoustic matter, as much as there is no horizon within an acoustic expanse. The imaging capacity produced in Schlieren techniques is a useful byproduct of an intervention photography affords at a deeper level of presences.

In Mach's images of wave phenomena, the film plane acts as a partition of sorts forced between sensation interactions plumbing traces from a more primary configuration of elements. It is in this sense that his approach to sensation might be seen to include an unstated yet explicit re-thinking of the epistemic purpose ascribed to the photographic plate. Numerous photographs, directly imaging 'processes' (e.g., acoustic refraction, air turbulence, electromagnetic interference, and electrical spark discharge), particularly the ones taken over the course of five years spanning 1888 – 1893, reinforce this position. In contrast to normative optic models of that period, Mach arguably approaches the photographic process as an inanimate version of 'sensation taking hold'. Through this approach, the photosensitive emulsion is understood to be a subtle 'memory substance' that engages and preserves unfolding 'sensation' complexes. On the surface of the plate, the silver halide crystals suspended in a gelatin membrane become an inorganic sensitized skin and the developing process acts to preserve a cross-sectional registration of sensed processes. Possibly the most exemplary photographs of such epidermal character are Mach's spark studies where discharging electric-

6 For instance one could contrast what I'm proposing as Mach's photo-sensing approach to photography (and its underlying understanding a sensation-complex spatiality), with the chrono-photographic work of his contemporary Étienne-Jules Marey (where the camera is seen to intervene in the 'matter' of time by breaking durations of optic spatiality into an incrementally sequenced appearance). Admittedly this argument demands a more careful unpacking of Mach's photographic practice assessed in relation to other prevailing normative models of photography at that time and remains beyond the scope of this current inquiry.

ity is sent shooting across the surface the film plate literally burning tracks into the emulsion as it travels. The eyes participation with such imprints of matter occurs only at a later stage, brought in primarily for its deciphering capacities. Mach's relation to the Schlieren images is that of discerning a 'legibility of traces'. He reads the surface of the image as one would read a hieroglyphic text.

Just as Mach's photographs of the behavior of sound are no longer ocular artifacts of optical space, but rather imprints of tactile interactions, such can be understood the Phased-space of sound projected by way of WFS as a reverse Schlieren image, mobilizing the gradient patches of phase back into the thickened folds of propagating waves. Similarly to Schlieren photography that does not include the configuration of the eye until after the 'image' is produced, so does WFS only introduce the listener after the phase patterns have been set in motion. The sound model of WFS excludes the idea of the listener altogether from its mode of sound production, reintroducing the ear as a non-idealized entity into a homogeneous field of listening possibilities.

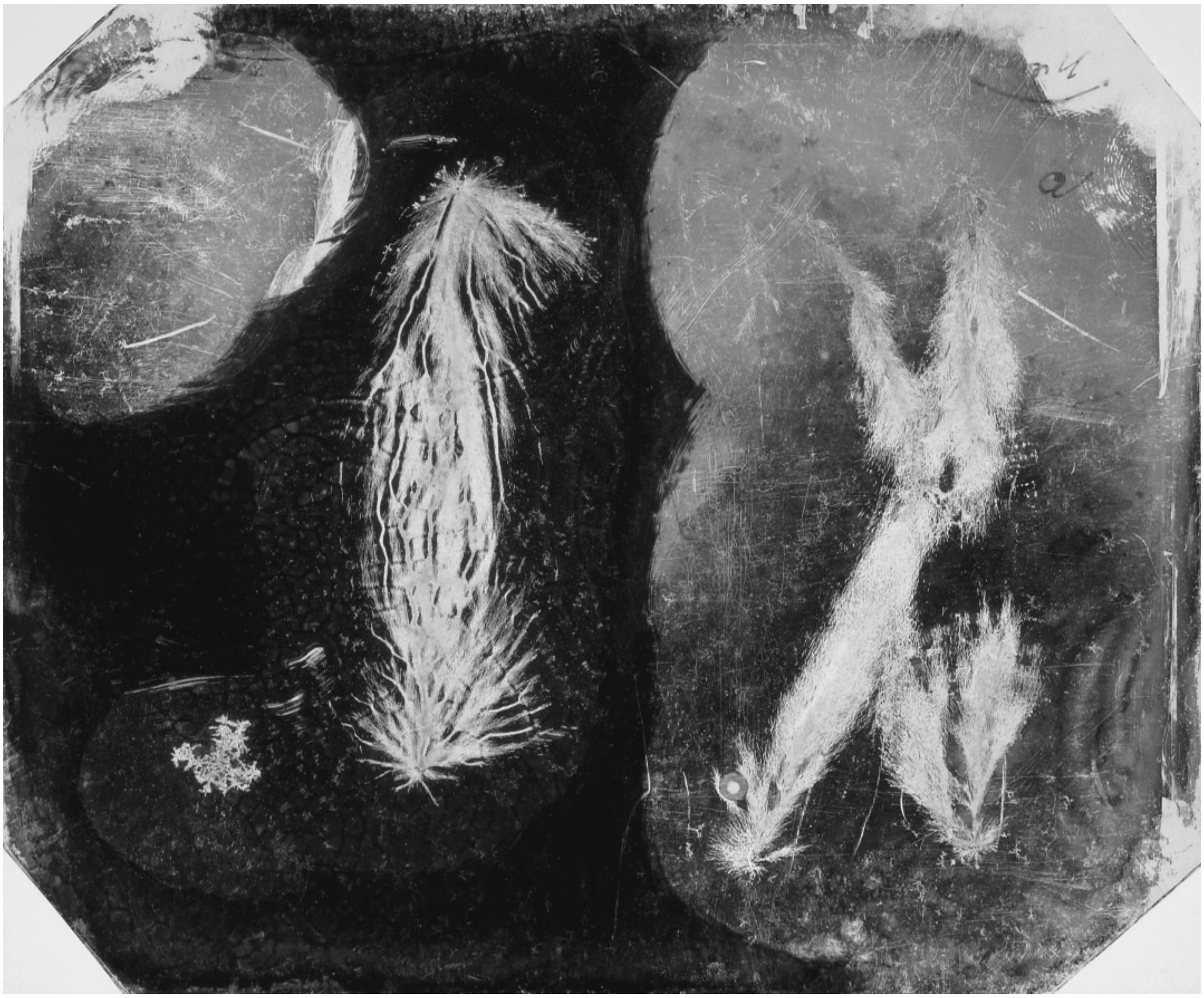

Figure 4.2 Spark discharge, Ernst Mach, date unknown (Photo Deutsches Museum ©)

One striking quality of WFS is the way in which sounds materialize in experience as distinctly spatial presences, nearly possessing dimensional attributes such as mass and length. Each position within the wave field is equally charged with acoustic formations. To hear or receive in such fields means to transfigure sonic events into acoustic intelligibility and thus transform invisible interactions into coherent localizable events. Anywhere within that field, each listener unfolds their own relational aural environment where the particular constellation of sonic events will be as unique and multiple as the number of varying points of hearing opened into the expanse of sonic interactions. To hear such configurations, means to participate in a polycentric experience, not very different from the everyday acoustic environment. As such, there is no inscribed orientation to a WFS setup, each direction is equally charged with aural potentiality. Contrary to the pronounced 'frontality' that can be found in many dedicated listening spaces (particularly with regards to theatres and concert halls), in WFS there is no 'front' nor 'back'; furthermore, WFS has no designated location from where the sounds are intended to emerge. For the listener within this realm of acoustic interactions, every sound appears as its own unique vanishing point, balanced within its own center of gravity, and enforcing a relational framework whose definitions and boundaries are re-determined within every progressing step in the triadic relations between sound-space-listener.

Correspondences between 'observer' and 'observed', where audible space itself is indeterminate until the act of listening has intervened within the confines of Phased-space, underlines that there is no 'absolute' sound-space from which to determine an auditory point-of-view. Phased-space is only known by way of its projection – by way of the imprint it leaves in sensing devices and by way of the audible worlds through which it communicates. Yet, Phased-space should not be thought of as detached from the framework through which we chose to extract its characteristics and behavior. No Phased-space exists 'as is'; rather, there are event-observer constellations informing every unfolding position of aural spatiality.

Importantly, Ernst Mach distinguished a categorical difference between 'geometric space' and what he calls 'physiological space'. For Mach, physiological space is the only primary domain. He argues that geometric spaces are secondary human inventions abstracted out of experiences. Other than being a useful approximation, they should be regarded as little more than conventional abbreviations serving utilitarian ends. Such intellectually derived spaces tend to perpetuate their authority through historical and cultural circumstances to the extent that their secondary nature is no longer self-evident. For example, the geometrical space of the Euclidian kind is homogeneous and unlimited, essentially an abstraction when contrasted with the space of experience. In contrast, physiological space, the space-as-lived, is heterogeneous and observer-centric. It is a highly differentiated space whose measure of detail grows with increasing proximity to the locus of observation. Furthermore, in physiological space 'extension' itself is differently articulate depending on the direction of observation. In physiological space the notions of above/below, before/behind, right/left all have inherent significance, whereas they are completely superfluous to geometrical space.[7] Even when the point of observation mobilizes, and experiential space begins to approximate Euclidean space, that space will remain allied with poly-sensorial attributes, among which are colors, textures, and directionality.

From the vantage of Mach's 'sensation elements', one and the same strata that lines matter and mental processes, it takes little stretch of the imagination to suggest that certain traits attributed exclusively to the psychological domain might maintain other, possibly inorganic, equivalences. Admittedly Mach does not pursue this path in his writings considering the dubious scientific value he attributed to such hypothetical commonalities. For example, when considering the question whether crystals have sensations, he does not reject outright such a notion, but rather states that this is a question without scientific or practical meaning. (Mach, 1914, p. 244) One important question he is willing to partially entertain is that of 'memory'. In Chapter XI of his book *The Analysis of Sensation*, entitled 'Sensation, Memory and Association', Mach draws correspondences between faculties of consciousness and characteristics of matter with regards to their common 'retaining' capacities:

> 'In reality every psychical process leaves indelible traces behind, just as every physical process does. In both spheres there are irreversible processes: entropy increases, or the bond of a friendship that has been broken, and then renewed, is felt'. (Mach, 1914, p. 237)

Mach argues that the manner in which matter reveals the strain of time is apparent in such examples as geological erosion where the surface of the landscape records the passage of climatic transformations, or a wire that 'remembers' the accumulated postures from its previous coilings. Yet memory for Mach is some-

7 For a description of discrepancies between 'geometric space' and 'physiological space', see chapter XI, 'Biologic-Teleological Considerations as to Space', of *The Analysis of Sensations*.

what more complex in structure than the mere retaining capacities of past events. Memory involves certain instances from the past re-surfacing as a field of influence capable of directing processes in the present. (Mach, 1914, p. 237) Possibly the most vivid example of an inorganic memory cited is that of the phonograph, though Mach adds that the phonograph requires an external force to 'recall' its embedded memory whereas human memories have the capacity to play themselves automatically.

The Phased-space of acoustics may similarly be considered in terms of its 'memorizing' capacities. Within Phased-space every sound is already a trace imprinted upon a flux of vibrations. In contrast to the example of erosion, the domain of phase supports memories impressed in past occurrences that have real bearing upon the outcome of present conditions. With respect to a given crest in an expanse of propagating waves, the polarity and potency that specific wave will seem to possess at any given moment in time depends both on its own energetic state, as well as on the precise choreography of encounters imposed by proximal wave events. If a crest meets another crest, the wave's energy at that point in time will seem to momentarily multiply. Conversely, if that crest meets a trough – that same wave will instantaneously vanish, only resurface moments later, after the undertow has subsided.

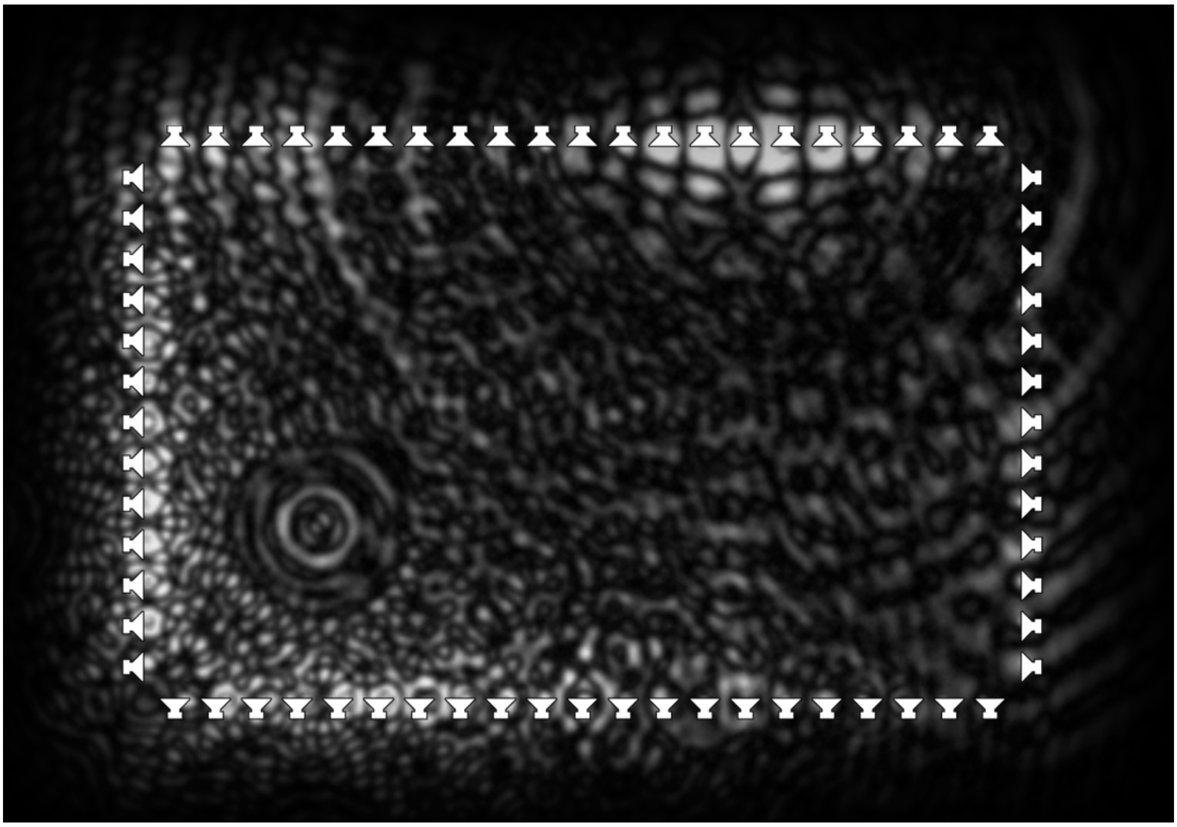

Figure 4.3 Phased-space sectional study, instantaneous pressure-front analysis in air of two vocal sound samples rendered via a frame array of wave field synthesis (Sound Field Plotting algorithm and image synthesis by Miguel Negrão)

In this sense, the characteristics of acoustic substances, themselves outcomes of sonic eventfulness, bear influence on encounters in the present tense. This form of memory would seem to be internal to the materiality of vibration itself, and our own perception of such acoustic sensations would then be yet another appearance of memory enfolding the former, thickening temporalities into spatialized durations. Perhaps under these particular circumstances, where memory is multiplied by memory, we can begin to explore the potency of such sonic temporalities – in the tension that arises between a memory patterning of acoustic interactions and the memory space of embodies sonic experiences. In addition, in such doublings, Mach's phonograph of inanimate memory actually begins to play and to take hold.

In consideration of such terms, WFS could be seen to set forth an expanded memory plane in search of listeners, perpetuating a domain within which every act of listening sets off a chain of delays, where perceptions enfold propagating times and spaces begin to multiply. The result is an expanded realm of potentiality for audible spaces that fade in and out of perceptual tangibility. For the listener in WFS sounds may appear to be inside, or external to, the physical location of the transducers. In certain instances, sound may even seem to extend beyond the visual confines of the performance hall itself. By way of rendering vibrations, resonating instances materializes in the absence of the very objects that supposedly produced those sounds in the first place. In other words, there is no visual confirmation for soundings rendered 'present'. This phantom quality is an indication of a much more mundane paradox brought to the fore in WFS: the coincidence of a listening position with a localized acoustic event is simultaneously the instance from which one derives the spatialized location of that same event. Seemingly, 'to hear' means to simultaneously occupy two positions – the one on the surface of the ear, the other cast back to an imagined point of emanation. For the situated listener, the sound is at once 'here' and 'out there'. Despite the fact that hearing is an explicitly tactile sense perception, perception will always trace that sound back to the estimated source, rarely paying attention to the proximity of vibrations. Audition, like vision, creates the impression of apprehension at a distance.

In WFS, by eliminating the visual cross-reference, one is left to grapple with the phantasmal appearances of sounds rendered tangible, albeit from the position of physical phenomenon the bind between a resonance and a location was never there in the first place. Sounds propagate by way of expansions in the cusp of events, projecting outwards in alternating patterns of residual timings. In other words, it is not the vibrating surface of objects that convey a sonic presence, but rather the *intervening distances* within which all the various vibrations combine to form a continuous cloud of eventfulness. Within this tangled matrix, the entire spatialized coherence is bundled up in an undivided shimmering mass, where each singular 'boundary' is enfolded within a multitude of other singularities. The uncanny aural ability to unravel this continuity into recognizable and discreetly localized 'events' happens effortlessly in every moment of listening. The tactile faculty of the ear remains for the most part shrouded beneath the listeners cognitive 'space-ing' operations.

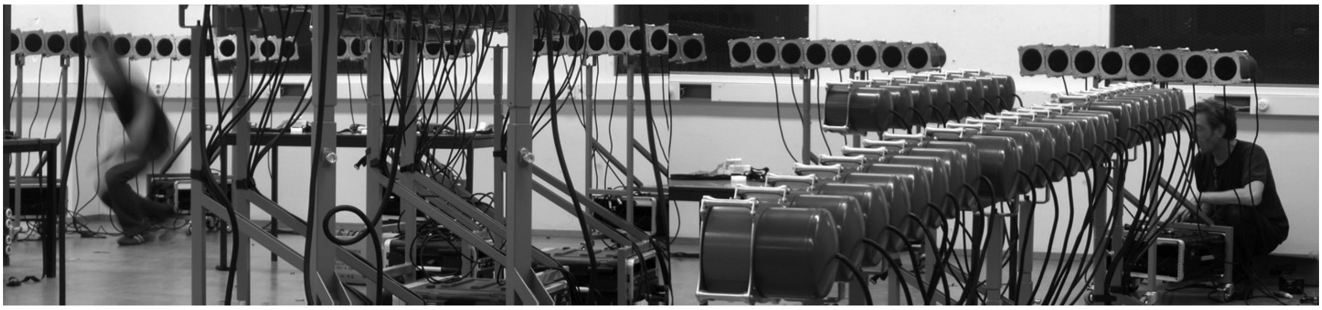

Figure 4.4 Wave Field Synthesis acoustic rendering setup, 192 loudspeaker array (Author's design)

Considering frequencies in terms of their physical sizes draws attention to the materiality of waves that sheath the body with an endodermis of fluctuating eventfulness. Hearing is more than just a matter restricted to the inner ear labyrinth. Sounds are in fact sensations that travel along bones, brush up against the skin and form resonances in the inner cavities of the body. Sound's capacity to be at once immersive, intimate, and visceral; whilst at the same time being recognizable, situated, and mundane, has no readily accessible logic. It simply is, and by being such, causes audible presences to flickers in and out of synch with the other tangible spaces and things cluttering our palpable worlds. The particular materiality of sound, as we are expressing it in our contemporary auditory practices, is at once spatially differentiated and inaccessibly abstract.

It is not so much the corporealizing of Phased-space that surfaces in WFS (as that would involve surpassing the reflexive functions of hearing), but the superimposition of such understandings of the space-of-sounds back into our audible worlds. The experience of sound gets torqued by the knowledge of sounds alternate modes of existence. Sound as a phenomena remains the same, but our relation to it, the aspects we subconsciously accumulate and subsequently internalize, gives the shape and materiality that sound is seen to possess. Consequently, the spaces that sound create, and the materiality it seems to occupy, will also be in a perpetual state of reconfiguration. By the very nature of this ongoing process, *hearing* itself is transformed.

Figure 4.5 Projectile shock wave, experiment setup, Ernst Mach, date unknown (Photo Deutsches Museum ©)

Every epoch, with its particular sonic preoccupations and acoustic materializations, inevitably hatches its own definition of a 'listener'. Consequently, the extents of 'hearing' will be determined by the myriad of practices, techniques, and epistemologies condensing the various aural fields in any given historic and cultural context. Within our contemporary practices it would seem that the further we materialize the Phased-space of vibrational eventfulness, by way of electro-acoustic techniques as well as by way of alternative modes of vision – the more this remote aspect of sound will be seen to intrude upon the normative soundscape. As vibration itself is seen to grow skin, so will the stable confines that delineated the clear 'edges' of things begin to melt back onto the flux of peripheral forces. And the faculties of perception, like a television station that has slipped out of reception, gets challenged by unfamiliar signals, interfering ever so slightly with the mundane shape of 'things'.

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Chapter 05

Earth-bound Sound: Oscillations of Hearing, Ocean and Air[1]

Section I

Global Sounds

Figure 5.1 Pandemic spread prevention respirator type KN95. (Photo by author)

This text follows oscillations of hearing, water and air in conjunction with notions of sound that are terrestrially situated, geologically invested, contextually distributed and predominantly earth-bound.[2] Why sound and why now? In other words, why should we recalibrate sound and hearing at this particular moment? One answer could gesture towards the pervasiveness of sonorities in times of political and ecological crisis and address the urge to attend to those sounds' inherent plurality as a means of negotiating the current complexities: the sounds of calving glaciers and noises of social unrest interspersed with uncanny silences of pandemic lockdowns and muted breath.[3]

1 A preliminary version of this text has been published in Ganchrow, R., "Earth-Bound Sound: Oscillations of Hearing, Ocean, and Air." *Theory & Event* 24, no. 1 (2021): 67–116. https://doi.org/10.1353/tae.2021.0003.

2 The term earth-bound highlights the site-specificity of quotidian events, interlinked with conditional processes in and around the earth. This text observes dynamic physicality of sounds in earth's milieu that are literal *circuits* patched through organic-inorganic, perceptual-physical, techno-social agglomerations. It adopts a vantage in which all the various attentions to sound are one continual field of operations. Sounds that are at once in-situ and circumstantially specific, while at the same time expansive, proccesual, possibly even poly-temporal, multi-locational and spatially diverse.

3 This text is being written at the time when the COVID-19 coronavirus is rapidly spreading from China's Hubei province, and with it the distinctive sounds of a global pandemic. I was in the habit of collecting its sounds while they were constrained to Hubei, but could not keep pace once they circulated more broadly. Much like the virus, the sounds have recurring patterns: the worldwide sounds of infected breathing from the COVID-19 virus coupled with the sound of mechanical respirators; muffled voices speaking through face masks; the appearance of breezes, plant rustles and other feeble ambient sounds in city centers; the increased reverberation in supermarkets as shelf stocks dwindled; the descending pitch on European highways as trucks overtook car lanes; countless sounds of domesticity echoing through online video streaming; the playback of curfew announcements from mobile PA systems in Wuhan that then reappeared in Spanish translation on megaphone-touting drones in Madrid that morphed into Boston Dynamics' robotic dog SPOT broadcasting social distancing messages at Bishan-Ang Mo Kio Park in Singapore; the communal Hubei province tower-block hymns infecting balconies in Italy and beyond; and the collective clapping meme that for a while transmitted faster than the virus itself until it was met by the sounds of distress from overworked, ill-equipped and underpaid vital personnel. Possibly the most pervasive sound of the pandemic is the decline of seismic background noise in the earth's crust and low-frequency ocean oscillations.(Gibney, 2020; McVeigh, 2020) As the situation unfolds, seismometers in Belgium, California and Greece have measured a decrease of up to one-third of human-induced seismic vibrations due to lockdowns currently in place. With one notable exception, India, where vibrations from the mass urban exodus still underway make palpable the disparities in lockdown policies as they intersect with the underprivileged, homeless and

Acoustic attentions are at least timely if not altogether symptomatic of this juncture. Interests in sound's malleable qualities come not only from attentions to a densely sonorous milieu, but also from the manner sound's behaviors are analogous to experiences of interlinked environs cluttered with migrations, shifting identities, precarious existences and alarming environmental change. Today, awareness of evanescence seems to be more of a common trait than a quality reserved for sounds. On the other hand, there is much to be learned from the making and unmaking of sonic entities. After all sound is a quintessential shape-shifting materiality. Sounds are distinctively situated but also importantly transitional. The spaces and identities heard in sound accurately reflect the *extents* of hearing and *dynamics* of context. Different kinds of listening reflect the diversity and scope of sounds that can be heard. It's in that sense that closer attention to sound's manners of manifestation and modes of operation could become paramount for rethinking other context-bound materializations and spatiotemporal entities in our midst. Sounds partake in physical processes that cannot be divorced from qualities, and their spatial operations are entwined with the contexts through which those qualities manifest.

Earth-bound Sound

Sounds are native to their circuits of propagation, inhabiting locales and distributing over non-localized contexts. Vibrations traveling through air, water and ground have their historicity not only in the 200-year career of acoustics in science, culture, technology and warfare, but also in the natural history of terrestrial movements. Everything sounding in surrounds relies on a meshwork of earth-bound interconnections sustaining those operations. The audible characteristics of fluctuations in air rely on structural aspects of the gasses in which they propel that are themselves outcomes of billions of years of energetic modulations in biota and geology.[4] The sounds we hear would not be the same sounds when heard through alternate gasses. Neither would the shapes and mechanisms of listening likely be the same. Biological organs, their environments of hearing, and techniques of sounding and listening are all tightly knotted and continually shifting in complex terrestrial circuits. Technologies of hearing and listening, along with impressions of sound and sonic experience, are part of those earth-bound circuits and partially *contribute* to the dynamics.

The coevolution of earth's crust, organisms, oceans and air is a physical fact latent to anything that sounds. Sound radiates environments, coevolving with organisms, coevolving with flora, coevolving with minerals, coevolving with topography, coevolving with oceans and atmosphere. Admittedly that cascade is not plainly audible as the features holding vibrations in auditory attention are the same ones masking the continuities.

Vibrations take on structure as they coevolve. Vibrational appearances are as distinctive as leaf shapes or animal hide patterns. Sonic structures are not merely the result of processes but in fact *are* processes sounding their contexts of operation. Sounds that squawk, rattle, chirp, squeak, squeal, grunt, hiss, roar, bark, howl, warble, purr, yelp, tweet, hoot, screech and speak, join in to accompany other, abiotic sounds such as babbling brooks, rumbling thunder, murmuring wind, pattering rain, white noise waterfalls,

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migrant sectors of society. The still rapidly shifting dynamics of global pandemic sounds is at odds with the temporal pace of publishing. By the time this text goes to print, the scope and spectrum of pandemic sounds will inevitably have changed. And with them the *sense* of what has been networked and the *scope* of what was engulfed in these globally active sounds.

4 In the example of the atmosphere, rising oxygen levels caused by an abundance of photosynthesis alters the speed of sound in air. The physical sizes of organisms, and their hearing and sounding apparatuses, coevolve with the sizes and speeds of wavelengths propagating through oxygenating air. The spectral-spread of vibrations in air reflects species diversity clustering along distinctive bandwidths of activity (e.g., bacteria in ultrasound, insects in high-frequency, mammals in midrange, and elephants and whales in infrasound). Audio technologies — particularly sound-making devices — also scale to the wavelength and wave speeds, governed by properties of wave refraction and physical properties of wave interfaces. Insects are a notable exception in that they are relatively small in comparison with the size of wavelengths to which they attend. To compensate, insects have developed diverse vibration sensing systems, including pressure differential receivers (hearing from either side of a vibrating membrane) and externalized motion-sensing hairs. The speed of sound in air is a time-calibrating factor in binaural hearing, suggesting that land animal thresholds of directional hearing are coupled with the general distribution of flora and fauna on earth.

pink noised earth warble (and heartbeats), and brown noised meandering dust and time-delayed signals travelling long-distance underwater.[5] These and other behavioral energetics travelling through ground and waters constitute the substance-borne multitude of earth-bound effervescence. Air that conducts human hearing is not merely a medium for signals in transit but are, in fact, aspects in the *structuring* of the earth's atmosphere. Ears, the vibrations to which they attend, and the gasses, liquids and solids through which they propel, are coupled components in continually reconfiguring structures. Sounding is an integral *tendency* of terrestrial eventfulness, not an inscriptive functional afterthought. From the scraping of cricket wings to the vocalization of whales, to the snapping of shrimps and clicks of dolphin echolocation, life speaks not merely of communication but more fundamentally of *terrestrial vibrancy*.[6]

Neutral Sounds?

Seemingly neutral generalizations of sound – as signal, as communication, as acoustics, as force, as spectrum, as waveforms, as decibels, as knowledge, and even as music – have much to do with the utility such definitions provide and the manners in which those sonic materials remain productive within respective social circuits. Universalized sounds circulate predetermined sonic identities that function in equally determinate realms of social production. If you are seeking *communication* in a sound, you are likely to find your signal, medium senders, and receivers inside. Similarly, if you're seeking *location* in a sound it will likely trace back to a 'source'. If you're perusing *patterns*, those materializations are abundant in techniques of sound visualization. The peculiar mechanism through which vibrational fields – that encounter substances only in passing and are not owned by any discipline, technique or culture – manifest as discrete materialized identities, especially while circulating in the social praxis, has much to do with the agency those sonic identities provide to their attentive circuits.[7] The latter three categories in particular – sound as speech communication, as geospatial location, and as visual spectrum – gain pronounced currency within far-from-neutral contexts of warfare, though their propagations continue elsewhere.

A vibration's ability to be multiple sound identities is a virtue, just as long as anyone of those identities doesn't become too insistent. More on that later, but suffice to say that something essential is lost in sound generalizations especially when obscured from their formative contexts and endowed with implied neutrality: sounds reduced to deliverables, isolated from their circumstances and resounding in a perpetual present, become diminished in their actuality as they are confined to projected models. Moreover, features

5 White noise is common in the natural world. For example thermal noise appears as the random jostling of electrons as voltage encounters conductor resistance, commonly experienced as radio static. Energy distribution across the spectrum in white noise is nearly flat, meaning it contains all frequencies in equal power. Other shades of noise such as pink noise expresses a 1/f power spectrum (i.e., inversely proportional to the frequency). Brown noise consists of $1/f^2$ spectrum meaning it has more power in the lower frequencies. These three noise behaviors are typical of non-periodic sounding structures in the natural world. For example brown noise 'random walks' observed in time delay patterning of signals traversing the SOFAR channel (MacLeish & Rayan, 1977, p. 39).

6 The examples of echolocation in shrews and dolphins (exploring their habitat) or the explosive clicks of snapping shrimp (used to stun their prey) are forms of animal sounding where communication does not play a role. The communication bias in physiology may itself be a carry-over from communication biases in audio and media literature. For a discussion of the communication bias in media theory see Richard Cavell's introduction in *Remediating McLuhan* (Cavell, 2016, p. 09). Furthermore, modeling communication as information in transit is misleading. Communication has a more primary function of affect in sentient circuits. In terms of its terrestrial agency, the arrival of messages is midway through that process, not its destination.

7 There are certain parallels in the environmental agency of audible sounds and expressions of language. Both hearing and language (along with other sensory expressions) assist in delivering processual surrounds with distinctive features and outlines. The thingness of perceived surroundings may indeed be an unavoidable feature of embodied perception, but the boundary-enforcing capacities of sensory *expressions* is not to be underestimated in the upkeep. There is much at stake with sensory vocabularies (not to mention syntax) in the parsing of selves and surrounds. The matterphorical in language pointed out by the editors of this volume – words that world by forming continuities with their fields of action – finds its counterpart in spatial materializations of audible sounds. Both participate in the making (and unmaking) of tangible identities, endowed with relational agencies and operating in concrete spaces of action. It's in that sense that sensory expressions don't merely represent, they actively partake in the structuring of events, giving texture to continuities that are also the situational relations of an expanse. Words, like sounds, literally *take place*.

of those models themselves exert forces back into the extant. Sonic models enacted through practices, techniques, and devices themselves produce *territorial conditions*. More troublingly, such reductions are often inversely proportional with the violence they exert on fields adjoining their operations and/or other sounds escaping their determinate frames of utility.[8]

Hearing in Earth Circuits

Hearing is steeped in earth circuits.[9] The coevolution of hearing, sounding, and environment intertwine qualities of attention, environmental features, chemical and mineral structures, and electrical agency. Human technologies of listening and sounding embody well-established terrestrial dynamics though often unknowingly and with unexpected results.

Perceived sounds *materialize* fluctuations and produce *spaces of action*. However, they share no common 'acoustic space'. Instead sounds open onto a multitude of overlapping, intersecting, and often discordant, spaces. When sounds manifest in human experience, they do not terminate in bodies. Sounds continue to propagate and multiply, refracting through actions, expressions, language, and technique, incurring temporal shifts as they refract and entangling additional contexts in their pathways.

Hearing is always in the making, though its variance has no particular direction or rate of change. Configurations of hearing are complex, heterogeneous, and context-specific. When tendencies or directions do arise, they remain incidental, constrained to the contextual dynamics native to their productive circuits. For example the coevolution of pollen anther structures in flowers and vibrational behaviors in bees (known as buzz pollination) evolved on 45 separate occasions and reverted back even more times to non-sonic pollination since the Cretaceous (Cardinal et al., 2018, p. 594).

Likewise tympanic ears arose several times, independently and repeatedly, among a variety of land animals such as ancestors of frogs, birds, and mammals. Though notably tympanic ears (with higher frequency reach) initially appeared simultaneously, across *all* groups, during the Triassic, coinciding with the emergence of high-frequency *buzzing* insects possibly drawing collective attentions (Christensen-Dalsgaard & Carr, 2008, pp. 02–03; Clack, 1997). Praying mantises evolve tympanic hearing on 14 occasions and subsequent ear loss is closely coupled with diminished flying abilities (wing size reduction or absence), apparently no longer needing to listen for bats in the underbrush (Yager, 1990, p. 517). In a contrasting example, the Australian whistling moth (Hecatesia thyridion) also grew ultrasonic bat-detecting ears but then additionally developed social habits of ultrasonic singing (Alcock et al., 1989, p. 28). Conversely, some bats lost their appetite for insects (fruit bats) yet retained echolocation abilities initially keyed on insects that then went on to entangle morphologies of plants (Heithaus, 1982, pp. 329–330).

Fluctuations modulated through human disciplines, practices, techniques, *and* narratives do not escape these broader earth-bound dynamics. While hearing transitions, it does not get 'better' per se but rather critically adjusts to in-situ features drawn into attention. Stories of sounds getting louder, of sounds disappearing, of sounds progressing in some way or another, reveal the function of sound in narratives

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8 Generalized sounds deplete sonic diversity. Heterogeneous sounding territories forced through universal models, cut sounds off from their diverse contextual agencies, reducing them to isolated effects. Likewise, vibrations getting in the way of predetermined sonic tasks, especially in fields of communication, are often degraded to noise and consequently resisted in the sounding circuit. Histories of ambient noise reduction in electroacoustic techniques express those traits. A more apparent example of violence incurred by applied sonic models is damage to marine life caught in signal paths of navy sonar or seismic hydrocarbon exploration. Both methods calibrate sound intensity with specific target bodies in mind (submarines and seafloors respectively), disregarding the impacts on other entities caught between sender and receiver. Since the introduction of high-powered tactical sonar around 1950, there have been over 120 reported mass stranding of beaked whales, some with direct traceable links to naval sonar exercises. (D'Amico et al., 2009).

9 Sentient hearing and particularly technologically mediated human hearing of ocean and air are the core of the text, mostly for practical reasons of scope: tracking encounters of water and air that alter ears, eventually listening back on the atmosphere and oceans as a whole, is unwieldy enough. However hearing does have equivalent processes in inorganic matter and interlinking auditory attentions with inorganic attentions opens up other dynamic aspects. For a preliminary account of inorganic sensation and inanimate hearing see the author's reflection in *Phased Space* and *Sound Attention* (Ganchrow, 2010, pp. 187–190) (Ganchrow, 2019, pp. 177–178).

predisposed to the rhetoric of 'progress' as well as 'demise'. Furthermore, it's not the sounds themselves that are changing, nor the subjects that are transforming, but rather configurations in their formative contexts along with calibrations in attentive circuits with which the sounds, observers and environs are permanently enmeshed. Identities, qualities, characteristics observed in sounds are real, though those attributes remain tightly bound to expansive interlinked meshworks. Attending to sound's infrastructures hints at the dazzling complexity that fluctuant continuities, shared by countless entities, incur while refracting through terrestrial expanse, only a fraction of which crop up in human experience.

Figure 5.2 Trichodesma boissieri in blossom with downward oriented buzz pollination (sonication) anthers. (Photo by author)

Hearing and sounding emerge simultaneously through on-going energetic transferences crisscrossing the organic and inorganic alike. Wavering dynamics can be found back in morphological features of listening and sounding: structures that ripple, curve, flex, funnel, knock, pulse, undulate, and sway. Distant pasts remain latently present in everyday hearing. To observe this persistence of the past *within* the present one must find hearing back through the movements of tectonic plates and eon-long oscillations of oceans and climate. In some sense our auditory organs are adjusting sedimentary clumps, deposited at critical interfaces in the complex modulations of being. Their permanence and the permanence of the attentions they hold, like the permanence of air and mountain ranges, is only ever quasi-stable.

Section II

In mapping the broader scope of the making and unmaking of terrestrial audibility, the bigger picture is never quite big enough. No account can fully capture the range and complexity of sensory worlds that are entwined with habits and techniques, patching through locales, in sway with geology and steeped in energies travelling every which way. On the other hand, attending to cardinal sites and subjects in the dynamics, while navigating interlinks, partially provides access to the infrastructures.[10]

10 Following the refraction of events traversing terrestrial expanse inevitably entangle an incomprehensible number of contexts. Stringing together vastly distributed (spatially and temporally) episodes introduces a degree of injustice to

The following section is intended as a *literal oscillation* through conductive networks patching together air, hairs, oceans, heads, atoms, appetite, membranes, muskets, bombs, blasts, bones, birds, boats, horns, crickets, coils, fish, mammals, distances, desires, ears, magnets, fears, swim bladders, ship's hulls, mountains, carbon, hydrogen, quartz, earthworms, piezoelectric salt, proteins, helium, submarines, snakes, telephones, maps, facsimile paper, coasts, nations, craters, volcanoes, the moon, whales, and people. The itinerary follows meandering patterns and contextual relays of hearing, refracting through turbulent earth circuits, with particular emphasis on *physical* configurations and *attentive* formations taking shape in the company of waves.

The movement is one among many. It is by definition fractured, biased, and incomplete. Connective links may first appear as disruptive cuts, but only to the stream of narrative logic. The gaps are also there to provide some ventilation, for the air that fills words to escape back to atmosphere. Your reading assists the exhale.

Hair Transducer - Sense Traverse

Sensing the presence of waves is sparked in transduction. Transducers are common features in sensory organs, as well as audio devices such as microphones and loudspeakers, converting physical oscillations into electrical fluctuations. Transducers are predominantly found in mechanoreceptor cilia hairs at the interfaces of organisms and environments. Ciliated hair cells are some of the organism's most sensitive movement instrumentation: bullfrog cilia are seismically tuned to hear feeble infrasound ground vibrations (Narins & Lewis, 1984, p. 1384).[11] Cricket hairs are sensitized down to the limits of physicality itself, just above the barrage of atomic-scale thermal noise, and paradoxically can sense agitations below that threshold by piggybacking on stochastic resonance (Shimozawa et al., 2003, pp. 146–156). What exactly crickets may be listening to, below the scale of atoms, is an open question. But for humans, subatomic space and its inherent 'noisiness' is becoming increasingly important, particularly in quantum computing where fragile qubits (themselves erratic bits of matter) require isolation from 'noisy' surrounds to perform their quantum calculations. Quantum microphones that can hear thermal noise with a precision greater than a single phonon are currently under development. Eavesdropping on insect hearing could provide another access (Arrangoiz-Arriola et al., 2019, p. 537; Gillard et al., 2017, p. 38).

Animal hearing was born underwater. Mechanoreceptor hairs embedded in dimples on the sides of fish – known as the lateral line organs – are an ancient fluid motion sensory system still active in aquatic vertebrates. As currents envelop the fish, lateral line receptors register delay patterns in predominant waves along the surface arrayed receptors, providing the fish with an orientation of activities in surrounding water, especially nearby schooling fish, and, predators. A long-held assumption that cilia hairs, in human and other mammalian inner ears, evolved from the lateral line in fish has been revised to include a broader range of transducer hairs including those on spider legs, mosquito antennae and sprouting from cricket cerci, all thought to derive from a common ancestral transducer hair type (Popper et al., 1992, p. 54).

Lateral line organs sense low-frequency vibrations (until around 150Hz) and water currents that help determining the direction, speed and relative size of nearby moving subjects but its range is rather limited for hearing (Bleckmann, 2008, p. 145). Broader-spectrum fish ears are located elsewhere in their body and likely developed in tandem with the swim bladder organ to which the inner ears in many fish are still connected.[12] The swim bladder primarily controls degrees of buoyancy, but it also functions as private reso-

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the contexts and subjects through which events take shape, by patching through select aspects rather than providing comprehensive accounts. In my experience, there seems to be a tradeoff between narrating a context and narrating the dynamics. This section attempts the latter.

11 Paleontology literature designates mechnoreceptor cilia hairs as nature's original electrical transducers. It is, for example, stated that "[t]hese sensory cells are transducers of motion that transform mechanical into electrical energy." (Gans, 1992, p. 06) or that "[t]he hair cells are the ultimate transducers, which translate motion into something nerves 'understand'." (Bergeijk et al., 1961, p. 108) Telephones, microphones, and loudspeakers unknowingly inherited transductive circuits of organisms at a time before the term 'biomimicry' was coined.

12 Paleontology literature makes distinctions between hearing organs that transduce particle motion acceleration (e.g.,

nance chamber for fish that hear through it. This sac of pressurized air (filled mostly with oxygen in ocean fish) is used to amplify underwater sounds echoing through its interior. In some cases fish produce sounds with it, like the grunts of toadfish and Atlantic croaker fish. The swim bladder resembles aspects of the middle ear in land animals, however evolutionary trajectories suggest that when the sac surfaced from the oceans, it burst open to become lungs, forming other continuities with the earth's atmosphere.

Speed in Gas - Hearing Distance

The emergence of earth's third atmosphere – involving the oxygenation of oceans and air – is initiated by oxygen emissions from countless photosynthesizing algae, fueling the appearance of oxygen clinging organisms, (until then oxygen was toxic for life). At early stages in that process, iron ores and sulfur absorbed the oxygen and formed layered ochre, red and brown mineral seabed sediments. It's only after earth's crust stopped rusting that free oxygen began escaping into the atmosphere and complex organisms emerge. That process is linked to exchanges of continental carbonate reserves and possibly even with the motions of tectonic plates, the rise of continents and even rusting the moon (Lee et al., 2016, p. 07; Li et al., 2020, p. 01; Rosing et al., 2006, pp. 109–110). Attention actually changes the world, and if predominant human attentions are currently imprinting in geological strata, it's partially thanks algae's initial attention to sunlight. Since that process began some 2.4 billion years ago, there have been major fluctuations in atmosphere oxygen content.

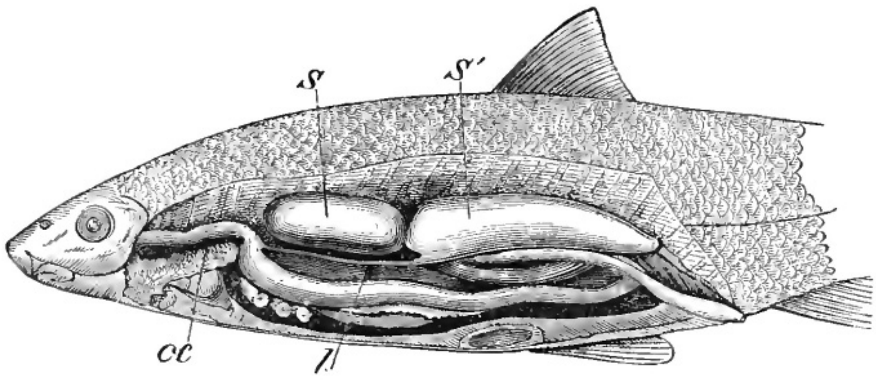

Figure 5.3 Air-filled fish swim bladder (indicated by S and S'). Illustration, "Longitudinal Section of a Bleak", in Fairchild, Herman L., How Animals Breathe (The Popular Science Monthly, New York, 1882), p. 747, Fig. 07.

A particularly captivating period of aeration is the oxygen-bound burst in biodiversity known as the Cambrian Explosion when more familiar life forms started appearing. The precise manners in which this happened, as well as the duration of the 'explosion' remains a lively debate, but the fossil record suggests a tangle of oxygen, proteins, eyes, legs, ferric oxides, mineralized-shells, boreholes, teeth and claws contributing to the outburst. Recent studies point towards a critical tipping point in oxygenation, somewhere in the range of 3% - 10%, that facilitate the emergence of predators, kick-starting a biological arms race (Sperling et al., 2013, pp. 13449–13450, 2015, p. 451).

Metaphors such as 'arms race' and 'explosion', prevalent in discussions of the Cambrian are borrowed from military jargon, making parallels with territories of conflict and *their* related outbursts of (techno) morphological transformation. Regardless of the historical context in which the term was coined, the very

the lateral line) versus organs that transduce pressure-differences (the swim bladder and fish inner ears), distinctions that are important for identifying evolutionary lineages of organ types. The current text takes a more general approach to hearing as such, focusing instead on commonalities in vibration-sensing organs in their *transductive* functions. Transductions that *introduce continuities* between motions in fluids, organs, hairs, voltage and qualities of hearing.

notion of an *abrupt blast of biota* underscores the intermittent, heterogeneous nature of evolutionary thrusts.

It is only in the last few million years that oxygen in the earth's atmosphere has stabilized at around 21%. That ratio, together with air's other prominent gas nitrogen, sets the current standard for the speed of sound, cited in acoustic literature, to 343 meters per second at sea level, at 20°C, at room temperature. Incidentally, anywhere outside that 'room' the acoustic standard continually endures smaller fluctuations through encounters with shifting clouds, sun, wind, elevation, humidity, and barometric pressure.

In acoustics, time is also a distance, rendered in wave-lengths (audible pitch) as well as wave-travels (audible echo). Sounds start appearing as physical sizes in 17th century Europe where it had theological implications at the time, for instance in timing delays of Judgment Day trumpeting heard at different positions on the globe. Determining the speed of sound in air also had practical importance as means of surveying. Counting the time it takes for sound to bounce back from an embankment could determine the distance between field troops and an enemy fortification. Establishing sounds as distances was aided by the fact that the prevalent materiality of sound at the time was strictly geometric: sounds travelling along straight-line rays cling like cobwebs to their sources in illustrations of the German Jesuit scholar Athanasius Kircher.

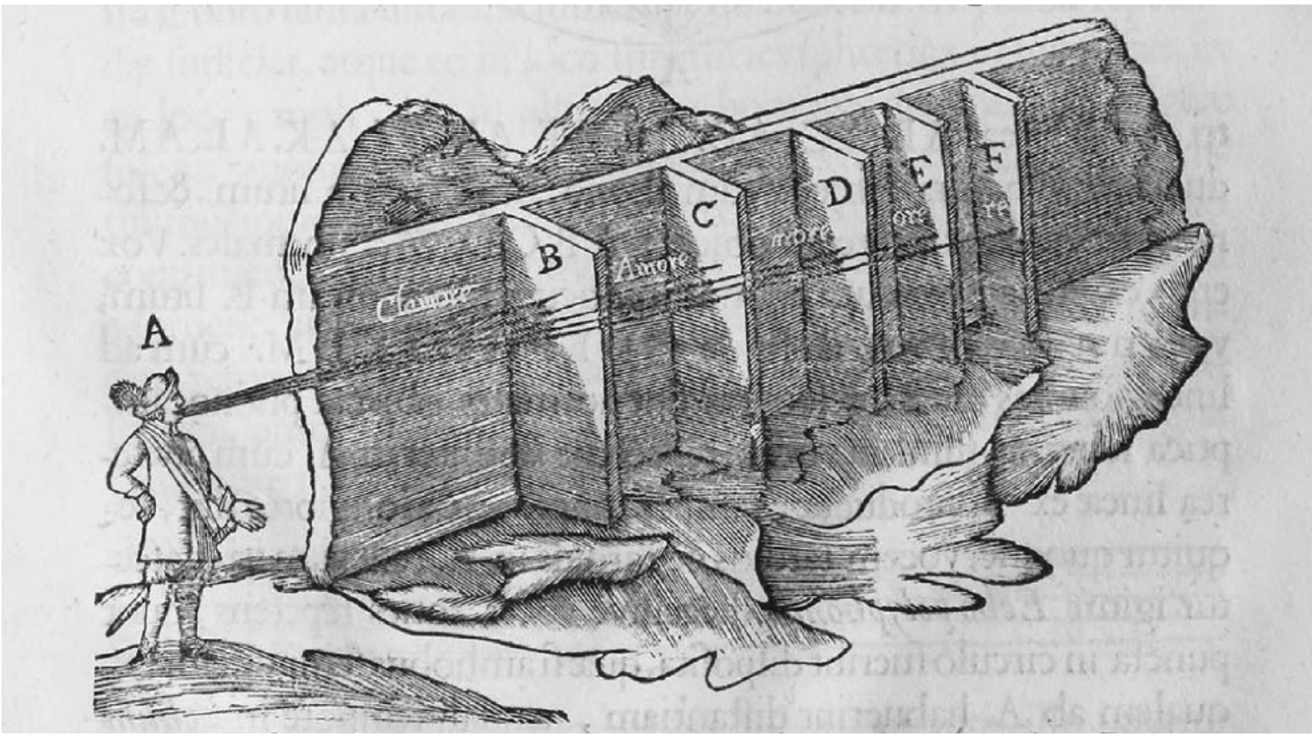

Figure 5.4 Echo distance ranging with spoken words in Athanasius Kircher's Phonurgia Nova. Illustration in Kircher, Athanasius, Phonurgia Nova (Rudolf Dreherr, Campidona, 1673).

The French monk and proto-acoustician Marin Mersenne's first attempts at calculating the speed of sound were by counting spoken syllables bouncing off surfaces at known distances, using his heartbeat as a stopwatch. Kircher expanded on Mersenne's advice testing his voice reflections off trees, rivers and metallic surfaces and noticed that wind and weather conditions affect the echo returns. Better results were attained with two participants and a musket-blast, observing the time-slip between the flash of light and blast of air. An interval of 21 hours 5 and 2/3 minutes was Mersenne's estimated calculation for a round-the-world sound.[13] The same calculation using today's time-keeping and acoustic standards is 32 and 1/2 hours. In

13 Marin Mersenne's Judgment Day sound calculation is barrowed from Fredrik Vinton Hunt's book *Origins in Acoustics* (F. V. Hunt, 1978), presenting a genealogy of Hunt's native discipline of acoustics in which he was a central academic figure in the electro-acoustic era. Hunt is particularly qualified to address long-range cataclysmic sounds considering he headed the Harvard Underwater Sound Laboratory (HUSL) that was instrumental in development of sound-based submarine detection and acoustic homing torpedoes during World War II. Prior to attending to the fidelity of underwater sounds, Hunt (together with John Alvin Pierce) devised a phonograph stylus that rested more lightly in

practice it's closer to 36 hours.

Sounds circumnavigating earth in its earliest atmosphere would likely have taken less than 10 hours. The speed of sound in earth's primordial atmosphere, before life emerged, was around 4 times faster than today. Not only has the speed of sound changed, but also the kinds of sounds in relation to predominant structures in the environment. The 165 million-year-old bush cricket – known as *Archaboilus musicus* – chirred nearly one octave lower than its descendants today, presumably to better transmit through the Jurassic vegetation of giant ferns and conifer trees. A team consisting of paleontologists, entomologists, and bioacousticians painstakingly recovered the katydid's chirp from fossilized wing serrations (the chirp producing feature) discovered in northwest China, releasing a fragment of the Jurassic playback into contemporary air (Gu et al., 2012).

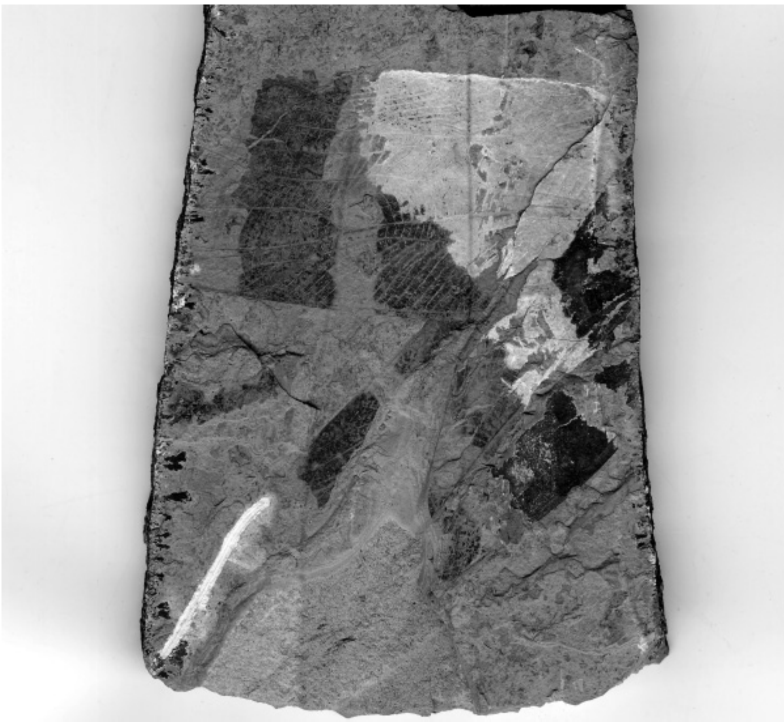

Figure 5.5 Fossilized Jurassic katydid (Archaboilus musicus) with intact chirp-producing wing serrations. Photo courtesy of Dr. Junjie Gu and Prof. Dong Ren, College of Life Sciences, Capital Normal University, Beijing, China.

Escaping Earth - Gas Powered

Helium only accounts for a fraction of today's air composition. However reserves of Helium in earth's mantle and oceans are thought to be actual *fossils* of earth's early atmosphere from a time when helium was abundant (Clarke et al., 1969, p. 219; Craig & Lupton, 1976, pp. 381–383; Zahnle et al., 2010, p. 04). To our ears today, the disappearance of helium sounds laughable, at least that's the reaction it provokes when speaking with helium-filled lungs. The squeakiness of words propelled through helium, sounds the mismatch of oscillations resonating the vocal tract in an inappropriate gas. This banal party-trick humbly demonstrates the coupling of human voice and the atmosphere with oxygen (and nitrogen) rich air.[14] The milieu of the human voice also entangles land conditions: languages of dry high altitude regions contain more plosives

record grooves, providing higher frequency reach, that ushered in the era of high-fidelity sound (Bauer, 1975, p. 1327). Hunt hatched the idea of ocean-wide echo ranging that lead to the development of ultra-long range sonar testing in Bermuda in the 1960's (Frosch, 1981). Though possibly his most far-reaching contribution was simply coining the word 'sonar' that has since penetrated and integrated into numerous languages.

14 The cartoonish effect of speaking through helium occurs due to the mismatch of increased wave sizes in relation with resonant shape of the vocal tract. The speed of sound in helium that is nearly three times faster than in air, resonates the vocal tract such that higher frequency partials accentuate and the lower ones diminish. The effect is like speaking through a shortened vocal tract.

(inhibiting vocal cord dehydration), while low-lying, humid climate-borne languages are richer in vowels (Everett, 2017, pp. 01–04). Likewise birdsong temporal structures at times reflect acoustic qualities of habitat: Birdsongs in open landscapes consist of clicks and rapid trills while woodland species have longer intonation and slower paced calls to accommodate forest reverberation (counteracting the abundant tree trunk echoes that incur temporal smearing) (Naguib, 2003, p. 1749; Wiley, 1991, pp. 983–985).

Hydrogen is another one of earth's primordial gasses currently scarce in the atmosphere. Hydrogen was most likely the predominant conductive medium of earth's primal sounds. Earth's earliest atmosphere is thought to consist of water vapor and hydrogen only a fraction of the latter is still in our air. Most of earth's original hydrogen wrangled itself loose from gravity and drifted off into outer space.[15] Beyond earth, hydrogen is by far the most abundant element in the universe, accounting for nearly 90% of all extant matter. On earth many microorganisms such as green algae actively produce hydrogen during photosynthesis by prying it loose from water molecules with the assistance of sunlight. Sun energy itself features an ongoing process of 'hydrogen burning' where four hydrogen protons fuse to become helium. Humans too produce hydrogen, mostly by extraction from hydrocarbons, but also from water, aided by electricity (electrolysis), and most recently by splitting water with light.

Up until now hydrogen has been limited to energy-intense techniques such as petrochemical processing and rocket propulsion engines. The Apollo mission spacecraft engines burned liquid hydrogen to achieve escape velocity, breaking away from earth's gravity much in the same way earth's original hydrogen escaped into outer space. Recently, the aerospace industry has been looking into exporting water splitting methods to the moon, where reportedly lunar ice will fuel the next revolution in mineral extraction and commercialization of the moon by breaking water chemical bonds into hydrogen (energy for mineral processing) and oxygen (air for future earthling inhabitants) (Galchen, 2019).

When NASA intentionally crashed its lunar probe Ranger 9 into the moon, while broadcasting live imagery over national television on March 24th, 1965, it did not produce airborne sounds. Instead, the force of the collision transduced through the moons surface, in seismic vibrations and topsoil motions. Its sounds are still slowly unfolding in the visible geological morphologies of the anthropogenic crater left behind.

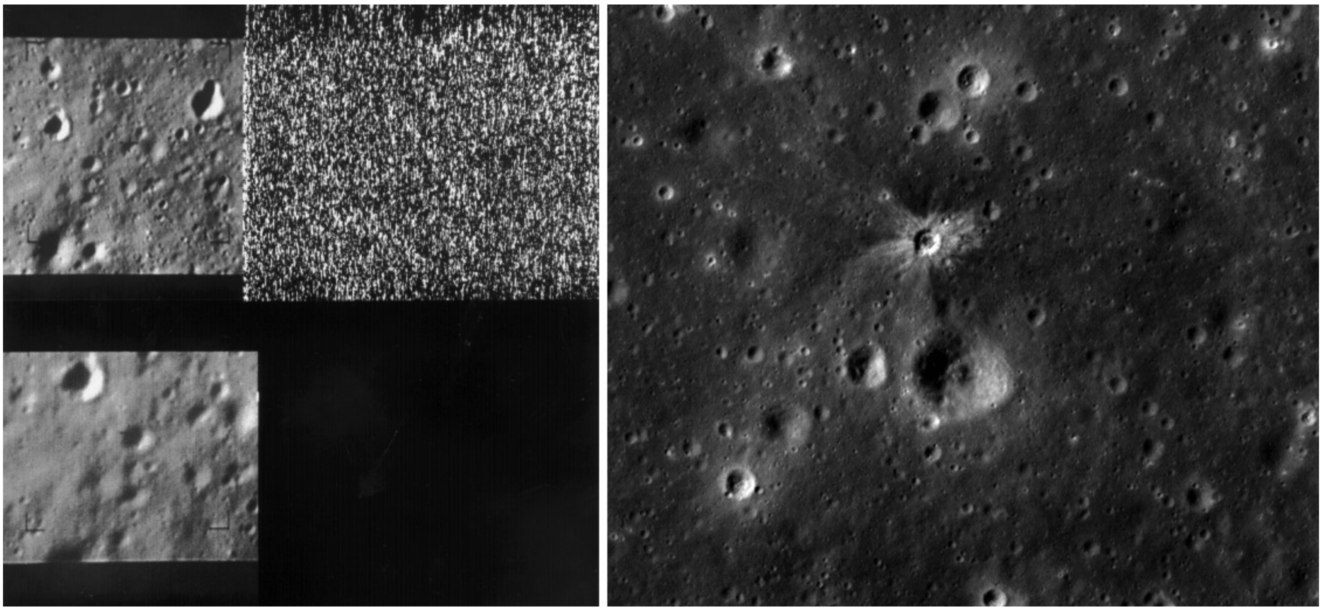

Figure 5.6 Left: Final images from a live televised broadcast of NASA's Ranger 9, lunar impact trajectory probe, crashing into the moon on 24 March, 1965. Right: Anthropogenic lunar crater of Ranger 9's impact. (Photo NASA/JPL)

Hydrogen Ears - Scaled Hearing

In the mid 20th century, in seeking a scaled measure for the excursions of the human eardrum, au-

15 The precise chemical composition of earth's primordial atmosphere remains a topic of debate, though current estimations point to hydrogen as a prime component. See *e.g.,* (Hart, 1978, p. 29) or (Zahnle et al., 2010, pp. 03–04).

thors of acoustics literature reached for the hydrogen atom:

> For the sounds encountered in ordinary conversation the displacement [of the eardrum] is about the same as the diameter of a hydrogen molecule, or 10^{-8} (1/100,000,000) centimeter (Bergeijk et al., 1961, p. 138).

For the quietest audible sounds, eardrum motions scale down even further:

> At the most favorable pitch, an ordinary ear can detect sound pressures smaller than 10^{-10} cm of normal atmospheric pressure, which is one hundred-thousandth of the wavelength of light or *one-tenth* the diameter of the smallest atom [hydrogen]!"
> (Beranek, 1949, pp. 192–193)

At the lowest threshold of hearing, the human eardrum sways in subatomic motion, a realm where acoustic vibrations can intermingle with subatomic vibrations. As the smallest atom, consisting of a single electron linked to a nucleus with a single proton, hydrogen is a prime candidate for human micro measurements. For over a century hydrogen has been at the center of inquiries into structures of matter. Hydrogen was paramount in the development of quantum mechanics; its distinctive red signature wavelength (21 centimeter long) is central for red shift calculations in astronomical observations as well as discerning structure and age in the universe.

Standing waves within the hydrogen atom producing red, violet, blue and cyan vibrations, provide tangible evidence for *quantized* energy transitions of the atomic structure. Erwin Schrödinger's 1926 equation for the derivation of standing waves in hydrogen accurately predicts its spectral series, defining a crucial waymark towards an understanding of wave–particle duality, at the same time expanding human attention to waves below the surfaces of tangible matter (Schrödinger, 1926, pp. 861–876).

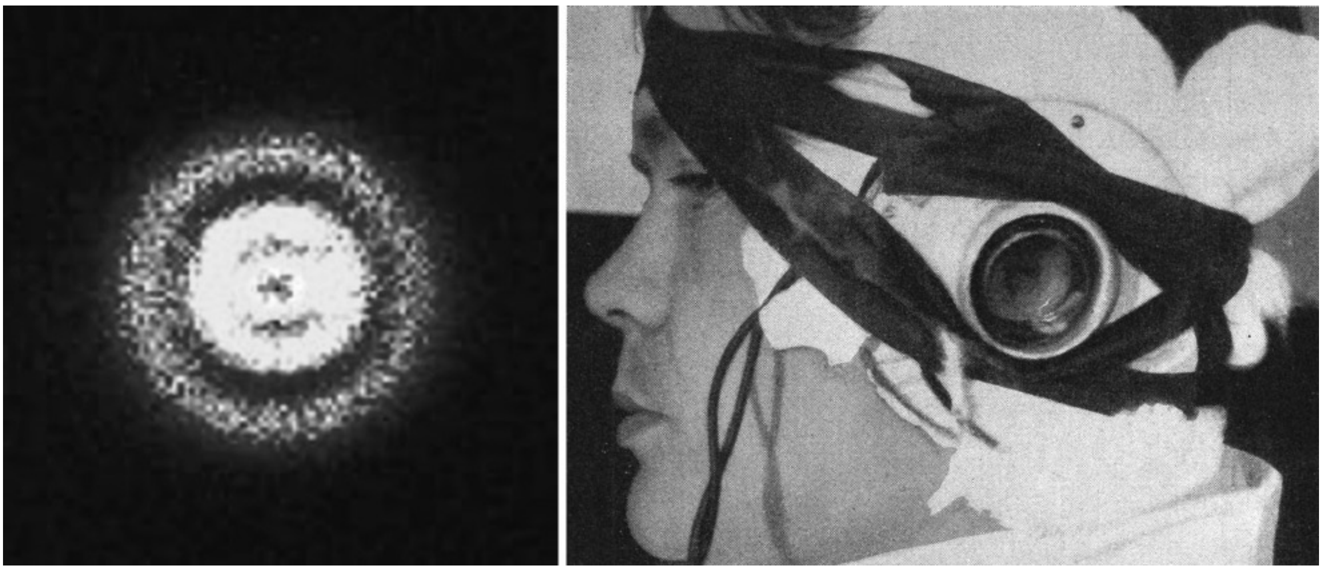

Figure 5.7 Left: Quantum microscope direct observation of nodal resonance structure in a hydrogen atom. Image crop, "Experimental observation of the transverse nodal structure of four atomic hydrogen Stark states", from Stodolna et al., Hydrogen Atoms under Magnification (Physical Review Letters 110, no. 21, 2013), p. 213001-3, Fig. 03. Right: Physiologist Alvar Wilska conducting eardrum excursion measurements on his own ear c. 1935. Photo courtesy of Archives of the physiological institute, University of Helsinki,Publications and reprints of the physiological institute, from Wilska, Alvar, Eine Methode zur Bestimmung der Hörschwellenamplituden des Trommelfells bei verschiedenen Frequnzen (Skandinavisches Archiv Für Physiologie, vol. 72, 1935), p. 163, Fig. 02.

The two previously mentioned hydrogen-eardrum references from acoustic literature refer to a single experiment in 1933 where the Finnish physiologist Alvar Wilska, glued a wooden stick to his own tympanic membrane to experimentally determine thresholds of human hearing. With the eardrum braced between a stick and the tiny auditory bones in the middle ear, electro-mechanical movements were directly transmitted to the inner ear by way of an induction coil at the end of the stick. Wilska's experiment is a curious crossover between electro-acoustics and physiology where the ear is momentarily rendered as a technical audio transducer with the stick acting as piston and the eardrum as loudspeaker membrane. Although the setup aims to provide an indication of the eardrum response to atmospheric sway, the atmosphere itself had to be removed from the experiment to perform the measurement.[16]

Schrödinger's Atmosphere - Intermittent Hearing

Nearly a decade before Erwin Schrödinger published the standing wave equation for the hydrogen atom, he spent a few years unwittingly listening to waves propagating overhead. Schrödinger's paper from 1917, addressing 'outer zone of abnormal audibility' (also known as acoustic shadows or zones of silence) describes acoustic lensing effects in the atmosphere as a consequence of temperature gradients in the sky. Schrödinger's temperature model corrected a predominant yet mistaken theory that zones of silence were produced by differences in wind speeds, at various elevations in the atmosphere (Schrödinger, 1917). The paper was written upon his return to civilian life in Vienna after a time in the Austro-Hungarian military serving as an *artillery* officer on the Italian front during World War I. Schrödinger's insight was no doubt informed by hearing echoing cannons in the mountainous terrain of Italy's northern border.

Refractive properties of air change with temperature in such a way that certain aerial layers rebound the lower partials of explosive booms, sending sounds skipping across the landscape.[17] The Tyrolean Alps and Dolomite mountains, along the Austrian-Italian frontier, were particularly affected by the ongoing barrage of shockwave echoes and human-induced avalanches, not to mention anthropogenic forms of land erosion such as blast tunneling and mortar bombardment.

Detonations of high explosive (sic) munitions impinge gigantic concentric patterns of alternating intensity on the earth's surface due to ricocheting effects between earth's crust and temperature inversion layers of the lower atmosphere. Alternating zones of audibility and silence, spaced tens or even hundreds of kilometers apart, radiate outwards from epicenters of large blasts, like rings on a bulls-eye target.

Zones of silence have been observed as early as 1666 in the Second Anglo-Dutch War when cannon blasts from a naval battle in the Dover Straits were plainly heard inland in London parks but not on the Dover coast (Pepys, 1666). Two centuries later, along the same coastline, the physicist John Tyndall conducted a series of tests to observe behaviors of long-range sound propagation over water. Later still, in the first half of the 20th century, iconic chalk and concrete sound mirrors were constructed on the bluffs as part of an experimental early-warning network trained on distant aircraft sounds.[18] Tyndall's tests included sounds from guns, cannons, an eleven-foot-long trumpet and steam-powered siren projected off the chalk cliffs and monitored from boats at sea. Results were inconclusive, though he suspected invisible 'acoustic clouds' effecting heterogeneous territories of audibility at sea (Tyndall, 1875, p. 553).

Tyndall was familiar with zones of silence, or what he termed 'acoustic opacity', from an earwitness account across the Atlantic in Virginia, at the Battle of Gaines' Mill:

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16 More recent studies point out that connections between membrane displacement and audibility are oversimplified and that more attention needs to be focused on complex vibrational patterns of the membrane, especially at higher frequencies (Konrádsson et al., 1987, p. 159). Contemporary tympanic measurements apply laser Doppler interferometry to study three dimensional vibration behaviors of the membrane.

17 Zones of silence are readily observable when lightning strikes silently. Under certain conditions, atmosphere temperature inversions cause thunder to bend upwards typically when the lightning occurs at an elevation of 4 km and the observer is at a distance of 22.5 km from the event.

18 Britain's Eastern coastline has been a prominent site for scrutinizing limits of landlubber hearing. In particular the southeastern chalk cliffs of Dover Straits were repeatedly used as a testing ground for theories of sound propagation and the development of long-range listening devices, in the contexts of shipping safety and airborne warfare respectively (Ganchrow, 2009, pp. 71–75) . The physicist John Tyndall's open-air sound experiments of 1874 attempted to remedy an epidemic of coastal shipwrecks occurring in 'thick weather' on Britain's periphery with audible fog signals. In the run-up to the tests, Tyndall mentions the failure of lighthouses to provide ample warning in foggy conditions, citing 273 sunken ships over the course of a decade due to poor visibility along the coast (Tyndall, 1875, p. 541).

> " I saw batteries of artillery on both sides come into action and fire rapidly. Several field-batteries on each side were plainly in sight [...] Yet, looking for nearly two hours, from about 5 to 7 p. m. on a midsummer afternoon, at a battle in which at least 50,000 men were actually engaged, and doubtless at least 100 pieces of field-artillery, through an atmosphere optically as limpid as possible, *not a single sound of the battle* was audible to General Randolph and myself [...] The cannonade of that very battle was distinctly heard at Amhurst Courthouse, 100 miles [to the] west." (R.G.H. Kean cited in Tyndall, 1874, p. 235)

Zones of silence were extensively encountered during the American Civil War, disrupting battlefield sound signaling, though their causes remained unknown. At the time acoustic shadows were heard as features of topography and wind, their operative spaces remained strictly geographic. With the outbreak of the World War I, zones of silence linked up with other long-distance sound oddities. For example, it was noticed that sounds of battle in France were more audible in England in the summer and in Germany in the winter (Ross, 2000, p. 138). Directly after the war, unusual behavior of long-distance sounds prompted orchestrated blast testing. Controlled munitions explosions were mapped – by way of coordinated, geographically distributed listeners – to their corresponding zones of audibility and silence. Outermost audibility rings from one large detonation conducted on December 18, 1925 at Kummersdorf – the central artillery testing and sound-ranging research site, south of Berlin – extended hundreds of kilometers over the borders into France and the Netherlands (Gutenberg, 1932, p. 129). Schrödinger's paper on refraction only explained sound rebounds in the lower atmosphere though the dynamics were more complex, subsequent reflective layers in the upper atmosphere were discovered by interpreting meandering meteor trail patterns careening across the sky (Lindemann & Dobson, 1923, pp. 411–437).

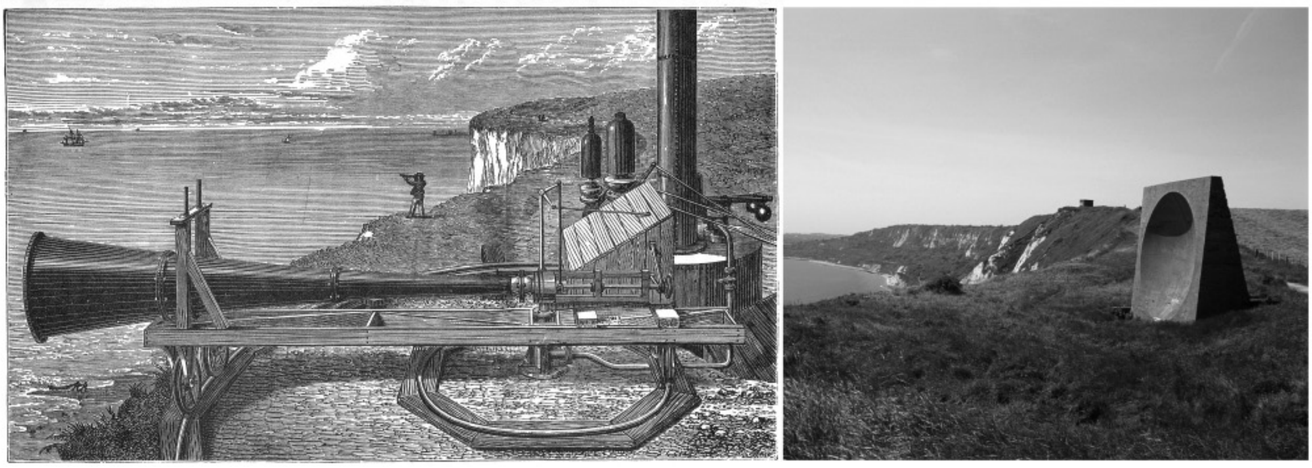


Figure 5.8 Left: Steam-powered siren (foghorn) employed in John Tyndall's 1873 experiments of sound propagation over water conducted at the Straits of Dover, Kent coast. Right: 20-foot early warning sound mirror, constructed in 1928 at Abbots Cliff, applied in monitoring aircraft sounds over the Straits of Dover, Kent coast. (Photo by author)

Some years later at Kummersdorf, the rocket engineer Wernher von Braun successfully tested a liquid propellants rockets that morphed into explosive-laden V-2 rockets and eventually transposed, along with von Braun himself, into the Apollo space program whose hydrogen fueled Saturn V launch rockets were the first to land humans amidst the moon's countless impact craters. Approximately 4 billion years earlier, during the Late Heavy Bombardment (LHB), when the moon got its pockmarks, a barrage of asteroids exploded in near-silence on the lunar surface, their shockwaves constrained to vibrations in the moon's substrate – at least that is the narrative the Apollo missions carried back inscribed in moon-rock samples. Here on earth, echoing reverberations of the LHB explosions – so intense that they presumably re-melted portions of the earth's upper crust – would have died-off one third quicker than today due to the methane rich air at the time. Airborne ears did not exist yet, but if any organisms lived through that period, they would have done so enduring colossal seismic jostling.

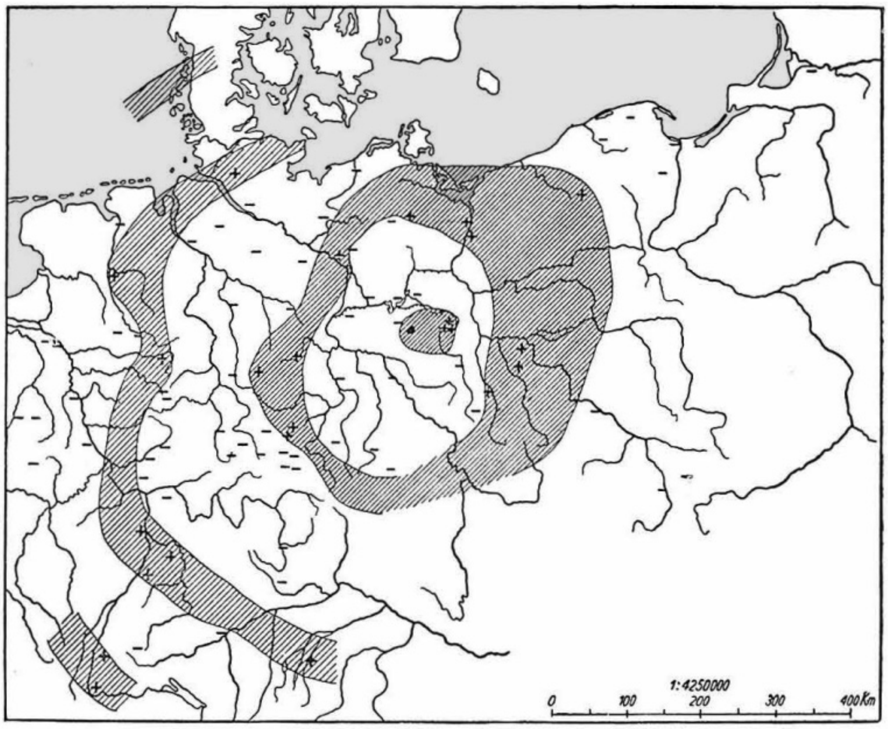


Figure 5.9 Zones of silence (-) and audibility (+) observed radiating from a coordinated detonation of 5,000 kg of ammunition at Kummersdorf artillery testing facility, south of Berlin, on December 18, 1925. Map adapted from "Positive (+) und negative (-) Beobachtungen der Sprengung in Kummersdorf am 18. Dezember 1925", in Gutenberg, B., Die Schallausbreitung in Der Atmosphäre (Handbuch Der Geophysik, vol. 9, 1932), p. 129, Fig. 51.

Krakatoa's Barometers - Hearing Air

Human abilities to hear large sections of air, appear when weather barometers link-up with telegraphy.[19] The earliest recognized atmospheric fluctuations at global scale originate in intense volcanic and meteorite explosions around the turn of the 19th century. Until that point, human perceptions of atmosphere oscillations were clearly divided between sounds the ear registers (as far as the wind blows and thunder rumbles) and changes in weather patterns (inaudible yet tangible oscillations of mercury columns and barometer read-outs). Those distinctions were nullified with the 1883 eruption of Krakatoa in Indonesia when the bottom end of sound dropped open into an abyss of ultra-slow atmospheric oscillations. Sounds from the massive volcanic explosions were audible to the naked ear in more than 50 widely-spaced geographic locations covering an area equivalent to approximately one thirteenth of the globe.

Inaudible pressure waves from the blast travelled even further, appearing in swells of barometer mercury and jerks of plotter styluses at forty weather-monitoring stations across the globe. Pulses from the explosion took approximately 36 hours to circumnavigate the globe, yet their presence continued registering on barometers up to five days later as the pressure waves continued circling the earth. When shockwaves from the eruption engulfed a British ship, 64 km away, force of the blast burst the eardrums of more than half the crewmembers.

19 Douglas Kahn has identified a vast array of overlapping contexts contributing to the emergence of global-scale attentions, particularly those entailing encounters with environmental energies. This text is indebted to insights from Kahn's navigations of long-sounds and intersects with several stations from those journeys.
For a comprehensive account of the scaling-up of human attention and hearing to earth magnitude, along with the cross-overs into cultural practices, see Kahn's *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts*. (Kahn, 2013)

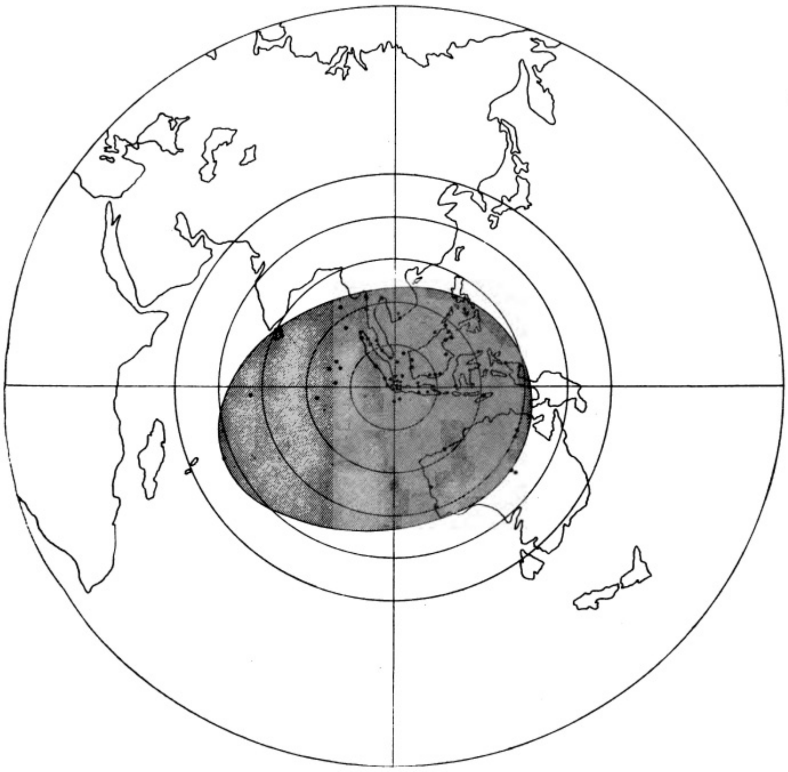


Figure 5.10 Map indicating approximate zone of audibility where sounds of the explosive eruptions from Indonesia's Krakatoa volcano were heard on August 26-27, 1883. Illustration, "Map Showing the Places at Which the Sounds of the Explosion Were Heard on Aug. 26-27", from Judd J. W. et al., The Eruption of Krakatoa and Subsequent Phenomena. Ed. George James Symons (London: Trübner & Co.) 1888, p. 154, Fig. 16.

Jawbone Ears - Impeded Hearing

Eardrums constitute a portion of animal skin and insect exoskeleton explicitly stretched to airborne fluctuations. Eardrums only appear when organisms crawled onto land. The series of tiny bones in the human middle ear, suspended in a pressurized chamber just behind the eardrum (stapes, incus and malleus), are in fact portions of a reptilian ancestor's jawbone. Earlier versions of our stapes functioned in suspending the animal's lower jaw (Fritzsch, 1992, p. 366). Mammals have long been busy converting the primitive jaw elements into a sensitive mechanism for transporting airborne motions from tympanum to the liquid-filled inner ear. Eardrums of mammals, reptiles and birds, remarkably similar in structure, are thought to derive from a common ancestor. Interestingly, though, the bird's middle-ear evolved separately, incorporating bones from the upper jaw while the human middle-ear derives from bones in the lower jaw (Kitazawa et al., 2015, p. 02). Regardless of which jaw portion a land animal happens to carry, their ear's midsection recalls the journey onto land.

Frogs and toads are the first amphibians to develop atmosphere-transducing ears. Insects, too, developed tympanal hearing with vibrating eardrums on various parts of their body such as legs, abdomens, wings, and necks. The Death's-Head moth has ultrasound-hearing eardrums fixed on its mouth.

Tympanic ears appear mostly in pairs though their numbers fluctuate in insects. Praying mantises only have one monaural ear on their chest while bladder grasshoppers have six pairs along their abdomen.[20] Other land animals never developed air sensitive outer ears. Many beetles are air-deaf, reacting instead to substrate vibrations. Darwin demonstrated earthworm's inability to hear airborne vibrations by subject-

20 Humans listening through insect ears sets our own hearing in broader perspective, though it is also partially motivated by micro-ambient noise reduction in quantum computing and increasingly miniaturized environmental monitoring circuits in mobile phones, drones, robots and small satellites and need for smaller, low-cost, more energy efficient environmental sensors (not to mention tightening the clasp on pesky insects).

ing them to shouts, whistling and tones from his piano. He did however note their exceptional sensitivity to conductive soil vibrations, an ability they apply when avoiding moles or surfacing for rain (C. Darwin, 1881, pp. 26–29). Herring gulls have learned to tap with their feet in a manner that lures them to the surface. The practice of 'worm grunting' or 'worm charming' involves rhythmically vibrating objects driven into the topsoil when collecting worms for fish bait.

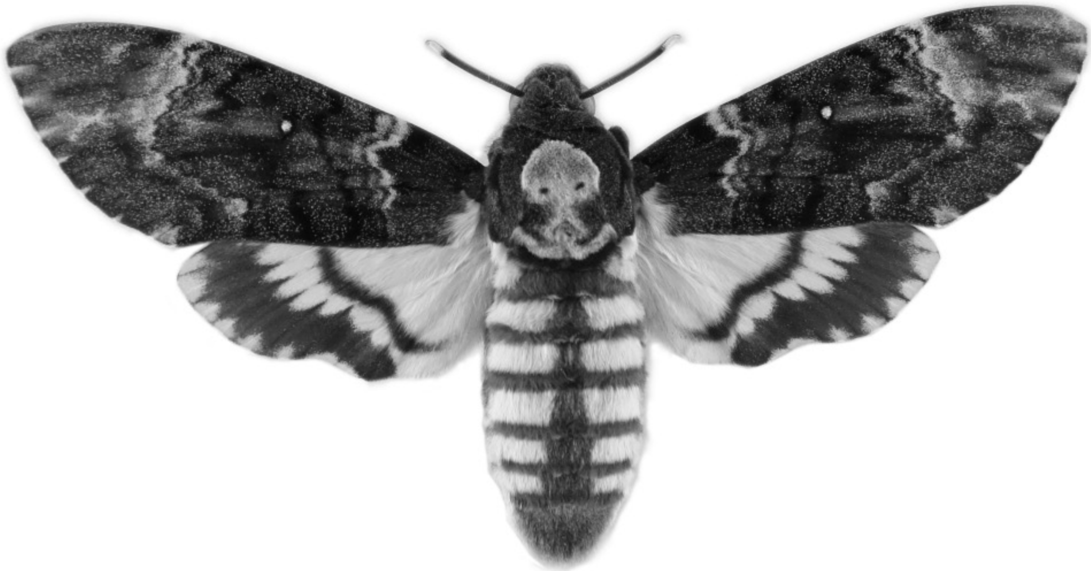


Figure 5.11 Death's-head moth (Acherontia lachesis). (Photo by author)

Vipers and other snakes localize prey by hearing ground vibrations through their lower jaw. Pattering rodents induce feeble topsoil oscillations that travel along either side of the snake's jawbone, arriving at the inner ears in slightly differing times. The jaw's function of breaking up vibrations (and not only food) along two separate pathways is a necessary feature of *directional hearing* (Friedel et al., 2008, pp. 048701–1).

Morganucodon is one of the earliest known ancestors possessing defining jaw joint features attributed to modern mammals. Morganucodon's physiognomy was halfway between a rat and a shrew with ears that sit midway on the journey to mammals. Its hearing organ is awkwardly situated *inside* the jawbone joint (with ear bones connected to the lower jaw), a feature that must have been particularly raucous for Morganucodon during mealtime. Paleontological interest in Morganucodon's ears is in the intermediate stage it presents towards human and other mammalian hearing. In the literature Morganucodon's ears are examined for acoustic fidelity, contrasted with ears of recent animals, and gauged with electronic circuit terminology:

> "When sound passes from one medium to another some part of the total energy will be *reflected at the boundary*. The remaining part of the energy will be transmitted into the second medium. The proportions of the total energy reflected and transmitted will depend on the acoustical *impedance* of the two media." (My emphasis, Kermack et al., 1981, p. 138)

The impedance is that of Morgunucodon's ears deemed incapable of appreciating the full gamut of airborne vibrations:

> "[T]he ear of Morgunucodon was probably not particularly efficient. It was reasonable at low frequencies up to one kilohertz but poor at high frequencies." (Kermack et al., 1981, p. 146)

Apparently, Morganucodon was suffering from a case of impedance mismatch. Although the earth at that time was imagined to be sounding in hi-fi splendor, much of the fidelity rebounded off stiff Triassic ears.

In the sea-to-land transition, surface tensions between the organism and its surroundings recalibrated. Pressure gradients in air are approximately one four-thousandth that of water, such that sound in air exerts only 1/63rd of the pressure developed by the same sound intensity underwater (van Bergeijk, 1966, p. 373). This pressure difference implies that early land animals may have arrived onshore practically air-deaf due to the mismatch of firm watertight ears interfacing with the pronounced elasticity of air. In short, the new airborne ears had to learn how to flex. At least that's the narrative that appears when ears are neatly arranged along a sequential trajectory of hi-fidelity progress.

Impedance matching mechanisms, such as tympanic middle ears, arose independently in reptiles, birds and mammals (Manley & Clack, 2004, pp. 1–25). The term *impedance matching* is borrowed from electrical engineering, where it is extensively applied in the design of communication networks in which input and output energy loads have been matched to maximize transfer between various parts of the electrical circuit. The paleontologist, Willem van Bergeijk, an authority on the evolution of hearing and a key proponent of the impedance matching theory in the development of terrestrial hearing, was no doubt aware of the parallels with communication networks considering he was an employee at Bell Telephone Laboratories at a time when U.S. telephones were already relayed coast-to-coast.

Electrical resistance in a metal wire increases proportionately with cable length, such that signal strength diminishes over distance. Calibrating resistances and sustaining electrical power over telephone networks, particularly in locations where wires (communication infrastructures) meet transducers (telephone receivers), is essential for designing national and international telephone grids. The application of electrical 'impedance' to a variety of materials in communication networks, as well as in prehistoric ears, is made possible by the shared mathematical behaviors such materials express when traversed by energetic flux.[21] An impedance mismatch on the receiver end would reflect part of the signal back towards its source, much in the way Morganucodon's ear reflected portions of impinging sounds back into air. Early long-distance telephone lines were plagued with such ghostly voices ricocheting through the wires. One can only imagine how earth's atmosphere sounded at that time echoing off stiff Triassic ears.

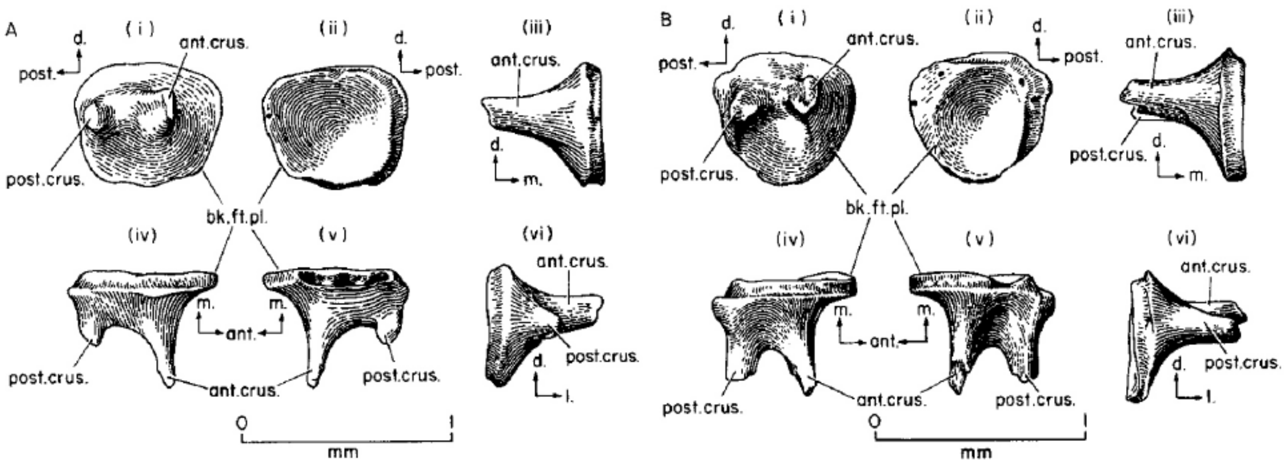


Figure 5.12 Middle ear stapes bone of Morganucodon. Illustration by A. J. Lee, "Morganucodon", in Kermack, Mussett, and Rigney, "The Skull of Morganucodon." (Zool. J. Linn. Soc, no. 1, 1981), p. 103, Fig. 84.

Deadhead Localization - Immobile Listening

Telephone receivers appeared early in directional hearing tests at psychophysics labs in the late 19th century. The experimental setup at the Psychological Laboratory of Harvard University included a wooden desk-chair positioned in the center of a spherical armature wired to batteries and coils. Sounds of various kinds and intensities, variably positioned around a listener's head, were administered through telephone re-

21 Impedance in acoustics is defined as the ratio of the force per unit area in relation with the displacement magnitude of a given surface across which sound is being transmitted.

ceivers suspended from the armature. The set-up resembles a scale model of immense point-to-point global telegraphy networks that rewired electrical circuitry through earth's upper mantle, moments before communication and electrical grids permanently detached from earth's native telluric currents.

Vibrational events intersect twice on binaural listeners, once at each ear. The bifurcating of event, occurring as vibrations split over *two* ears, is reunited in an auditory perception of depth. Hearing a sound from two different time-zones in the circumference of the head, produce relational frictions that also give rise to a sense of localization, of sounds placed back at their imagined sources.

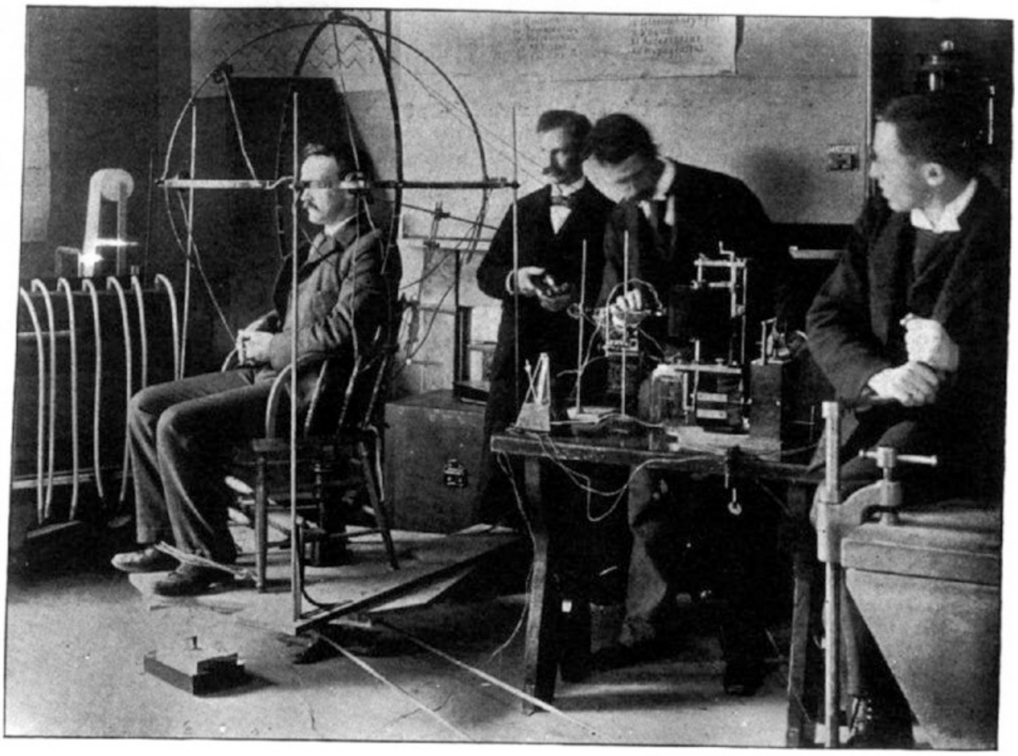


Figure 5.13 Experiment into the effects of dizziness on sound localization with subject seated in an apparatus for testing directional hearing. Photo, "Interior of a Laboratory Room, Influence of Dizziness on Localization of Sound", in Münsterberg, Hugo, Psychological Laboratory of Harvard University (Cambridge, Mass.: University Press of Cambridge, Mass. 1893), p. 24.

Alvar Wilska was early to point out the importance of the outer ear flaps (pinnae) in directional hearing, particularly in front / back discrimination. His previously mentioned glued eardrum experiment was in fact a component in a larger acoustic circuit observing directional discrimination, source localization and binaural hearing in humans. To faithfully measure spatial acoustics in the presence of ear-flaps, he acquired a human corpse, made a cast of the head, and replaced the eardrums with a pair of condenser microphones. He also prepared a padded sound-absorbing room to diminish the influence of room acoustics in the experiments. Test signals, monitored through the immobile head from an adjoining room, determined that forward-facing horizontal localization had the highest spatial resolution, attributed to acoustic phase, intensity and timing discriminations of two-eared hearing.

This isolated experiment, consisting of a dead head in a dead room, exercises a much wider set of tactical (as well as commercial) audile practices taking shape at the time.[22] Directional hearing and sound localization were central questions in auditory research and early experiments of stereophonic radio broadcasting that gain traction in the violent atmospheric disturbances of World War I.[23] The introduction of high

22 Wilska performed preliminary binaural tests at the Finnish Radio Broadcasting Company in the mid 30's in connection with early stereophonic radio broadcasting experiments. Research into binaural hearing in the 1920's and 1930's, besides the carry-over from sound-ranging techniques in World War I, were also partially motivated by entertainment and recording industry speculation over multi-channel audio formats.

23 Binaural localization is the ability to localize sound in three-dimensional space. Binaural auditory perception in land animals involves a complex combination of factors: comb filtering in the outer ear (pinna) and other head-related transfer function effects (HRTF), amplitude differences of sounds at either ear (interaural level differences), time differ-

explosives marks the shift from tower fortifications (and related optics) to trench warfare (centered on acoustics) with its auxiliary problems of mortar, gunfire, and aircraft localization. Concerted efforts were taken to decipher battlefield acoustics producing a multitude of experimental geo-spatial sound monitoring, registration and localization techniques. In particular artillery sound-ranging, methods for deriving gun positions by means of binaural sound monitoring, emerged simultaneously in German, Austrian, British, and French armies.

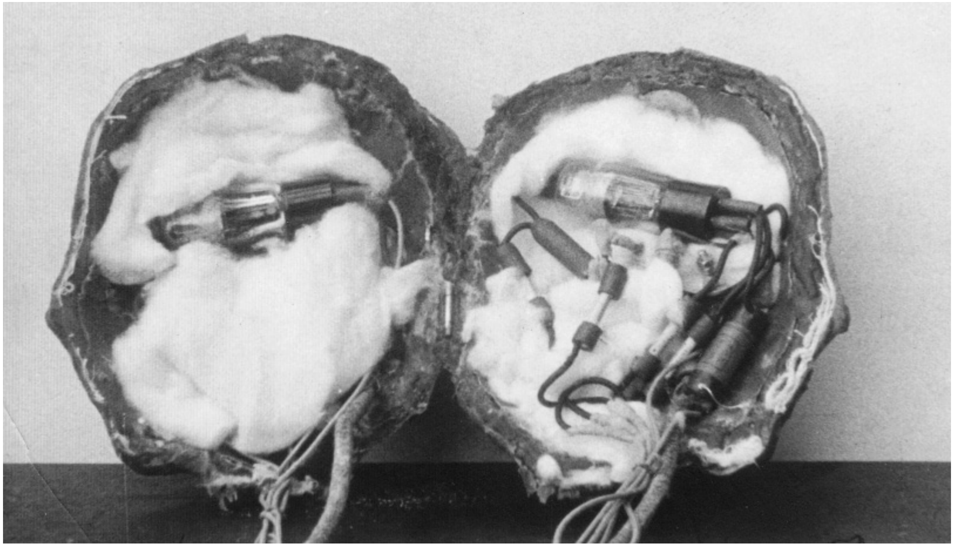


Figure 5.14 Cast human head binaural microphone by Alvar Wilska, open view. (Photo by studio Neittamo Oy, c. 1938, courtesy of Helsinki University Museum)

The development of listening devices and acoustic architectures – first through unplugged amplification by guiding vibrational energy over conical and curved surfaces, and later with the aid of electro-acoustics – render geospatial territories by way of sound. The transformation from optical to sonic methods of observation in warfare matches similar shifts in medical sciences with the introduction of auditory diagnostics. An abundance of stethoscopes fixed to the early binaural sound locators attests to continuities. Percussive histories spanning impacts, collisions, explosions, implosions disrupt as well as induce reconfigurations in terrestrial hearing.

The Orthophone (conceived by Maurice Claude) and the Wertheimer-Hornbostel sound locator (conceived by Max Wertheimer and Erich von Hornbostel), appearing almost simultaneously, are some of the earliest devices exploiting inbuilt human directional hearing for tactical purposes. Wertheimer and Hornbostel's tripod-mounted mobile sound locator is based on binaural experiments conducted at the Berliner Psychologisches Institut, headed at the time by Carl Stumpf who was also their former mentor. The drafting of experimental psychology and acoustic attributes for military ends can have far-reaching implications long after conflicts expire, when perceptual calibrations, specialized measurement techniques, standards, and devices refract into civilian domains.[24] Wartime calibrations of hearing, shackled to specific observational

ences of sounds arriving at either ear (interaural time differences), not to mention cross-correlation with visual and tactile experience. Binaural mechanisms, existing in vertebrate and invertebrates, nearly always involves hearing through two ears (or more), where arrival time and level differences are central in determining a sound's position. Auditory mechanisms for estimating elevation, azimuth and distance differ. Sensitivities also differ from species to species, suggesting *various aspects of dimensional perceptions of space* may have had *different evolutionary histories* (Fay, 2005, p. 03). In humans, binaural localization emerged as a distinctive category of hearing in 19th century psychophysics experiments that had direct tactical utility in World War I. In the years between 1900 – 1920 Carl Stumpf's experimental psychology auditory laboratories in Berlin expanded over 25 rooms of the former imperial castle, organized in four sub-departments serving musicology, medical and military purposes. Stumpf states that "During the war all the large nations involved in the conflict called upon experimental psychologists to collaborate. As the representative of psychology in the capital I was heavily involved in organizing this." (Stumpf & Trippett, 2012, pp. 238 & 249) Interaural time differences, the binaural comparison of sound waves coming from the same source, were the predominant feature exploited in sound-ranging and direction finding applications. Sound manifesting as spatial *positions* is an example of a pervasive sonic materiality that was initially enforced through tactical acoustic monitoring. Although directional hearing is an inbuilt aspect of human binaural audition, Cartesian localization of sounds is not.

24 See for example the cold-war era drafting of behavioral science into the defense industry, political campaigning and

methods and devices, underscore the manners in which human sensations (and reactions) become increasingly integrated as functional relays in hybrid bio-electro-mechanical combat circuits. The Berliner Psychologisches Institut experiments helped established directional hearing as a question of *timing differences* between the two ears, followed-up in experiments like those of Wilska's at the Institute of Physiology at the University of Helsinki.

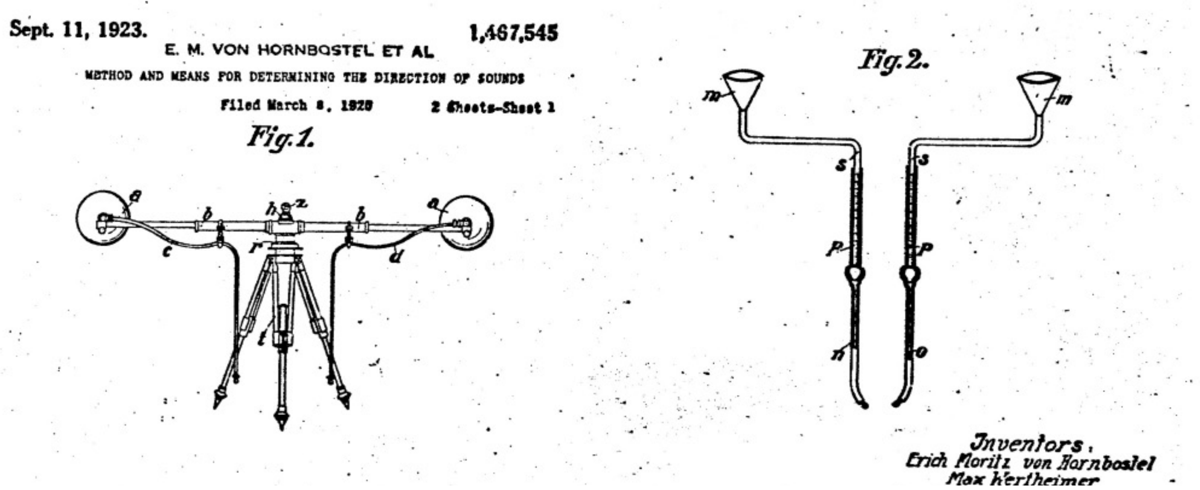


Figure 5.15   Hornbostel-Wertheimer binaural 'sound locator' 1923 US patent, following the original 1915 German patent (No. 301669)

The 'T' shaped Orthophone, deployed in French trenches, works on the same binaural principal as the Wertheimer-Hornbostel sound locator. The ear openings are extended, by way of tubes, to funnels fixed at the ends of a rotating horizontal rod. The effects are that of listening through a bloated head: exaggerated time differences between the ears provided accurate horizontal orientation towards a firing gun that when triangulated with orientations from two or more subsequent units (at other geographic positions), produce a geometrically determinate artillery position on a map.

Similar tactics were applied to binaural geophones in the First World War for detecting ground movements and tunneling operations outside the visible range. Coordinated binaural listening expands the limits of a single observer to match the morphing territories of the battlefront.

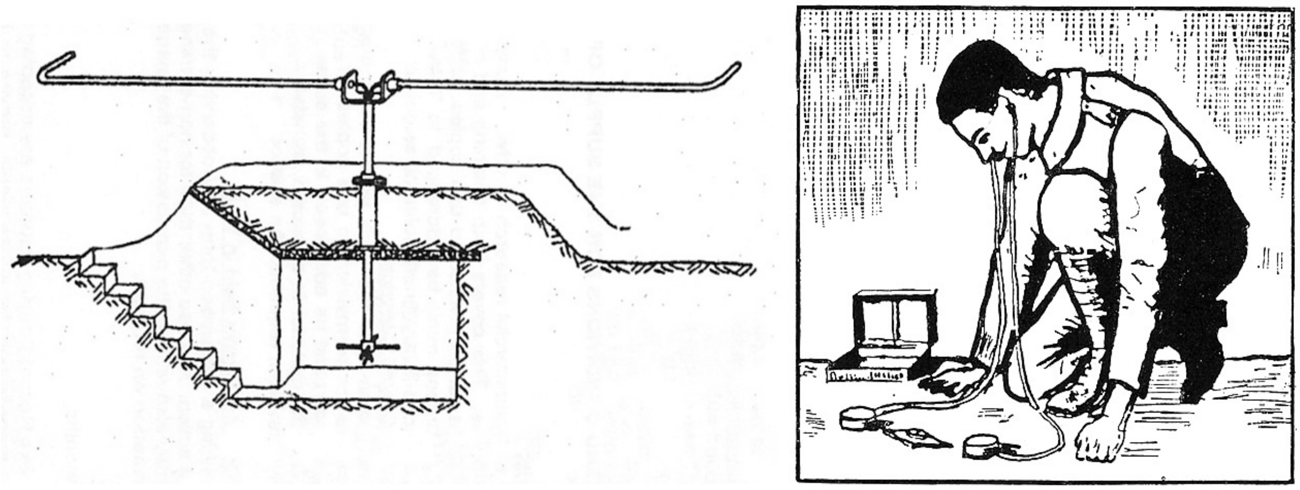


Figure 5.16   Left: Claude Maurice's binaural 'Orthophone' c. 1916, applied in trench warfare by the French artillery sound ranging division. Right: Binaural geophone applied in tunnelling detection during the First World War. (Illustration from J. Neill (ed), The New Zealand Tunnelling Company 1915-1919, Whitcombe and Tombs, 1922)

Irradiate Air - Hydrogen Sounding

The hydrogen isotope deuterium is thought to be one of the earliest forms of matter, a remnant from

commerce in this *Nature* article (Lepore, 2020).

the first twenty minutes after the Big Bang. Deuterium and tritium, the heavier and more rare variants of hydrogen, are also part of the core ignition mechanism in hydrogen bombs (Wald, 1987). The Soviet RDS-202 hydrogen bomb (Tzar Bomba) of 1961, detonated over the Novaya Zemlya archipelago in the Arctic Ocean, was the largest yield weapon ever set off, producing shockwaves that temporarily rendered the atmosphere, along with the earth's interior, as a gigantic echo chamber. Impact from the explosion, estimated at over 3,300 Hiroshima bombs exploding simultaneously, transduced a 5.0 Richter scale magnitude earthquake into the earth's crust. Oscillations from the explosion were picked up on nearly 1000 meteorological barographs at worldwide weather stations and onboard ships (Wexler & Hass, 1962, p. 3875). Stations in New Zealand recorded the passage of pressure waves circumnavigating the globe, three times, over the course of several days, as October transitioned to November (Farkas, 1962, pp. 765–766). Correlated data from hundreds of barometric readings produced a pressurized map looming over North America where political tensions were rendered as variations in local air pressure.

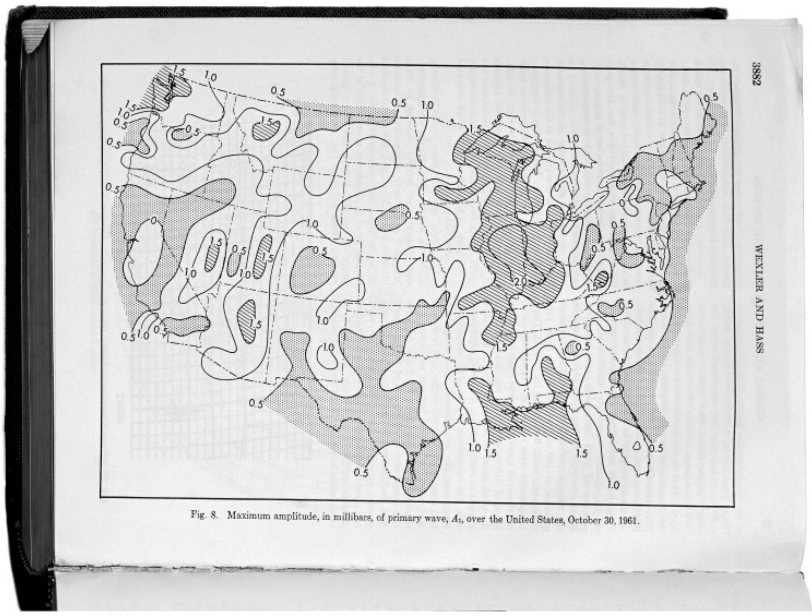


Figure 5.17 Pressure wave distribution from the Soviet RDS-202 (Tzar Bomba) nuclear blast in the Arctic, registered in air fluctuation anomalies above the United States on October 30, 1961. Map in Wexler, H. et al., (Global Atmospheric Pressure Effects of the October 30, 1961, Explosion, Journal of Geophysical Research, vol. 67, no. 10, 1962).

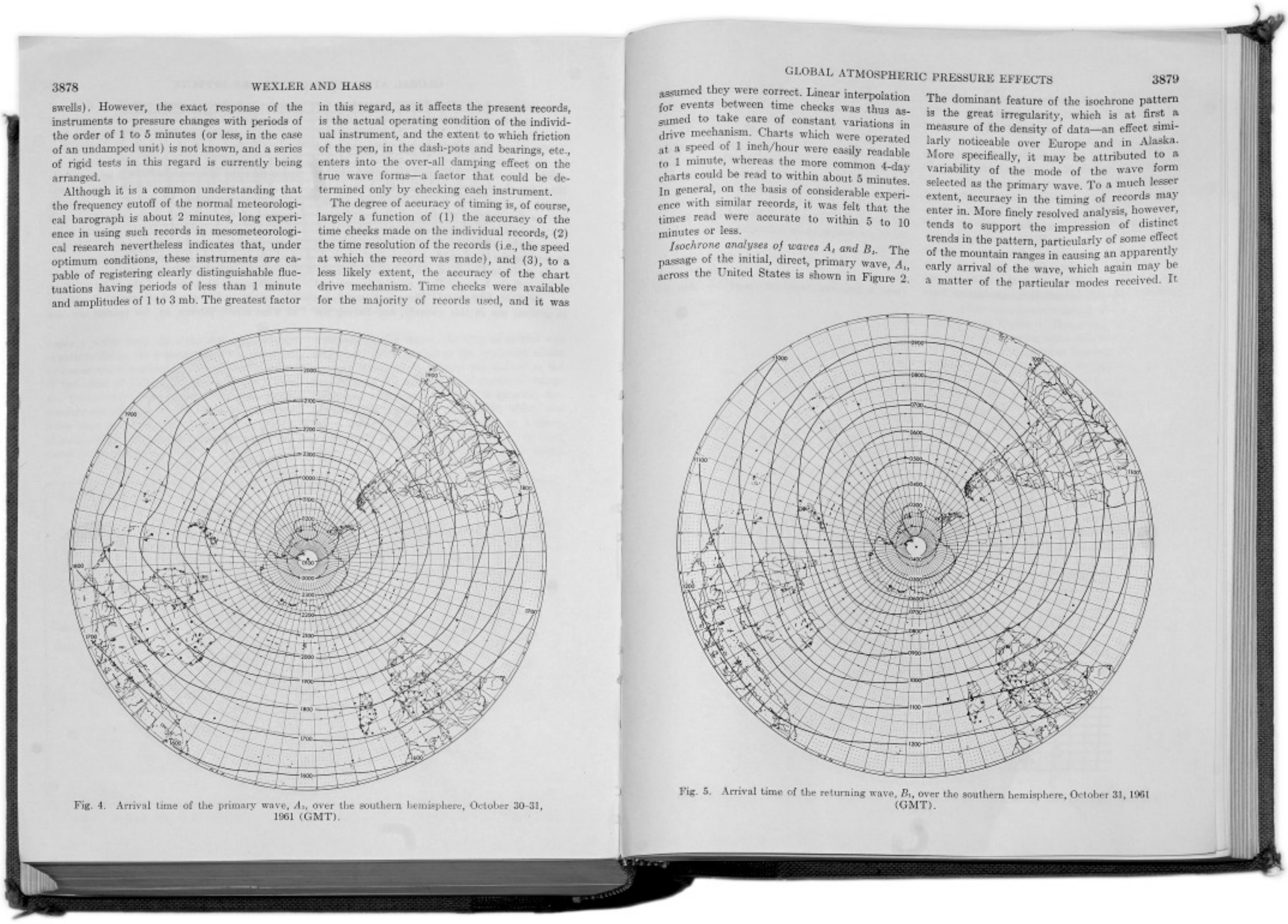
On the other side of the globe from the blast, waves converged at the antipodal, producing an echo off the coast of Antarctica that whales most likely heard.

In the 1950's Ryōzaburo Yamamoto began following United States and Soviet hydrogen bomb testing from barogram signatures at stations across Japan from his post at the Meteorological Research Institute of Kyoto University. By comparing the time delays of various geographic locations, Yamamoto correlated the epicenter of a barogram anomaly from March 27th, 1954, with an American 9.5 megaton thermonuclear explosion at Bikini Atoll in the Marshall Islands (Yamamoto, 1954, p. 120). This was the first time an *anthropogenic* blast had been registered on such a scale. Notably by way of isochronus geo-spatial localization methods – listening through visual media of microbarogam traces, correlated with geographical maps – that extend battlefield sound-ranging techniques over the horizon.

U.S. nuclear bombing at Bikini Atoll began in the summer of 1946 with Operation Crossroads, a series of explosions designed to test the effects of nuclear blasts on warships. It was also tested the effects of nuclear imagery on geopolitics in the Atomic Age, by ensuring audibility of the blasts through mute photographs.[25] Nearly half the world's supply of film was present at the tests (Weisgall, 1994, p. 121). The event was open to international media, 166 reporters attended including photojournalists from Life Magazine,

25 On 20 Aug, 2020 the Russian state nuclear agency (Rosatom) released formerly classified footage, on You Tube with English subtitles, of the Tsar Bomba detonation in connection with the 75th anniversary of Russia's atomic industry, causing a delayed refraction of the 1961 event that echoed through international media similarly to the manner Operation Crossroads explosion imagery circulated in its time, only now operating in a more complex, opaque and unpredictable framework of transnational media dynamics.

Associated Press and International New Service (Office of the Historian Joint Task Force One, 1946, pp. 41 & 86). Together with the official 50,000 still images and over 457 km of motion picture film exposed during the tests qualifies Operation Crossroads as one the most imaged events in human history (Office of the Historian Joint Task Force One, 1946, p. 09).



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swells). However, the exact response of the instruments to pressure changes with periods of the order of 1 to 5 minutes (or less, in the case of an undamped unit) is not known, and a series of rigid tests in this regard is currently being arranged.

Although it is a common understanding that the frequency cutoff of the normal meteorological barograph is about 2 minutes, long experience in using such records in mesometeorological research nevertheless indicates that, under optimum conditions, these instruments *are* capable of registering clearly distinguishable fluctuations having periods of less than 1 minute and amplitudes of 1 to 3 mb. The greatest factor in this regard, as it affects the present records, is the actual operating condition of the individual instrument, and the extent to which friction of the pen, in the dash-pots and bearings, etc., enters into the over-all damping effect on the true wave forms—a factor that could be determined only by checking each instrument.

The degree of accuracy of timing is, of course, largely a function of (1) the accuracy of the time checks made on the individual records, (2) the time resolution of the records (i.e., the speed at which the record was made), and (3), to a less likely extent, the accuracy of the chart drive mechanism. Time checks were available for the majority of records used, and it was

Fig. 4. Arrival time of the primary wave, A_1, over the southern hemisphere, October 30-31, 1961 (GMT).

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assumed they were correct. Linear interpolation for events between time checks was thus assumed to take care of constant variations in drive mechanism. Charts which were operated at a speed of 1 inch/hour were easily readable to 1 minute, whereas the more common 4-day charts could be read to within about 5 minutes. In general, on the basis of considerable experience with similar records, it was felt that the times read were accurate to within 5 to 10 minutes or less.

Isochrone analyses of waves A_1 and B_1. The passage of the initial, direct, primary wave, A_1, across the United States is shown in Figure 2. The dominant feature of the isochrone pattern is the great irregularity, which is at first a measure of the density of data—an effect similarly noticeable over Europe and in Alaska. More specifically, it may be attributed to a variability of the mode of the wave form selected as the primary wave. To a much lesser extent, accuracy in the timing of records may enter in. More finely resolved analysis, however, tends to support the impression of distinct trends in the pattern, particularly of some effect of the mountain ranges in causing an apparently early arrival of the wave, which again may be a matter of the particular modes received. It

Fig. 5. Arrival time of the returning wave, B_1, over the southern hemisphere, October 31, 1961 (GMT).

Figure 5.18 Two consecutive antipodal echoes from the Soviet RDS-202 (Tzar Bomba) nuclear blast, detonated over Novaya Zemlya island in the Arctic Ocean. Map indicates pressure wave convergences (twice circumnavigating the globe) off the coast of Antarctica, between October 30 and 31, 1961. Maps in Wexler, H. et al., Global Atmospheric Pressure Effects of the October 30, 1961, Explosion, (Journal of Geophysical Research, vol. 67, no. 10, 1962).

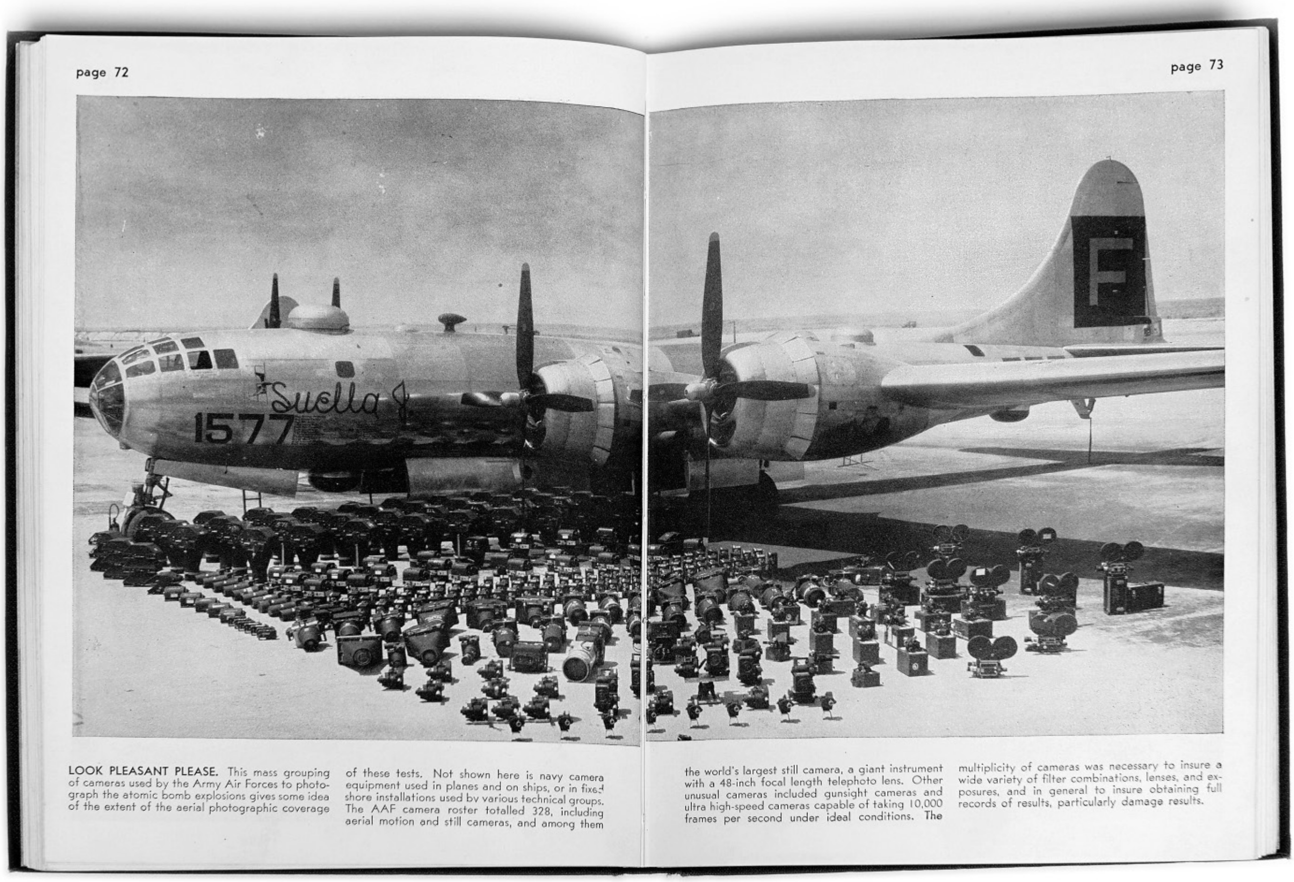
Some of the blast footage cropped up in Stanley Kubrick's film *Dr. Strangelove* (1964), where images of moored target ships in the Bikini Atoll lagoon are plainly visible in the closing explosion sequence.[26] In Kubrick's Cold War 'comedy' a single actor – Peter Sellers – portrays three contrasting characters, one of which is Wernher von Braun who in real life portrayed two contrasting roles in rocket propulsion, embodied in the slippage from the V-2 to Apollo projects. A similar slippage was underway with sound-ranging equipment salvaged from *Prinz Eugen,* a target boat in the lagoon, which became pivotal for sound surveillance methods that followed.

The seized heavy cruiser *Prinz Eugen* operated till the end of the war partially owing to its hull-mounted Gruppenhorchgerät (GHG), or 'group listening apparatus', consisting of 120 piezoelectric Rochelle-salt transducers, the most extensive system in use (Hackmann, 1986, p. 86). GHG hydrophone arrays, also fitted on the sides of U-boats, functioned similarly to the lateral lines in fish that derive positions of activities in surrounding waters from delay patterns in waterborne vibrations.[27] The integration of listening

26 The full title of the film is *Dr. Strangelove or: How I Learned to Stop Worrying and Love the Bomb.* In the film Peter Sellers plays three roles: Group Captain Mandrake, U.S. President Merkin Muffley and the foreign accented nuclear scientist Dr. Strangelove. It's the role of Dr. Strangelove that I (and others) attribute to Wernher von Braun. See for example David Denby, *The Half Century Anniversary of Dr. Strangelove* (Denby, 2014).

27 There is more than a mere functional resemblance between the transduction of water vibrations into electrical currents in mechanoreceptors in fish and GHG hydrophones in submarines. Both systems evolve in saline water; both

membranes along the ship's hull meant that predatory listening became an inbuilt feature in vessels. GHG hydrophones were selectively tuned to predominant propeller frequencies of ships whose angular position could be derived from differences in wave-front arrival times at the various points along the transducer array. *Prinz Eugen's* array was dismantled before deployment to Bikini Atoll, refitted on the specially constructed conning tower of the USS Flying Fish submarine (SS-229) and set to work in sonar experiments at the Naval Underwater Sound Laboratory in the 50's (Rössler, 1991, p. 39).



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LOOK PLEASANT PLEASE. This mass grouping of cameras used by the Army Air Forces to photograph the atomic bomb explosions gives some idea of the extent of the aerial photographic coverage of these tests. Not shown here is navy camera equipment used in planes and on ships, or in fixed shore installations used by various technical groups. The AAF camera roster totalled 328, including aerial motion and still cameras, and among them the world's largest still camera, a giant instrument with a 48-inch focal length telephoto lens. Other unusual cameras included gunsight cameras and ultra high-speed cameras capable of taking 10,000 frames per second under ideal conditions. The multiplicity of cameras was necessary to insure a wide variety of filter combinations, lenses, and exposures, and in general to insure obtaining full records of results, particularly damage results.

Figure 5.19 Photographic equipment employed by the U.S. Army Air Forces in documenting the Operation Crossroads atomic bomb explosions at Bikini Atoll, 1946. Additional to these 328 cameras, numerous others motion and still cameras onboard ships and onshore were engaged in imaging the blasts. (Photo by author, "Thorium Refraction", digital print 40 cm x 30 cm, 1/6 sec, 55 mm radioactive thorium lens)

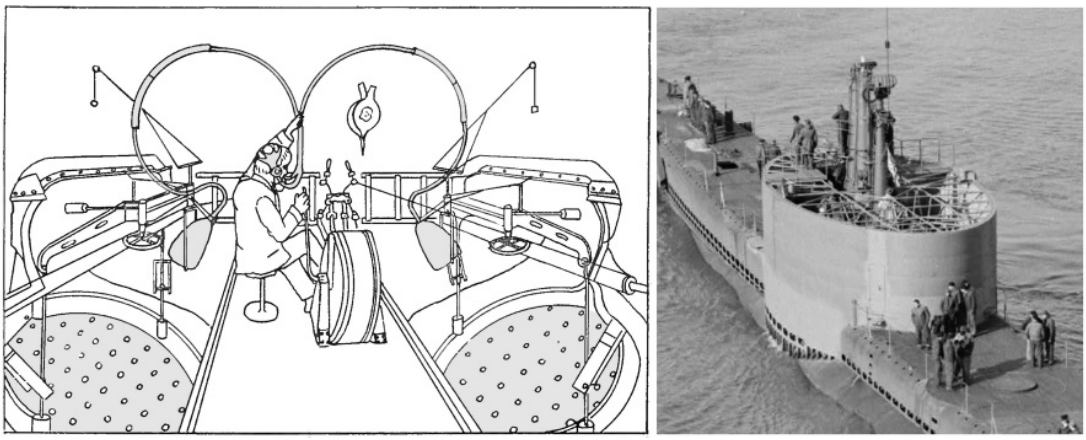


Figure 5.20 Left: Walser hull-mounted acoustic lenses and integrated binaural listening station c. 1917. Right: USS Flying Fish submarine (SS-229) with adapted conning tower designed to house Prinz Eugen's salvaged Gruppenhorchgerät (GHG) hydrophone array, 23 Mar,

systems trigger immediate response to presence in nearby fields of action. Both systems bias *localization* as the primary function of hearing and demonstrate that the materialization of sounds-as-location is particularly enforced in the spaces of *predatory circuits*. Parallels can be found in the *kinds of spaces* that manifest in *processes of localization*.

Noteworthy in the post war era is an abundance of *arrayed* microphone techniques similar to the German GHG array, which itself was based on the earlier American multi-spot hydrophone designs, themselves apparently tracing back to a single French aquatic apparatus named Walser (Hackmann, 1986, pp. 94–95). Lieutenant Georges Walser's 1917 binaural system was more of the listening station than a device, incorporating two sizable acoustic lenses bulging out of either side of the ship's hull. The lenses were composed of a mosaic of smaller flexible diaphragms directly coupled with water beneath the vessel that broke up the incoming wavefronts and transferred them into a phased-array of air vibrations in the cabin that were then collected in funnels and piped to a binaural headset. The outer appearance is that of bulging insect eyes peering into the deep. Of all the binaural listening devices developed throughout conflicts, the Walser most faithfully reflects the contortions of human hearing forcefully gazing through Euclidean optics.

After the tests subsided, impacts of the explosions continued traversing in slow motion refractions, irradiating marine-life, displacing islanders and homesteads, transducing through disease inflicted Marshallese, devastating birth defects, radioactive algae, and travelling further afield through international news and global nuclear proliferation. The three names given to the Operation Crossroads blasts contained one plosive an affricate and a vowel. Able, Baker, Charlie are the first three letters of the Allied phonetic spelling alphabet used in electronic speech transmission (Charlie-Oboe-Mike-Mike-Uncle-Nan-Item-Charlie-Able-Tare-Item-Oboe-Nan: 'communication'). Approximately two millennia earlier, Aristotle described travelling human voice as "air that has taken a certain form and is carried along" (Aristotle, 1927, p. 152, section 901-b). He could not, however, have anticipated the impacts.

Figure 5.21 Operation Crossroads detonations were attended by numerious news correspondents, some of whom witnessed the atomic blasts from an airborne B-17 bomber, aptly named 'The Voice'. Subsequent commentary and imagery from the explosions, circulated through the international press, prolonged and expanded the Bikini Atoll transductions. (Photo in Office of the Historian Joint Task Force One. Operation Crossroads, 1946, p. 86.)

Long Waves - Imaging Oceans

The sound spectrograph was a speech visualization device developed clandestinely at Bell Telephone Laboratories as a visual aid in deciphering scrambled-speech communication (ciphony) during World War II. (U.S. Office of Scientific Research and Development. National Defense Research Committee. Division 13 of NDRC., 1946, p. vii) It produced spectrogram printouts, electronically burned into facsimile paper, mapping the frequency components of a sound as a function of time (Koenig et al., 1946, p. 28). Visualization provided optical access to electro-acoustic manipulations encrypting tactical voice communication that otherwise escaped the ear.[28]

Directly after the war the spectrographs were pitched-down from the human voice and set to work on lower-frequency bandwidths of submarine sounds in a large-scale underwater sound surveillance program. Some of the devices escaped and found their way to oceanography departments, where they were applied to hearing fish 'speak'. The landmark bioacoustics book *Sounds of Western North Atlantic Fishes:*

28 The spectrogram (an interface for visualizing sound spectra) originates in military applications of Bell Telephone Laboratories' spectrograph. The facsimile spectrograph begins its career in classified speech communication, migrates to underwater surveillance, oceanography, linguistics and meteorology, then replicates in digital media, turning up in a multitude of other sonic practices notably commercial sound editing software where its primary role in sound visualization is second only to the waveform.

A Reference File of Underwater Biological Sounds, (Fish & Mowbray, 1970) by the marine biologists Marie Poland Fish and electrical engineer William Mowbray graphically illustrates the coupling of voice calibrated oceanographic listening and visual spectrograms. The book painstakingly catalogues voices of 153 Atlantic fish species, providing 'voice prints' of fish that croak, click, bark, hum, rasp, whistle, knock, thump, cluck, grate, growl and grunt. The research on fish by Fish, documented in the book, was navy funded and also assisted in training operational listeners to distinguish between the sounds of marine bioacoustics and Soviet submarines. Over the course of the research it was discovered that sounds of toadfish were loud enough to detonate acoustically-triggered naval mines. Likewise, the sounds of Atlantic croaker fish, and other fish's swim bladder sounds, coincided with critical bands of submarine propellers.

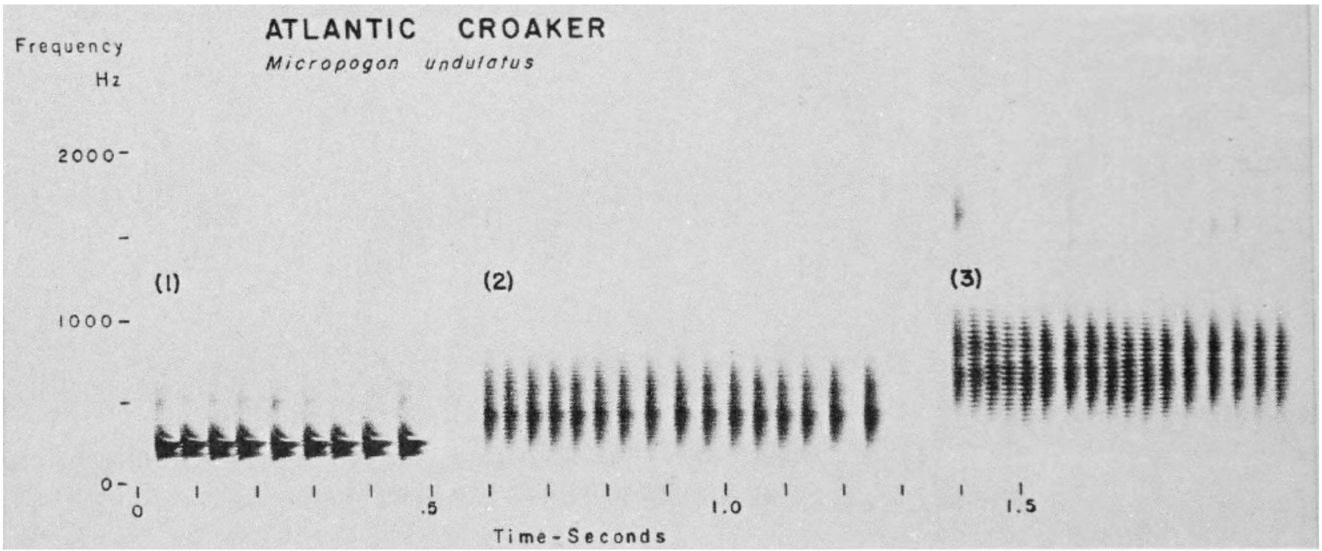


Figure 5.22 Spectrogram of Atlantic croaker fish swim bladder produced sounds. Image, "Spectra of three croaks recorded at different times: (1) 0.39-m male at CBL; (2) 0.2-m male at VIMS; (3) 0.14-m male at Beaufort", in Fish, Marie Poland, and William H. Mowbray. Sounds of Western North Atlantic Fishes: A Reference File of Biological Underwater Sounds (Baltimore: Johns Hopkins Press, 1970), p. 106, Fig. 174.

Figure 5.23 Monitoring station with live spectrogram plotting of underwater Sound Surveillance System (SOSUS) hydrophone seabed array on facsimile spectrograph plotters. Stills from "Watch in the Sea: Project Caesar", Navy and Marine Corps Productions 24458-DN, c. 1960.

Visual spectrograms (and not headphones) were the primary medium for 'hearing' characteristic propeller, engine, and marine life signatures in underwater sounds. A submarine's *'acoustic signature'* (also denoted in the technical literature as 'acoustic portraits') is unique to each vessel and combines idiosyncratic effects of hull vibrations, onboard equipment rumble, pumps, propellers and frictions of the boat with water. Such acoustic traits are traceable in spectrogram prints (Weir, 2006, p. 09). Spectrogram consoles, linked to coordinated fixed seabed hydrophone arrays, were the backbone of the ocean-wide Sound Surveillance System (SOSUS) monitored distant motions of Soviet submarines in the northern Atlantic and Pacific oceans.

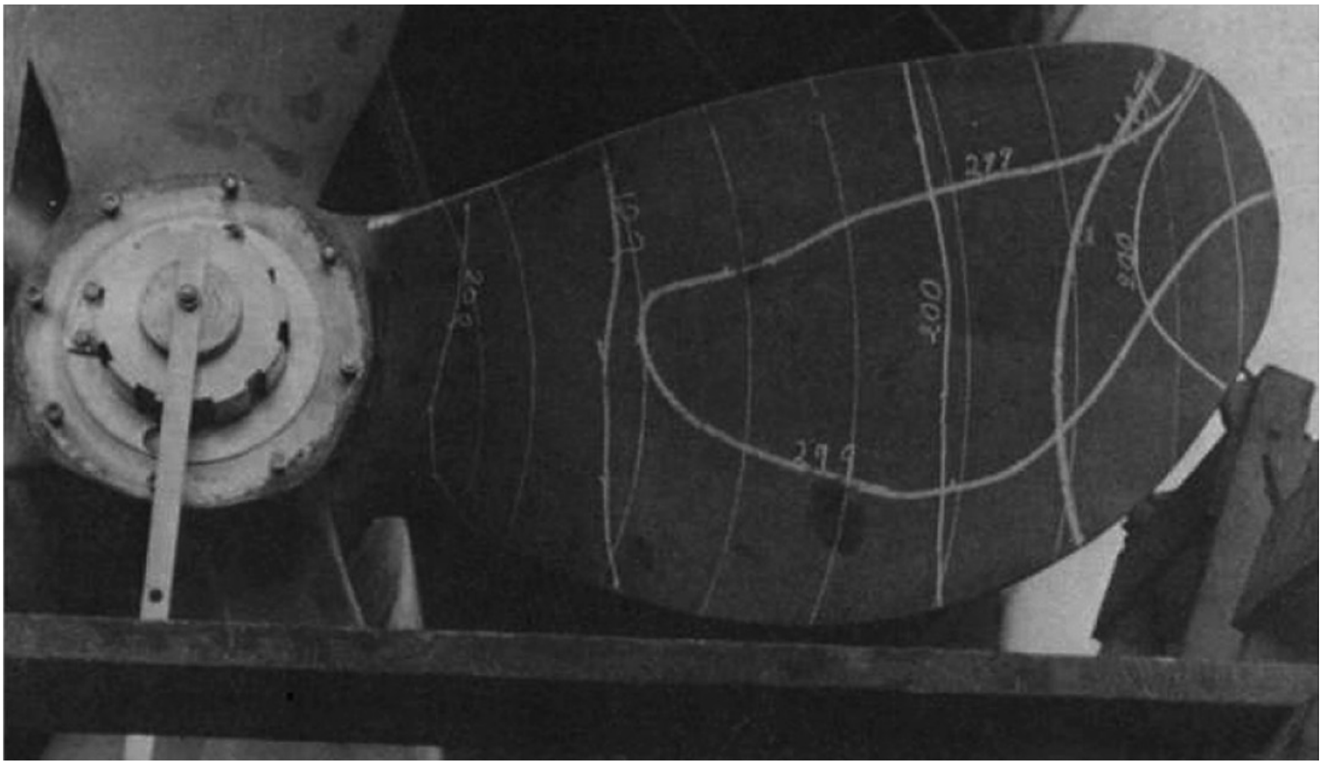


Figure 5.24 Analysis of the USS Goethals propeller natural modes of vibration used to resolve 'singing propeller' sonic signatures, c. 1940. In Klein, "Underwater Sound Research and Applications Before 1939." Defense Research Laboratory University of Texas, 1967, p. 43, Fig. 11.

Combining the incoming signals from the hydrophone arrays in various time-delay configurations (a procedure known as 'beam-forming') could focus and steer the directions of long-range listening. A composite of listening 'beams' – with 2-5 degrees azimuth resolution – fanning out across the ocean were relayed back by way of coaxial cables (developed by Bell Telephone Laboratories and Western Electric, based on commercial telephone multiplex technologies) to coastal monitoring stations. Each station in the network maintained a battery of greyscale facsimile spectrographs, one plotter for each listening beam, churning out a continual stream of visualized ocean spectra. The ongoing chatter of station-hall plotters, in some cases numbering in the hundreds, produced their own distinctive sounds. Accompanied by the pungent smell of ozone (a toxic form of oxygen with an extra molecular atom) escaping from the plotters, formed micro-atmospheres of fearful ocean transductions.

While listening for submarine signatures, other scripts materialized on the printouts, such as the calls of blue whales that according to one station attendant "look like 'commas' amidst the TV static of the [ocean] spectrograms" (George Gagnon quoted in Amato, 1993, p. 550). The commas follow the slight curved sweeping pitch of blue whale calls, punctuating pauses in scrolls of vigilant listening. A Lieutenant, serving as an operation listener for over 20 years, learned to distinguish between five whale species and got into the habit of tracking individual whales, by way of their vocal signatures, as they traversed the oceans. One such whale, affectionately named Old Blue, was apparently tracked for 43 days on its 1450-mile journey encircling Bermuda.

Channeled Water – Channeled Air

Hydrophone arrays in the SOSUS network relied on long-distance transmitting properties of the SOFAR ocean layer where they were strategically located, building on an earlier underwater localization methods after which the channel is named. The SOund Fixing And Ranging (SOFAR) channel still bears the mark of rescue functions it served in locating stranded boats and ejected pilots. Combined conditions of water-pressure and temperature produce the SOFAR ocean layer where sounds travel at minimum speed while remaining tucked inside the 'channel', much like ducted explosions traveling through the atmosphere. The so-called 'speaking tube' or 'voicepipe' effect in the ocean is particularly efficient in transporting lower frequency sounds such as whale vocalizations, at times thousands of kilometers from one ocean into another.[29] The terms speaking tube and voicepipe denote a family of primal speech communication devices consisting of two cones connected by an air pipe through which two-way speech can be transmitted over distances or slipped through barriers. Voicepipes can be found today mostly built into boats for intra-ship communication, though interests in piped voices trace back at least to the eavesdropping architecture in Athanasius Kircher's *Phonurgia Nova* (1673) or Francis Bacon's descriptions of the sound-houses in *New Atlantis* (1626).

Distress signals in SOFAR monitoring arrived from underwater explosive devices known as SOFAR Bombs deployed from life rafts. Impulsive signatures of TNT filled SOFAR Bombs, detonated at just the right depth inside the channel, were picked up on three widely-spaced hydrophones (two off the coast of California and one in Hawaii) and geometrically triangulated back to their source, pinpointing locations of stranded personnel thousands of kilometers away (Central Air Documents Office, 1949, pp. 10–11).


Leased Wire Associated Press

Roswell Daily Record

RECORD PHONES Business Office 2288 News Department 2287

Movies as Usual

Claims Army Is Stacking Courts Martial

Indiana Senator Lays Protest Before Patterson

RAAF Captures Flying Saucer On Ranch in Roswell Region

House Passes Tax Slash by Large Margin

Defeat Amendment By Demos to Remove Many from Rolls

Security Council Paves Way to Talks On Arms Reductions

No Details of Flying Disk Are Revealed

Roswell Hardware Man and Wife Report Disk Seen

Ex-King Carol Weds Mme. Lupescu

Some of Soviet Satellites May Attend Paris Meeting

Roswellians Have Differing Opinions On Flying Saucers

American League Wins All-Star Game

Miners and Operators Sign Highest Wage Pact in History

Figure 5.25 Cover page of the Roswell Daily Record (Roswell, New Mexico), July 8, 1947, detailing an apparent 'flying saucer' capture.

Oceanographer and geophysicist Maurice Ewing, one of first to describe the sound properties in the channel and instrumental in recruiting the layer as a medium for distress signal transmissions, also envisioned a similar eavesdropping layer, with equivalent wave refraction properties, in earth's atmosphere. After tactical listening took to the sea and developed long-range capacities, it resurfaced onboard helium-filled balloons, this time settling in the upper atmosphere. The short-lived *Project Mogul* incorporated microphones and radio transmitters fixed in arrays of high-altitude balloons, trained on future sounds of Soviet explosions half a world away. However, the project never encountered its anticipated blasts, terminating one year prior to the first Soviet nuclear bomb. Nevertheless, a spurious signal from the project is still circulating: on July 7th, 1947 one of the balloons fell back to earth, crashing at a desert ranch near Roswell, New Mexico, prompting a front page article in the Roswell Daily Record of a captured 'flying saucer'. Although the paper corrected that assertion the following day, the so-called 'Roswell UFO Incident', refracting through conspiracy theories and sediment in tabloid publishing and online media, sustains an unintentional echo of the event refracting into the present day.

29 Sound is constrained to the deep sound ocean channel SOFAR due to refraction properties of sonic energy where propagating sounds tend to bend back towards zones of lower speed when traversing inhomogeneous mediums.

Eons before the SOFAR channel was named, it was discovered by migrating whales and deployed in their own long-distance wordless vocalizations, literally traversing oceans through the deep sound channel. The family of baleen whales – of which the blue whale is the largest and one of the loudest creatures ever to inhabit the earth – have developed very low frequency infrasound abilities (blue whale calls can reach below 13 Hz) (Cummings & Thompson, 1971, p. 1193). In the channel, underwater sounds lasting less than one second at the source can extend to durations of over twenty seconds 3000 kilometers away, slowly building-up in intensity and ending in abrupt crescendos (the so-called SOFAR crescendo), like reverberation in a gigantic hall only played back in reverse (Hamilton, 1949, p. 167). Analysis of ocean spectra from SOSUS arrays, lasting over a decade, revealed basin-wide seasonal swells of low-frequency energy activated by fin, blue and Sai whale chorusing (Stafford, 2010, pp. 11–20). Distant blue and fin whale calls were also discovered to be the source of the eerie 'Jezebel Monster' haunting early SOSUS ocean monitoring (aka Project Jezebel) (Bookman, 2015).

Figure 5.26 Fossilized whale inner ear (tympanic bulla), c. 18 million years, South Carolina. (Photo by author)

Ocean Returns – Restructuring

At the peak of Eocene global warming, around 49 million years ago, there was little or no ice on earth; there were crocodiles in the Arctic and pine forests in the Antarctic. When the mammalian branch (that later evolved into whales, porpoises, and dolphins) decided to return to the oceans around the same time (escaping the heat?), one of the first features they lost was their eardrum (Luo & Gingerich, 1999, p. 89; Nummela et al., 2007, p. 1190).

Whales derive from hoofed land animals returning to the waters with fully developed mammalian binaural hearing. Although this ability was dampened in the initial immersion (it took around 10 million years for the ears to adapt to water), some whales went on to develop the most acute underwater directional hearing.[30] Echolocation in toothed whales (including dolphins and porpoises) takes shape some 15 million years after immersion, in the Southern hemisphere, during colossal transitions to climate (from greenhouse to icehouse) and earth tectonics (Steeman et al., 2009, p. 557). At that time, the opening of Drake Passage, connecting the Atlantic and Pacific oceans, massively altered current flows, cooling the continent and forming the Antarctic ice cap. According to one prevalent hypothesis, the development of marine animal echo-

30 Sounds in seawater travel more than four times faster than in air, slightly varying with conditions of temperature, salinity, pressure. Binaural timing calibrations in land animals are short-circuited with the increased propagation speed underwater as timing discrepancies between the two ears diminish coupled with the bone conduction through the skull causing interference between the two ears (Luo & Gingerich, 1999, p. 89). Adaptations to water hearing in whales include various morphological and structural transformations (Nummela et al., 2007, p. 728).

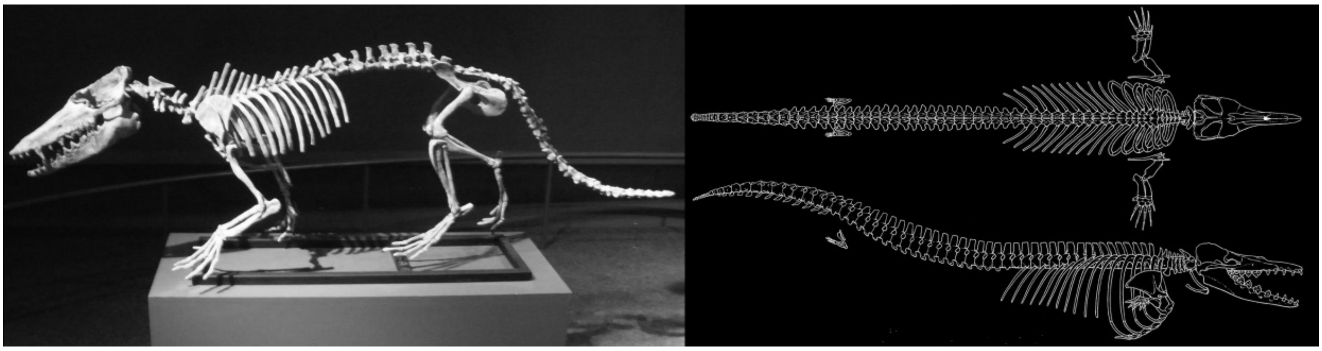


Figure 5.27 Eocene cetacean evolution from the walking whale Pakicetus (originating in what is now Pakistan), to the fully aquatic Dorudon (extinct basilosauridae whale lineage found on all continents, including Antarctica). (Photo by Ghedoghedo CC BY-SA 3.0 DEED. Illustration by Gingerich et al. CC BY 2.5. Collage by author.)

location is intertwined with those geological transformations (hunting in murky rivers and dimmer deeper waters) (Fordyce, 1980, pp. 333–334; Steeman et al., 2009, pp. 581–582) that together with changes in head structure and the evolution of two proteins (claudin-14 and Prestin) help sharpen whale hearing (Liu et al., 2010, p. 1834; Xu et al., 2013, p. 213). In other words configurations of aquatic echo sounding may contain traces of restructuring oceans, calcium phosphate modulations (whale skull modification), vibration channeling fats (such as the dolphin's sound-focusing forehead 'melon'), oscillations in planetary hearing (from ocean to land and back to the ocean), and assemblies of amino acids (proteins).[31]

Ocean Sounding — Crackling

For the longest time oceans were considered silent, partially because underwater sounds seldom pierce the waterline. On the rare occasions when land ears do get wet, sounds tend to muffle in flooded ears. Even sounds water above its surface, in air, was little understood. The Dutch physicist who discovered the mathematics behind vibrating air bubbles in water opens the 1933 paper announcing the discovery with the statement:

> "As a mater of fact, we know very little about the murmur of the brook, the roar of the cataract, of the humming of the sea." (Minnaert, 1933, p. 235)

A significant turning point was already underway at the time William Bragg's 1919 Christmas lecture series at the Royal Institution of England echoes that aquatic deafness with a talk titled 'Sounds of the Sea' that begins with the statement :

> "The depths of the sear are very silent, in striking contrast with the noisiness of the land […] in the deep sea there is very little movement of the water […] the inhabitants of the sea are quiet in their movements."(Bragg, 1920, p. 131)

The lecture series, later published in a book titled *The World of Sound* (1920), begins with a general talk on the nature of acoustics (What is Sound?) followed up with talks on human sonic habits and habitats (Sounds of Music / Sounds in the Town / Sounds in the Country) ending with two talks on sounds of the ocean: Sounds of the Sea, and, Sounds in (Underwater) War. The latter picks up a looped-evolutionary narrative of human ears returning to water in order to engage in combat, that exemplifies the coevolution of water warfare and underwater human listening.

> "It is ages and ages since animals left water for land and developed the present ear with its marvellous powers of detecting sound. And now after all this time we

31 Phenotypic plasticity is the technical term in evolutionary theory denoting dynamic alterations in an organism's behavior, morphology and physiology responding to changes in its environment (West-Eberhard, 2008, p. 2701). This includes isolated patterns in a single organism as well as broader transformation in developments of a species. My emphasis however is on the event as a whole, where energetic dynamics, traveling through a variety of physical phenomena on a global scale produce certain localized effects that transduce into tendencies or abilities in biotic agglomerations.

have […] to fight once more a great enemy lurking in the sea […] how shall we detect the submarine?" (Bragg, 1920, p. 161).

Bragg was involved in the design of submarine detection by way of induction loops and ASDIC (AntiSubmarine Detection Investigation Committee), development of directional hydrophones, and underwater echo-ranging employing the newly discovered quartz crystal microphones. William shared the 1915 Nobel Prize with his son Lawrence, for their work on X-ray spectrometry and electromagnetic radiation and absorption effects for determining crystal structures. William eventually headed the Royal Society (1935-1940) while Lawrence, his son, also got involved in tactical acoustic research. Lawrence was appointed head of sound ranging in the British Army in 1914. On his team was the physicists W.S. Tucker who developed the first artillery detection microphone, that measured changes in electrical resistance of a wire suspended in a Helmholtz resonator tuned to infrasound range of artillery blasts (Scarth, 1999, p. 05).

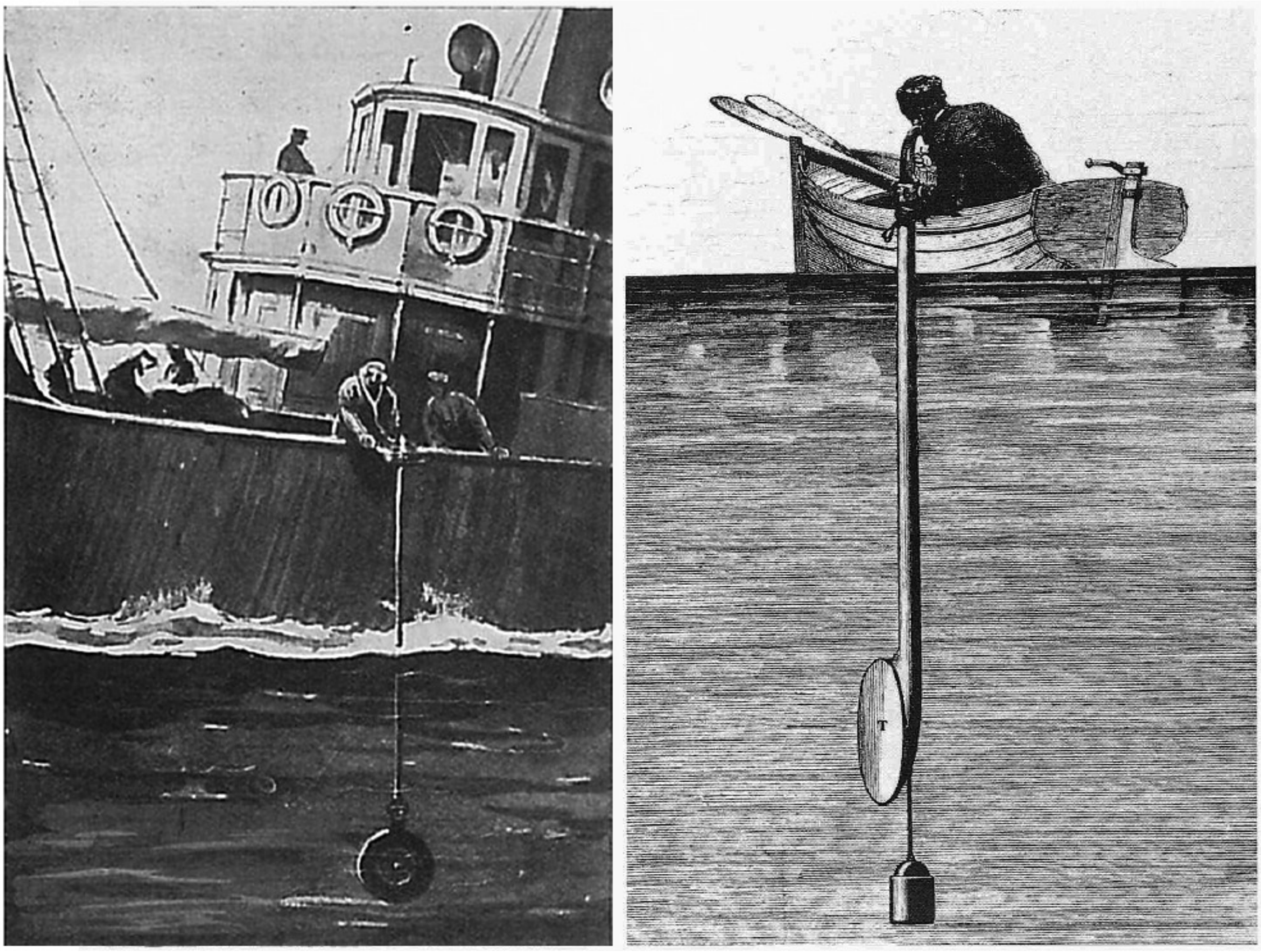


Figure 5.28 Developments in underwater listening. Left: Pendulum type uni-directional hydrophone for submarine monitoring, c. 1919. Right: Jean-Daniel Colladon's submersible ear trumpet, part of an experiment setup for measuring the speed of sound propagation in water, carried out in Lake Geneva in 1841. (Illustrations from W. Bragg, The World of Sound, 1920, p.176 and Souvenirs et Memoires Autobiographic de Jean-Daniel Colladon, 1893, p. 135)

When hydrophones-aided human ears entered the oceans they discovered a world teeming with sonic activity as the so-called 'silent deep' erupted into audibility. Noteworthy were the sounds the ocean itself produced such as surface oscillations, breaking waves or rain and hail pelting the waterline as well as marine life that can 'bark' and 'gobble, gobble' (porpoises) or the variety of fish sounds that boop, honk, drum, hiss, spit suck, rasp, crunch, grind and scape(Knudsen et al., 1948, pp. 419–420).

Croaker fish and snapping shrimp drew particular attention due to the sustained noise levels they produce in water. Shrimp beds emanate ongoing background noise from the countless clacking of claws while sounds of croaker fish – individually resembling the 'tapping of a woodpecker on a dry pole' – appear as a continuous roar when encountered en masse (Knudsen et al., 1948, pp. 421–423).

Up until that time, snapping shrimp sounds contained many other sounds: small vessels operating in tropical waters reported 'crackling' sounds echoing in the holds, transduced through the ship's hull, much like water sounds echoing in fish's swim bladder. Unidentified crackles emanating from nearby shrimp beds were characterized as 'static crashes' or 'coal rolling down a metal chute' and even like the sounds of 'dragging a blackberry vine' (Johnson et al., 1947, p. 123).

In 1942 a U.S. submarine operating in Indonesian waters encountering such sounds suspected a 'newfangled' form of Japanese sonar, until a series of sustained Navy funded observations decisively categorized snapping shrimp sounds as band-limited ocean *noise*.[32] Snaps from single shrimps accumulated in shrimp bed colonies, forming ongoing crackles with distinctive acoustic features described in a research document as 'the explosive noises produced by brisk burning of large quantities of dry twigs or frying of fat. [...] With increasing distance from the source, the sounds merge into a sizzle and finally a hiss without distinct cracks' (Johnson et al., 1947, p. 124). Another report characterizes coastal water sounds: "as one approached shallow water, the ordinary ambient noise was sometimes replaced by sounds resembling the sizzle of frying fat; on coming closer to the shore, the sound approximated the crackle of burning twigs or the crashes of static noise heard in a radio receiver." (Office of Scientific Research and Development, National Defense Research Committee & Tate, 1946, p. 251)

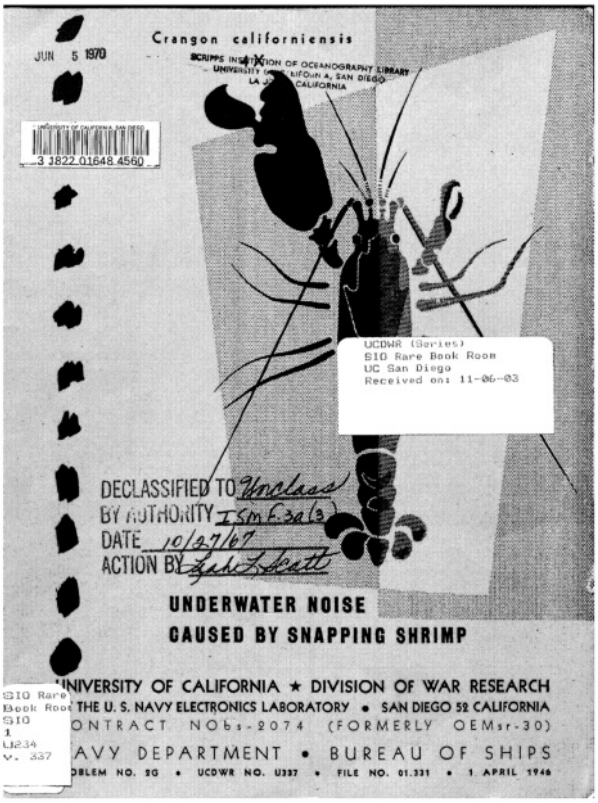


Figure 5.29 Cover image from a naval report concerning strategic analysis of snapping shrimp sounds. United States Navy Electronics Laboratory, "Underwater noise caused by snapping shrimp," (University of California Division of War Research publication no. U337, San Diego, 1946).

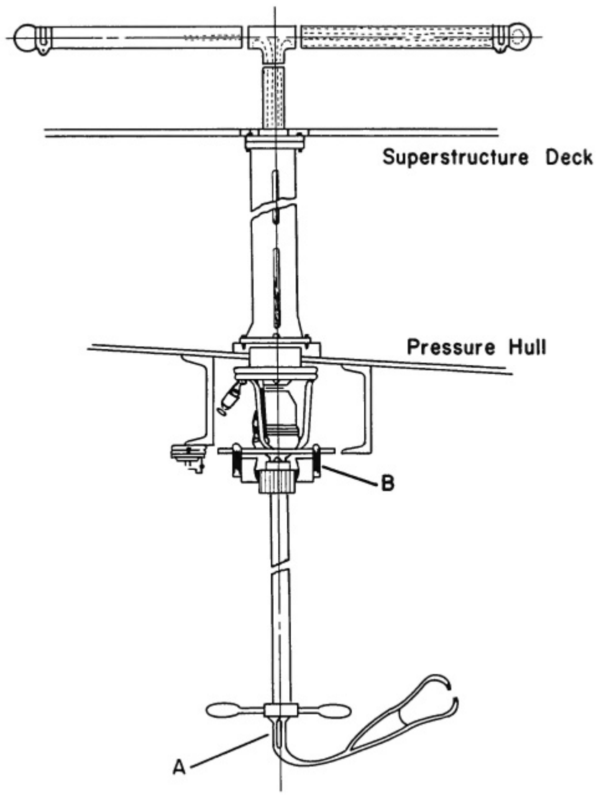


Figure 5.30 Underwater binaural listening device, hull-mounted, C-tube configuration direction finder. Illustration in Howeth "First Navy Sonar - World War 1 complete listening apparatus.", History of Communications-Electronics in the United States Navy, 1963), Fig. 26.1, p. 307.

The troublesome bandwidth was above 1000 Hz, particularly the range from 2000 Hz - 20,000 Hz,

32 Hillel Schwartz picked up shrimp signals polarizing to noise in the wake of ocean surveillance in his colossal study *Making Noise: From Babel to the Big Bang & Beyond*. In the book, Schwartz contextualizes shrimp noise in a much broader scope of noise polarizations taking shape across a vast network of social, cultural, technical, geographical domains at a variety of temporal and spatial scales. In the section on snapping shrimp Schwartz follows more closely the oceanographer Martin Johnson's involvement in the research (Schwartz, 2011).

where shrimp sound tends to dominate ocean spectra, potentially masking submarine sounds and echo ranging. A 74 page-long navy dossier summarizing snapping shrimp noises concludes that shrimp crackles pose some challenges for sonar, but not so much for submarine monitoring. The shrimp bandwidth only hampered hearing slow moving submarines (1-2 knots) but not the typical 'creeping movements' of clandestine Cold War operations, those sounds could still be detected over hydrophones (*Underwater Noise Caused by Snapping Shrimp*, 1946, p. 61).

Sounds of snapping shrimp are currently being reclassified, instead of noise, as a source of 'natural sonar' that together with fish voice monitoring and movement tracking, sent through AI circuits, may provide the basis of a biologically-patched underwater early warning system for detecting submarines and drones. [33] (Scharping, 2019)

Crystal Ears – Arrayed Hearing

The menace of U-boat strikes on transatlantic shipping brought human binaural ears back to the oceans with acoustic devices such as the C-Tube listener.[34] However human hearing initially did not take well to water, until it combined with quartz. The piezoelectric effect in crystals, discovered in 1880 by Jacques and Pierre Curie, was experimentally applied to submarine detection in Paul Langevin's 1917 transducer designs with the help of the electrical engineer Constantin Chilowsky. Langevin's working prototype could be applied both as sound receiver and projector, consisting of shards of quartz crystal sandwiched between steel plates. The first operational submarine sonar (asdic), aboard ten British ships, was made from slabs of quartz rock crystal obtained from a French optics firm, originally earmarked for chandeliers.

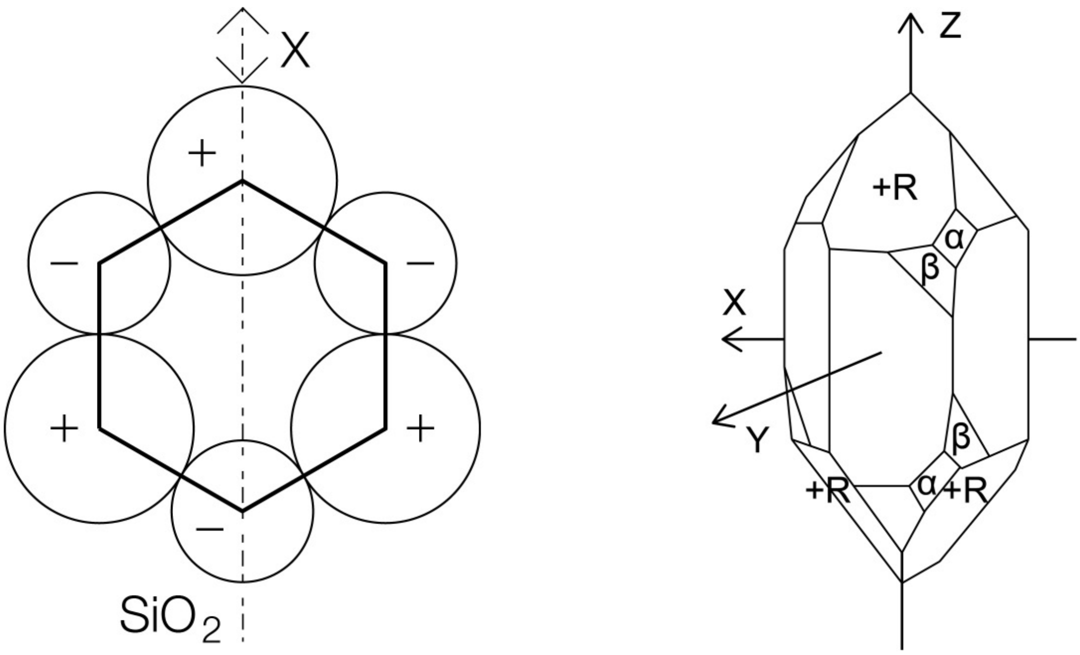


Figure 5.31 The crystal lattice structure of silicon and oxygen in quartz is responsible for piezoelectric potentials in the mineral. Quartz crystals in early hydrophone designs acted as pressure transducers converting water vibrations in to electrical oscillations and visa versa. Illustrations by author after Voigt, Woldemar, Lehrbuch der Kristallphysik (Leipzig: B.G. Teubner, 1910), p. 859, Fig. 193.

Granulated carbon had long been the mineral of choice for converting speech into electricity. By the

33 This emerging approach to drafting marine organisms as military sensors is justified in the following statement "Because marine organisms are ubiquitous in their environments, self-replicating, and largely self-sustaining, sensing systems that use marine organisms as their foundation would be discreet, cost-effective, and provide persistent undersea surveillance with a minimal logistical footprint. [...] By teaming marine organisms with distributed detection systems, PALS [Persistent Aquatic Living Sensors] aims to greatly extend the lifetime and range of undersea surveillance capabilities." (Adornato, 2019)

34 The C-tube developed for underwater monitoring in the North Atlantic is a watertight copy of the Wertheimer-Hornbostel sound locator, designed to be dangled off the side of ships or directly mounted through the hull of a boat.

1950's an estimated 40 million carbon microphones worldwide were translating polyglot conversations into electrical fluctuations through conductive telephone lines (F. V. Hunt, 1954, p. 37). However, carbon transducers turned out to be inefficient for underwater applications. Quartz crystal, on the other hand, excels as a microphone when in contact with dense materials. Vibrations in quartz create electrical potentials due to the lattice structure of silicon and oxygen molecules in the crystal. Piezoelectric quartz is a widespread naturally occurring transducer, hydrothermally formed in rock fissures under conditions of immense heat and pressure. Geological formations, with built-in quartz crystal microphones, continually relay earth's seismic agitations in myriads of electrical fluctuations through vast networks of telluric currents in the ground.

The invention of quartz crystal resonators revolutionized electronic signal broadcasting, specifically frequency control techniques that helped alleviate problems of station drift in radio transmission and reception. Electronically induced vibrations in slabs of rock quartz produce a resonance whose frequency is determined by physical properties of the slab. These tunable and robustly stable resonances deemed quartz a crucial component in electronic timing circuits, especially two-way radio. Quartz rock became the *keystone* of modern radio communication. In the early 1940's the demand for so called 'radio grade' crystals was such that it threatened to outrun the world supply of natural quartz, specifically the high-grade raw minerals sourced from Brazil. Clandestine mineralogy labs in Germany began experimenting with methods to synthetically fabricating quartz in autoclaves.

Figure 5.32 'Radio grade' quartz crystals became the keystone of modern radio communication in the 1940's. Stills from dir. LaVarre, A., "Crystals Go to War", Reeves Sound Laboratories, 1943.

As audio demands on rocks increased, pressure on quartz mineral resources incurred combinations of hearing with other piezoelectric crystals such as Rochelle-salt (sodium potassium tartrate) that has the advantage that it can be synthetically grown and industrially produced. Rochelle-salt grew also outside hydrophones and into consumer audio devices, notably in crystal cartridge phonograph pickups. From late 1930's onwards, crystal equipped phonographs were responsible for transducing the miniature topography of shellac record grooves into amplified patterns aerating common households. More recently human aquatic listening has been combining with high-powered piezoelectric ceramics such as lead zirconate titanate forming intricate hydrophone arrays with sensor elements now numbering in the hundreds.

The aquatic Sound Surveillance System continued developing into the 1990's with expanding ocean coverage. As political tensions waned, stations in the network either decommissioned or opened up for civilian research, tracking whales, monitoring underwater earthquakes and volcanoes or exploring techniques of ocean tomography. However in 2006, a new fixed hydrophone array was deposited in Japanese waters as part of the 'Fish Hook' Undersea Defense Line following advancements in Chinese naval capabilities, creating an even more expansive ocean monitoring system of which SOSUS is now a component (Ball & Tanter, 2015, pp. 53–54). That same year India reportedly began working on the barbed end of Fish Hook from the tip of Sumatra into the Bay of Bengal, extending the array from Japan, via Taiwan, the Philippines, Indonesia, up to the Andaman and Nicobar Islands (Singh, 2016). Currently (2020), the Chinese military is rumored to be constructing an 'Underwater Great Wall' hydrophone array in the South China Sea linked up by fiber optic cables, (Levick, 2018) while a comparable Russian long-range ocean surveillance system, known as 'Harmony', has supposedly commenced operations in the Arctic with an onshore monitoring station in Belushya Guba, Novaya Zemlya. The Harmony system can supposedly make "entire areas of the world's oceans 'transparent' by detecting all ships, submarines and even low-flying aircraft and helicopters." (Ramm, 2016)

Deployment of worldwide ocean surveillance networks are occurring amidst growing concerns of a renewed nuclear arms race – this time involving smaller mobile nuclear rockets (and drones) onboard trucks and submarines (Erlanger, 2019; Tisdall, 2020).

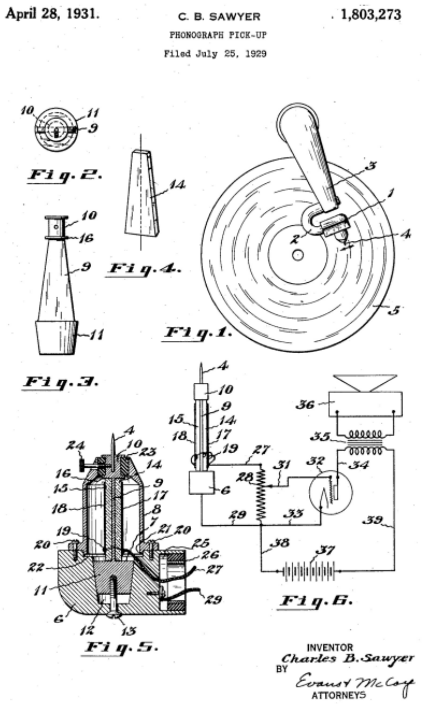


Figure 5.33 Piezoelectric Rochelle-salt phonograph cartridge 1931 US patent (No. 1803273).

Figure 5.34 Left: Cable perpetration of the underwater Sound Surveillance System (SOSUS) hydrophone seabed array. Still from "Watch in the Sea: Project Caesar", Navy and Marine Corps Productions 24458-DN, c. 1960. Right: Cable perpetration of the 'Underwater Great Wall' fiber-optic hydrophone array. Still from "China has begun to build the 'Underwater Great Wall', and the whereabouts of uninvited guests are under control!", China Central Television (CCTV), 24 May, 2018. http://military.cctv.com/2018/05/24/ARTID2GKodHKQivW8tinDka4180524.shtml

Three days ago, on July 12, 2020, an Oscar-II class Russian navy submarine was spotted entering the Baltic Sea (though likely only to attend the St. Petersburg Navel Day Parade) (Sutton, 2020). This nuclear class submarine, with reduced sonic signature, stealth propellers, and dangling hydrophone array from its rear fin, can reportedly deploy a Status-6 nuclear-armed autonomous torpedo. An NPR article published in 2018, discussing a leaked press image of the Status-6 torpedo, describes the device as a 'mysterious Russian weapon' or 'doomsday machine' – a direct quote from *Dr. Strangelove* that concludes with the detonation of the fictitious 'machine' in the closing montage of actual explosions, including the Bikini Atoll blast (Brumfiel, 2018).

The coevolution of hydrophone arrays and submarines has much in common with the coevolution of bats and moths. The bat-moth 'acoustic arms race' or 'predator-prey ecology', by far accounts for the co-evolution with the most military metaphors attached. Bats using 'sonar calls' or flying in quiet 'stealth mode' while moths acquire 'anti-bat defenses' such as 'bat-detecting' ears, evolving defensive flight tactics, even emitting echolocation 'jamming' sounds and ultrasound dampening wing scales. In response, bats go on to develop higher or lower pitched clicks, or click softer, to evade moth ears. And they're apparently still at it. The narrative is persuasive, if you accept that moth ears are only there for bats, and that bats develop chattering skills mostly at mealtime. The narrative works even better with a war film playing in the background.

Water Phase — Beam-forming

Development continued in the U.S. on Langevin's submersible transducers, mostly for high-frequency echo-ranging at the Sound Division (later Acoustics Division) at the Naval Research Laboratory headed by the physicist Harvey Hayes. Hayes' group improved the sensitivity of the device and replaced quartz with piezoelectric Rochelle-salt crystals.

Rochelle-salt ping was also tested pointing downward, plumbing seabed depth. Navy boats fitted with Rochelle-salt crystal sounders (Hayes Sonic Depth Finder) mapped underwater topographies in the Mediterranean, Pacific, Atlantic oceans in the early 1920's by bouncing sounds off the seabed (Nelson, 1971, p. 86). Depth was registered by listening beneath the boat while adjusting the timing of the transmitted pulse to the rebounding echo until both were heard simultaneously over the headphones. The time delay between transmission and reception registered on the bathymeter dial indicated the depth below the hull. Timing echo returns in bathymetric mapping recalls Marine Mersenne counting echo returns of his voice, only in this case syllables have grown dials and surveying took to the water.

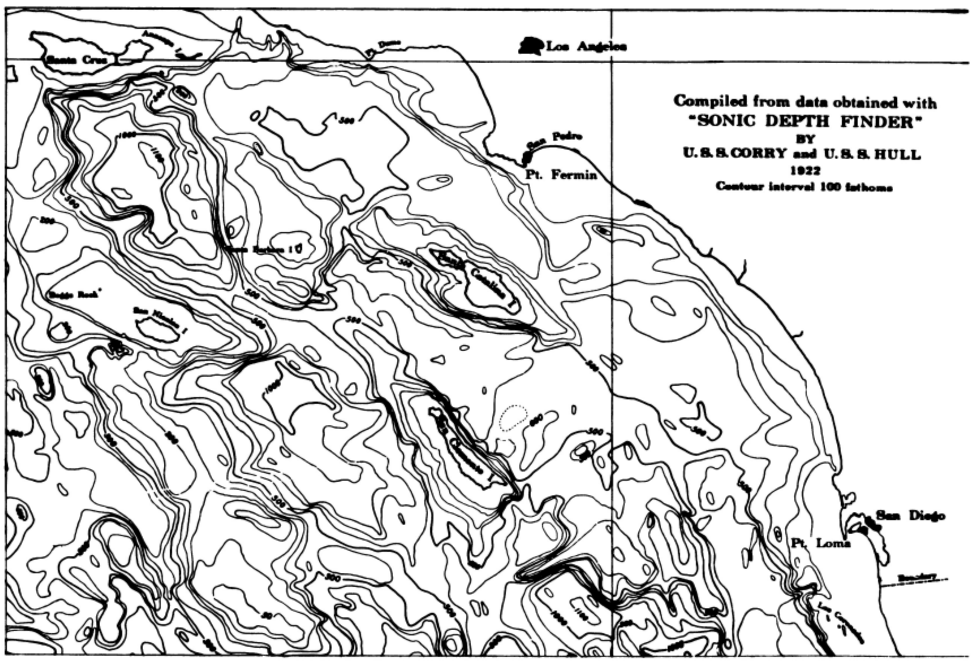


Figure 5.35 Echo-sounding bathymetric chart of the Pacific continental shelf, complied by US Navy boats fitted with Rochelle-salt crystal sounders (Hayes Sonic Depth Finder), 1922. Map from the US Navy's Hydrographic Office, 1923.

Mathematical modeling of underwater echo returns culminated in ray-tracing calculations developed between the mid 50's till the 90's, mapping ducting effects in long-range sound transmission, particularly through the SOFAR channel where sounds tend to extend in duration as echoes pile-up from the seabed and water surface. The 'SOFAR crescendo' effect occurs through successive, overlapping, time-delayed repetitions of the initial sound source reflecting and refracting through ocean structures and systems. Oddly though, the arrival of distant sounds build-*up* (and not down) in intensity, producing a kind of reverse-reverb to that experienced in air-filled halls. Sounds trapped in the SOFAR duct are the loudest, yet they travel the slowest. The first sounds heard from a distant underwater blast have traveled the furthest, by navigating faster through warmer (or denser) water layers outside the SOFAR channel. So although they arrive first, they have the longest journey (repeatedly ricocheting between the ocean surface and basin) such that their intensity will be lowest. Their spectral content (in the higher-frequency components) will also be dampened due to their higher attenuation rate relative to distance. Early echo arrivals are weak and separated by long intervals of silence. Subsequent arrivals increase in intensity while intervals decrease, resulting in a final crescendo, peaking in intensity that is directly followed by an abrupt termination of the sounds. This distinctive characteristic of long-range ocean sound transmission was studied through ray-tracing models that break-up the initial blast onto corresponding *trajectories of propagation*. Ray-tracing models, later implemented in algorithms for ocean tomography, came into prominence with experiments in long-range SOFAR transmission of underwater explosions monitored over remote deep-water hydrophones such as the WIGWAM underwater nuclear blast experiment of 1955 (Sheehy & Halley, 1957, pp. 464–469) and the Australia to Bermuda blast test of 1960 (Shockley et al., 1982, pp. 51–60) (detonated off the coast of Perth and picked up on Columbia University Geophysical Field Station hydrophone arrays).

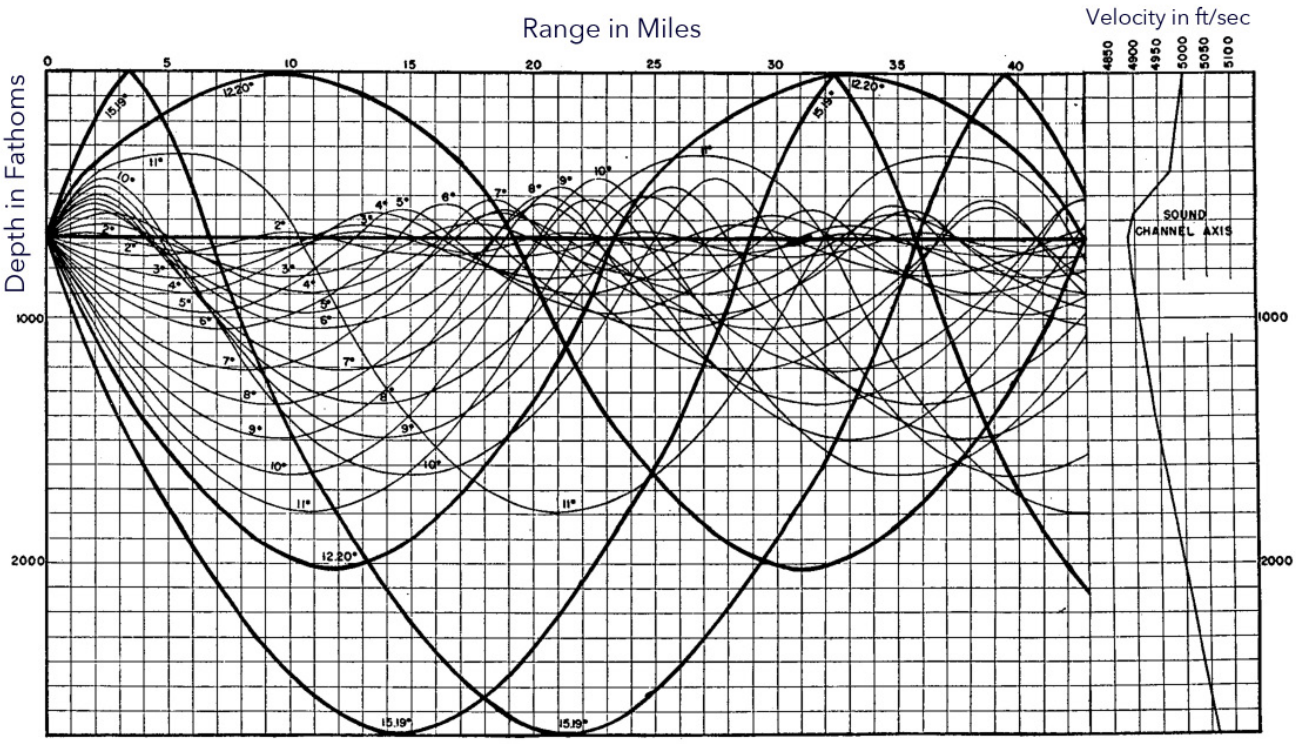


Figure 5.36 Ray refraction pattern of acoustic propagation in the deep sound channel (SOFAR channel) in the Atlantic Ocean. Diagram in Ewing and Worzel, Long-Range Sound Transmission (Geological Society of America, Memoir No. 27, 1948), p. 19, Fig. 05.

WIGWAM was the first and the largest in force-magnitude of the experiments, consisting of a 30-kton atomic bomb detonated in the SOFAR channel off the coast of California. Resulting sounds were monitored from three widely-spaced basin-mounted crystal hydrophones and recorded on magnetic-tape. Ocean-wide reverberations bouncing off topographic features such as islands and seamounts throughout the Pacific Ocean continued for nearly four hours. Notably, these two experiments provide examples where acoustic ray-tracing methods, developed some decades earlier for analysis of room acoustics by Wallace Sabine, scale-up rooms to the size of oceans. From that point onwards, the oceans ware technically subsumed into an array of dedicated spaces pried open for human listening.

A defining aspect in the context of underwater Cold War listening is the widespread incorporation of transducer *arrays* that spatially 'shape' pathways of energy propagation by way of signal phase manipulations, a process known as beam-forming. Beam-forming in acoustics likely derives from electromagnetic beam-forming antennas during World War II, especially phased-array microwave radars — operating with waves just a few centimeters long — that where able to shape and steer narrow electromagnetic beams, increasing angular accuracy. Phased-array techniques diminished the need for parabolic reflectors (as well as mechanical pivots) that up until that time were the primary means to direct, project and receive tightly bundled beams of acoustic or electromagnetic energy.[35] However there is a gap in the historical literature between techniques of radar phased-arrays and hydrophone phased-arrays that got lost somewhere in the surface tension of waves transitioning from air into water, or simply was misplaced in thermodynamics of conflict. Microwave phased-arrays that decided to stay on land eventually morphed into weather mapping radar. Household microwave ovens came from a different line.

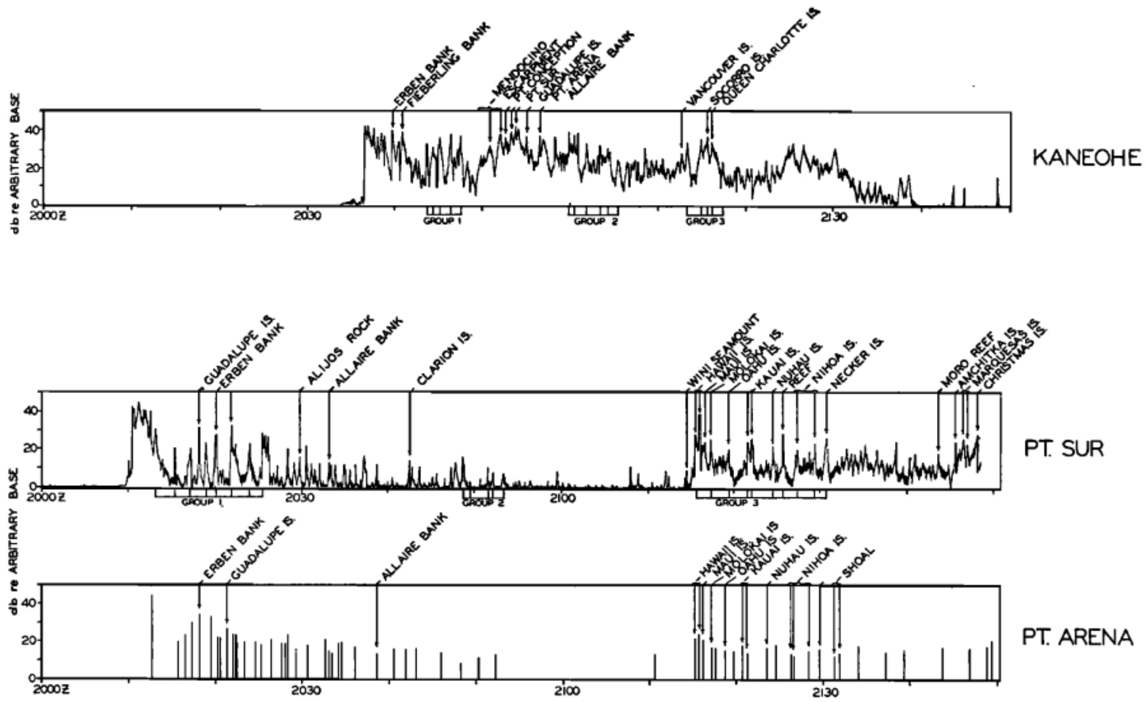


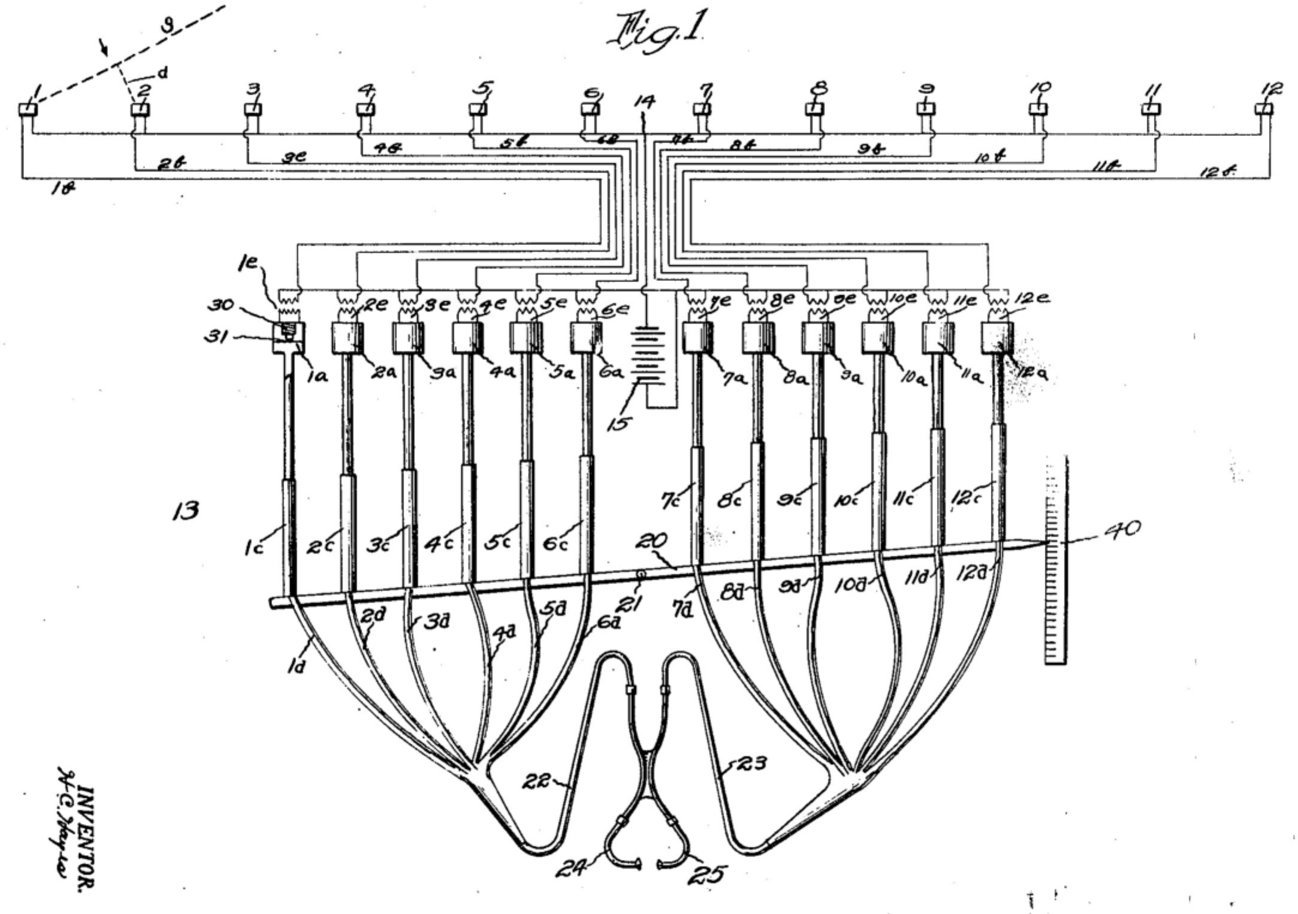
Figure 5.37 Ocean basin reverberation set off by a 30-kton atomic bomb detonated in the SOFAR channel off the coast of California. Three signals, monitored from separate locations, show reflections off land masses and underwater topography reverberating for several hours. Signal diagram in Sheehy, et al. "Measurement of the Attenuation of Low-Frequency Underwater Sound." The Journal of the Acoustical Society of America 29, no. 4 (April 1, 1957), Fig. 2, p. 466.

However, one forgotten ancestor of arrayed listening, that precedes phased-array antennae techniques, slightly alters the narrative: the same years Langevin was working on his aquatic quartz transducers, Harvey Hayes was working on a submersible line-array of microphones, employing common receivers like the ones on telephones at the time, that could be towed behind the vessel or mounted in a ship's hull. This so-called 'Electric Eel', the first towed sonar array, could detect submarines at a range of approximately two kilometers.[36] Hayes' Electric Eel is also the technical link between the Walser hull mounted binaural listener and U-boat GHG hydrophones and in fact already indicates the hull-mount option of the array in an illustration (Fig. 11) of the 1919 patent application.

The unique feature of Hayes' submersible microphone array is in its application of wave phase architecture. The 12-element microphone array is a flattened out *section* through one of Walser's binaural under-

35 The period spanning the two world wars, oscillations between acoustics / electromagnetics, ocean / air and vibrations / voltage are complex and sporadic. For example, at an intermediate stage between the wars, acoustic early warning systems along the eastern coast of Britain (sound mirrors) partially feed into electromagnetic techniques of aircraft detecting radar (Range and Direction Finding), expressing continuities in electromagnetic and acoustic methods of airborne listening (Ganchrow, 2006, pp. 204–217). Some years later, while crossing the waterline, techniques of beam-forming in radar convert back from electromagnetic into acoustic hydrophone arrays. For examples of phased-array antennae techniques developed during World War II see Luis Walter Alvarez' linear dipole array antenna or the X-band Mark 8 surface fire control radar from Bell Laboratories. For an early operational example of long-range phased array radar see the SCR-270 antenna array or the FuMG 41/42 Mammut.

36 Towed hydrophone arrays have reappeared in methods of ocean hydrocarbon surveying as well as advanced weapon systems such as the Russian Oscar-II class submarines.



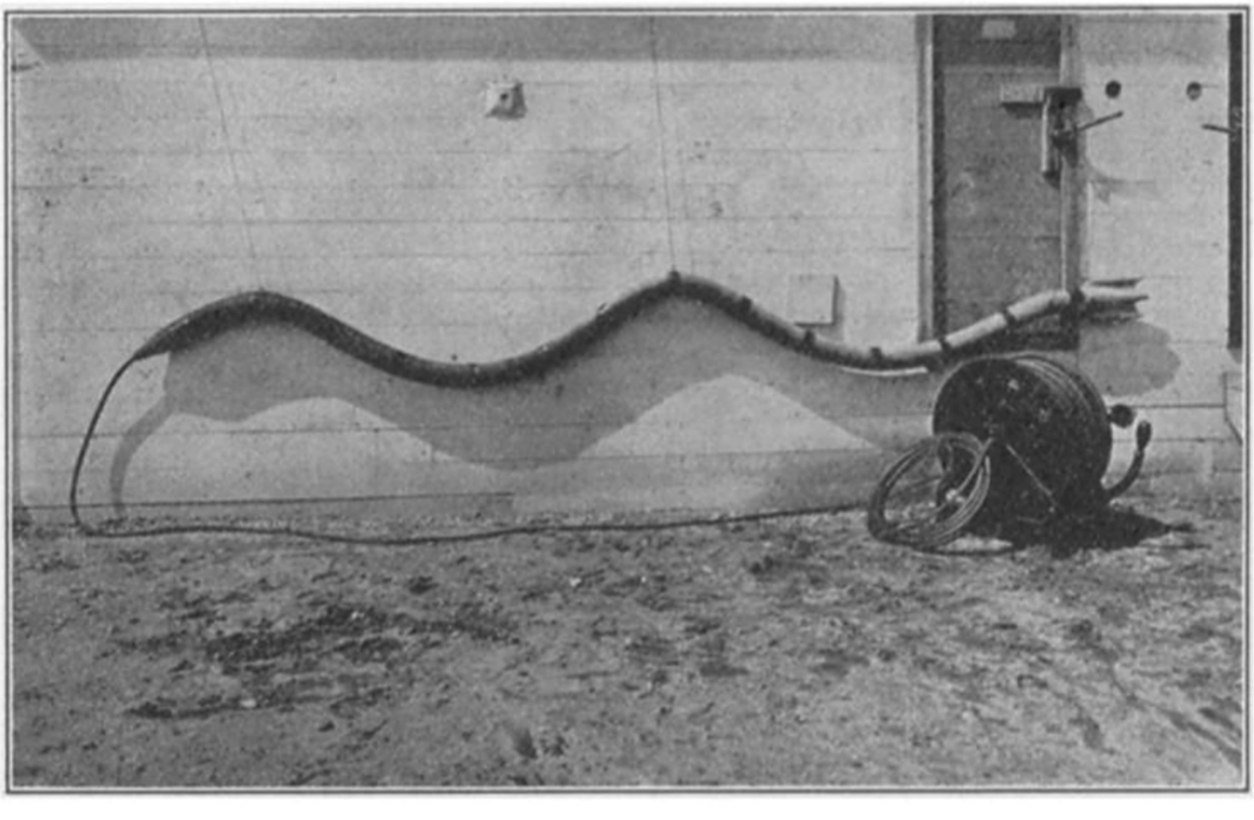


Figure 5.38 Hayes' patent and working prototype of the 'Electric Eel' (1923, No. US1470733), twelve-element microphone array for underwater surveillance. The device functions as a phased-array acoustic direction finder where the shifting parameter of 'time' (delta T) is constructed as a physically distinct element in the listening circuit (adjustable pipes, linking the microphones to the stethoscope, constitute a series of analogue delay-lines). Photo from Hayes, "Detection of Submarines" (Proceedings of the American Philosophical Society, 1920), Vol. 59, No. 1, p. 40.

water sound mirrors, where each microphone is equivalent to a diaphragm position in the mirror. Adjustable pipes, linked to the microphones, compensate for the loss of curvature. What's striking about the design is the designation of *time* as a physically separate element of the listening circuit. By contrast, sound mirrors and other acoustic reflectors have time embedded within their geometric form. The focusing of waves in a sound mirror is a matter of curvature: the direction of incoming waves manifest as discrete focal points of sound, midway between the geometric center of the dish and the surface of its concave shell (the so called caustic), from which sound source directions can be derived (Ganchrow, 2009, p. 72). In stark contrast, the Electric Eel design replaces the geometric model with one of physical *time delays*. Each sliding pipe, connected to a microphone output, functions as an adjustable delay-line, incrementally elongating or shrinking the distances sounds travel down the tube. Piped delay-line outputs are collected at the earpiece where all the time lags get combined. By simultaneously adjusting all the pipes with a pivoting arm, phase relations (the position within the wave motion at a given moment in time) equally adjust. At the point of maximum audibility, all sounds will be *in phase*, at which time a dial at the end of a pivoting pipe arm points the direction of an incoming sound.

The specific configuration of electromagnetics and acoustics in the listening array decouples geometry from space by *extracting time* and assigning it discrete components in the circuit. Once time becomes an independent parameter, it performs a function previously reserved to geometric shapes. Phasing waves, while following time delays in contours of the waveforms, materialize shapes of intensity, imaging interference patterns extracted from their vibrational continuities. In spatial terms, the shift from listening through sound mirrors to hearing in phased-arrays, is not so much a paradigm shift as much as it is *the displacement of space into features of time*.

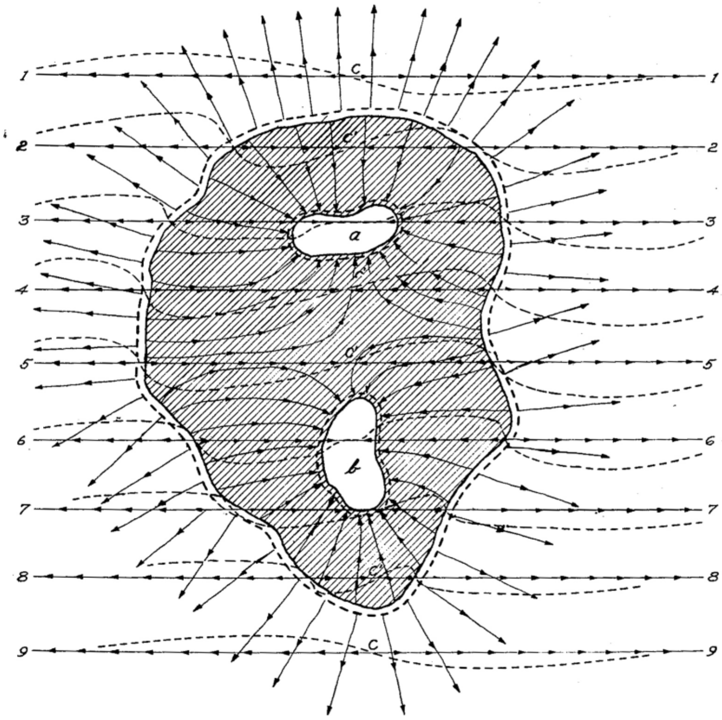


Figure 5.39 Illustration of electrical ground currents pertaining to an underling hydrocarbon formation from Hayes' patented method for electrical prospecting. Plan-view "of a portion of the earth's surface […] showing the general distribution of surface currents associated with the underlying oil bearing formation.". Diagram from Hayes' US patent for Electrical Prospecting (US2368217, 1945), Fig. 15.

In phased-space, geometric forms transition into *matters of time*. The patented design indicates a watershed moment. Once those floodgates had opened, spaces start cropping up everywhere waves abound. Spaces appear in gaps between correlated vibrations, in distances between wave-fronts, and from within the continuities of spatialized electrical potentials. It is the relational positions of tensions (pressure gradients, voltage and resistivity gradients) within a continuous medium that count. The type of energy as well as transport medium becomes interchangeable. In phased-space, ground, air and water take on equivalent material properties distinguished only in their indexes of refraction, conductivity, transport speeds and energetic dissipation rates. What remain differentiated are the kinds of forms manifest within each of the territories. Forms that increasingly materialize by way of mathematical functions, once extracted are rendered as utilitarian 'things'.

This shift in approach might also explain the abundance of civilian patents Hayes filed, for geophones and methods of 'electrical prospecting', coinciding with the period he was working on classified underwater tactical sound. Particularly notable is his electrical ground-surveying patent that applies geoelectric methods to determine boundaries of oil-bearing formations, by 'listening' through a phased-array of electrodes to telluric current anomalies in the ground (H. Hayes, 1940). The patent details a method for measuring sequential current potentials along arbitrary lines in the landscape, that when plotted on paper, reveal sections through electrical ground potentials travelling along boundaries of hydrocarbon formations. The method replaces acoustic force with electrical voltage and swaps submarines for oil cysts. If anything, Hayes' non-aquatic patents are indicative of much broader shifts in material attention underway. Through such time-delay synchronizing modes of observation the structural appearances of depth owes much of its presence to an instrumentation of wave-fronts. Hayes was literally banking (in both meanings of the word) on arrayed sensors to reveal features in the surrounds. The prominence of tomography (wave-based surface-penetrating imaging techniques) in geophysics, meteorology, oceanography, medical procedures as well as in hydrocarbon exploration currently in operation confirm Hayes' hunch. [37]

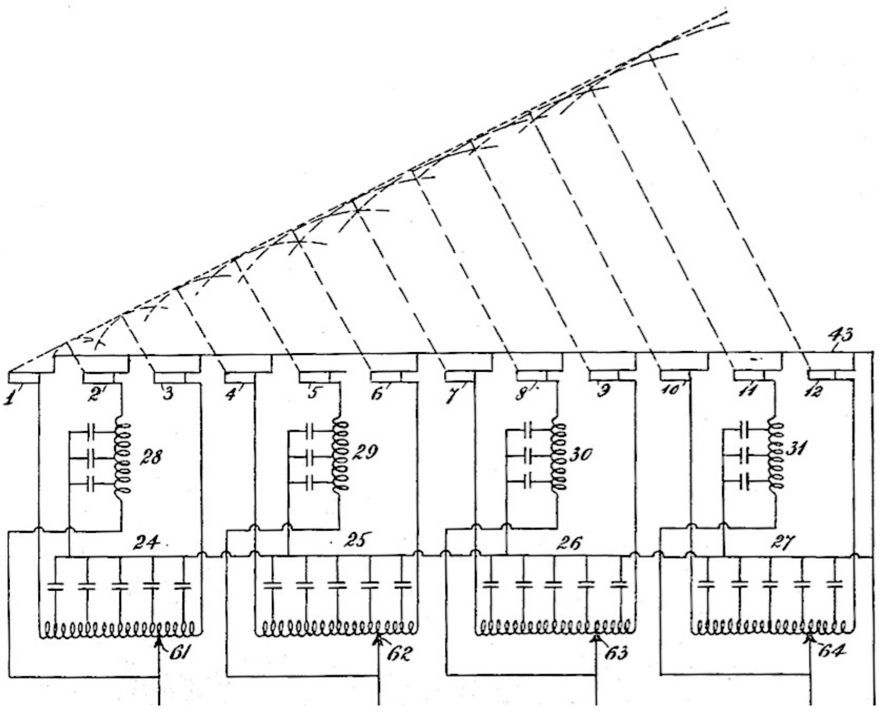


Figure 5.40 Acoustic wave shaping technique akin to wave field synthesis, yet preceding its invention by nearly seven decades. Twelve-channel phased-array with dedicated delay-lines. Hayes et al., Directive Sound Transmission, US patented No. 1681982, submitted 1919, granted 1928.

Curiously Hayes' 1919 patent application for the phased-array Electric Eel microphone was handed in with an additional patent: a phased array *sound projector* titled 'Directive Sound Transmission' (H. C. Hayes & Mason, 1928), similar in transducer layout but applying loudspeakers instead of microphones. Transduces operate in either direction when translating waves, like Langevin's aquatic quartz transducers that functioned as receivers as well as transmitters. Although there is no evidence the second invention was ever put to use, it seems Hayes may have patented the technique for Wave Field Synthesis nearly seven de-

37 For example the application geo-electric monitoring in oil well shaft drilling attests to continuities from WWI submarine monitoring to contemporary geo-electric monitoring techniques in petrochemical industries.

cades before the technology was invented.[38] Techniques, like evolutionary traits, don't always trace back to a single 'origin', rather they arise independently or intermittently where contextual relays and related attentions coincide.

Turbulent Air — Global Microphone

Human abilities to hear atmospheric structures rely on geographically distributed ears, mediated by mathematical computations and ballasted in visual charts and maps. Global-scale anthropogenic explosions revealed details of colossal acoustic events channeled through the zigzagging vertical axis of temperature inversions in the atmosphere, providing geometrical models of energy propagation, measured in TNT values, and expressed in ultra-low frequency rates: explosions in the kiloton range render oscillations of ten second periods whereas megaton explosions produce oscillations with periods upward of one minute and pressure waves tens of kilometers long.

Renewed interest in pulse propagations through the atmosphere coincide with the introduction of megaton-class thermonuclear testing that also retroactively scaled historical pulses – namely those of Krakatoa and the 1908 Siberian meteorite – set in measure with Cold War turbulence.[39] (Farkas, 1962, p. 3889) Nuclear explosions tested degrees of national might and also provided experimental data that tested models of wave propagation in the atmosphere: A comprehensive bibliography of infrasound research from 1971 includes over 600 published papers, a considerable portion of which pertains to the detection of infrasound from explosions in the atmosphere. (Thomas et al., 1971, pp. 400–425)

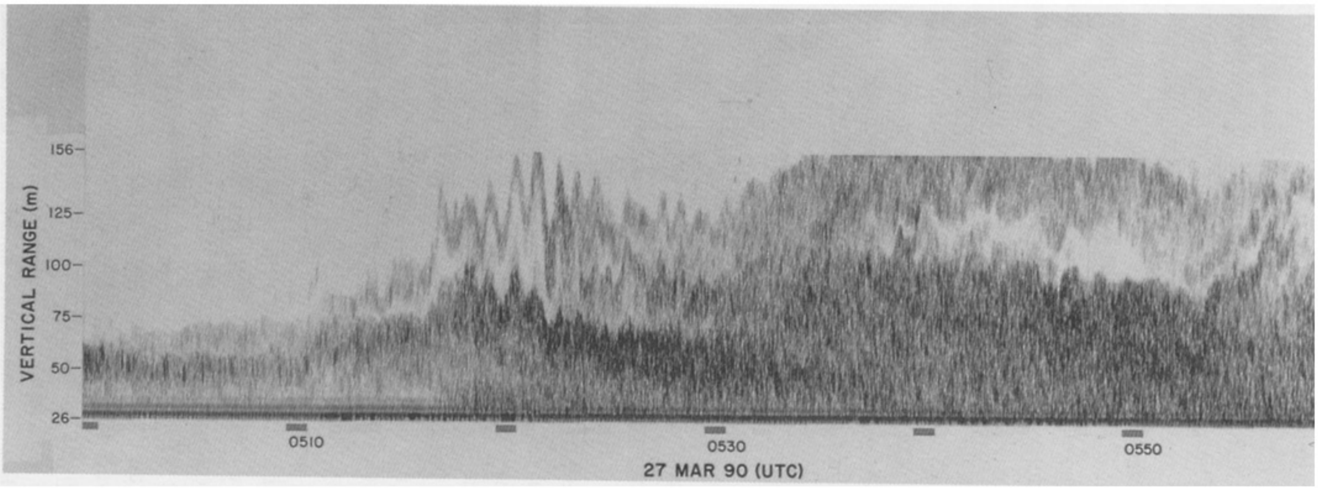


Figure 5.41 Facsimile spectrogram printout of acoustic gravity waves in the lower atmosphere at Barrow, Alaska, 27 March 1990. Image, "Sodar facsimile record obtained on 27 March 1990 at 0516 UTC showing a series of gravity waves" in Cheung, Tak Kee. Sodar Observations of the Stable Lower Atmospheric Boundary Layer at Barrow, Alaska. (Boundary-Layer Meteorology, vol. 57, no. 3, Nov., 1991), p. 259, Fig. 04.

A central question at the time was modeling the layered propagation channels through which infrasound's lower frequencies travel thousands of kilometers in the atmosphere. Although the number of discreet propagation layers differed from model to model, the spatial analogy of an onion-like atmosphere,

38 Wave Field Synthesis (WFS) was developed at Delft University of Technology in the late 1980's by Berkhout and de Vries (Berkhout, 1988), building on preceding phased-array techniques in oil and gas exploration (Berkhout's book from 1987 is titled *Applied Seismic Wave Theory*). The Fraunhofer Institute was the copyright holder from the early 2000's where it was adapted for use in the entertainment industry, specifically for immersive sound in cinema. Geophysical phased-arrays are a common thread linking Hayes' Directive Sound Transmission (DST) with WFS though unlike the arrays used in hydrocarbon exploration that only act as receivers, DST and WFS emit vibrations. To my knowledge there no other wave-field phased-array acoustic emitters developed in the interim. See chapter Phased-space for more discussion of Wave Field Synthesis.

39 A noteworthy number of published papers concerning the infrasonic registration of thermonuclear explosions in the Cold War era refer back to the eruption of Krakatoa and the 1908 Siberian meteor explosion, either as early examples of global pulse propagation in the atmosphere or as benchmark comparisons for anthropogenic explosion magnitudes e.g., (J. N. Hunt et al., 1960, p. 315) or (Wexler & Hass, 1962, p. 3885).

layered with waveguides came into prominence.[40]

Current land-based atmosphere-monitoring, in the wake of Cold War armament, scale up wider than oceans by linking sensor arrays to satellite communication. The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) monitor worldwide nuclear detonations. Construction (still underway) of the International Monitoring System (IMS), operated by the CTBTO, consists of a global array of coordinated infrasound and seismic sensors that render the entire earth surface and lower atmosphere as a gigantic microphone, notably tuned to vibrational *signatures* of nuclear blasts and trained on localization and magnitude estimation.

Blast testing activated acoustic oscillations in global ducts, revealing a category of waves that include earth's largest sounds namely acoustic-gravity waves (not to be confused with gravitational waves) first noticed in barograms in the 1950's and confirmed a decade later in sodar (sonic detection and ranging) facsimile printouts that evolved from a branch of Bell Lab's spectrographs that remained on land (Gossard & Munk, 1954, p. 259; McAllister et al., 1969, p. 583). Gravity waves with oscillation periods lasting several hours and wavelengths several hundred kilometers long, occupy so much air that they gain weight, gravity provides the restoring force in their oscillation (Yiğit & Medvedev, 2019, p. 42). The lowest, deepest motions of gravity waves crossfade into weather systems where waves can extend thousands of kilometers and with pressure cycles lasting several days.

Listening to thermonuclear explosions opened up human hearing to the domain of global infrasound, the territory connecting earth topography to oceans, the ionosphere and weather, as well as modern industrial practices. A crisscrossing domain of waves where whistling mountain ranges (lee waves), elephant vocalizations, ocean surface oscillations (microbaroms), earth's inherent rumble (background Lamb waves), ship motors, meteorites, ionosphere charge, wind farms, and nuclear explosions combine. And paradoxically, the point at which human hearing and sounding encompasses the entire atmosphere and oceans is also the threshold at which human hearing itself nearly goes extinct.

Figure 5.42 Acoustic gravity waves apparent in cloud formations off the coast of Angola and Namibia, June 26, 2016. Photo courtesy of MODIS, NASA/GISS, https://www.giss.nasa.gov/research/features/201607_gwaves/.

Section III

Hearing Attentions

Transformations of hearing within earth circuits occur through ongoing encounters with sensation, conditions, and locales. However initial accounts of evolution fell on deaf eyes: The sixth edition of Darwin's

40 The current climatological model divides the atmosphere into three primary layers observed in the vertical temperature structure of the air and relating to the dynamics and chemistry of the lower (Troposphere and Tropopause), middle (Stratosphere and Mesosphere), and upper atmosphere (Mesopause and Thermosphere).

On the Origin of Species (1872) mentions sound only once, in a section on animal attraction to beauty, exemplified in 'the music of birds'. The first edition of the book from 1859 contains no sounds at all.[41] Writing from a time before telephones and phonographs, Darwin's spaces of evolutionary variance evolved in muted surrounds.

While Darwin was working on his book, the science of acoustics and psychoacoustics were experiencing rapid growth. By the time Francis Darwin, the direct evolutionary descendant of Charles Darwin (his third son), published his 1917 book *Rustic Sounds* [!], (F. Darwin, 1917) the dissemination of sonic knowledge and proliferation sounding devices and techniques were out in full force. And so were the tangible shifts in human attention to sound. In the lapse of a single generation sound suddenly became a thing, and along with it the sense of sonorous surrounds themselves were transitioning. The book *Rustic Sound* (that includes a chapter titled 'war music') opens with an ode to the author's vernacular auditory experiences, culminating in a distinctive sound his father unknowingly produced, yet one that patched the Darwin family together, complete with homestead, in a circuit of sympathetic vibrations:

> "[A] sound I like to recall is connected with the memory of my father. He daily took a certain number of turns round a little wood planted by himself, and christened the Sandwalk. As he paced round it he struck his heavy iron-shod walking-stick against the ground, and its rhythmical click became a familiar sound that spoke of his presence near us, and was associated with his constant sympathy in our pursuits. It is a sound that seems to me to have lasted all those years that stretch from misty childish days until his death. I am sure that all his children loved that sound." (F. Darwin, 1917, p. 12)

Charles Darwin's sandwalks – which were soundwalks for his children – calibrate two overlapping circuits of Darwinian attention: Charles walked numerous laps daily on the gravel-paved track he also referred to as his 'thinking path', kicking pebbles as he walked. The late Cretaceous and Paleogene sedimentary sands at the family estate in Kent, along with the insects, songbirds, and curated foliage along the path, functioned as an ambulation circuit of temporal replays while working *On the Origin of Species*.[42] The same sands constituted material substrate through which the periodic thumping of Darwin's metal-capped stick closed a more immediate sound circuit with his own biological clan, and considering his fascination with topsoil, possibly also the earthworms.[43]

Rethinking human activities into the broader scope of terrestrial dynamics takes on pronounced urgency at the current juncture. However, impressions of audio techniques subsumed in earth motions do not transition smoothly. The grounding of hearing in earth circuits has its challenges, not least the mediation between long-term transformations in the organs of hearing (described by paleontologists and biologists) and the short-term transformations in perceptions of hearing (described by historians, anthropologist, and media theorists). The former seemingly occur over multi-generational transformations while the latter can be experienced within the lifespan of a single organism.[44] Nevertheless, geology demonstrates that these two realms complete one another. The line separating history from prehistory is arbitrarily set to the time when sedimentation of human language starts piling up in stacks of books. The term 'history' is anthropocentrical-

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41 There is a single passage in the first edition of *On the Origin of Species* (1859) referring to airborne sound (and light) as common stimulus of nerves, but nothing on the agency of sound in organisms or environments beyond courtship calls of 'singing' birds. In stark contrast, colors are everywhere, appearing more than eighty times in the book. There is a practical component to the absence, in the lack of devices and methods to accurately *document* and *collect* sounds at the time of Darwin's travels. Nevertheless the absence of *any* concern for sound suggest attentions were elsewhere.

42 Charles Darwin's sandwalks would have needed to wait until Spring 2022 for the return of prehistoric sounds when herds of 6,000 year absent bison are set to be released back into Kent woods (Carrington, 2020).

43 Darwin's 1881 book includes several mentions of the 'gravel-walk' in connection with observations of earthworms (C. Darwin, 1881).

44 The noticeable gap between the historicity of the senses (shifts in attention) and natural history (morphological changes), possibly reflects temporal biases of the respective disciplines (attentions clocked to life-spans of organisms and morphologies synched to geological clocks).

ly defined. There are tangible consequences to thinking across the gap, specifically when it comes to shared attentions: if the perceptual morphing of hearing, experienced by individuals in situated sonic practices, is different only in degree but not in kind from shifts experienced through larger temporal scale transformations in structures of listening and sounding; and if manners of experienced attentions determine degrees of environmental connectivity that also partially prefigure *possibilities* of future variance; then there is much at stake with our current attentive practices.[45]

Recent transformation in human sonic attention can be traced back through an abundance of auditory circuits taking shape approximately in the past two hundred years – a period known as 'the age of acoustics' where sound comes into scientific, military, public, and cultural prominence. Over that period human hearing coalesced with carbon, quartz, magnets, wax, shellac, vinyl, silicone, metals and electricity (among others), providing opportunities for hearing to fragment, transpose, cluster, array, and combine in unusual ways while accessing differing scales, time frames and densities of the surrounds. In the example of monitoring the atmosphere and oceans, such transformations are often tactically sustained, socially entrained, and politically rehearsed.[46]

Intensifications of sonic awareness feature prominently in domains of political tensions that play out in increasingly scaled-up acoustic spaces where agitations of global reach are registered as ongoing tremors from countless positions around the globe. Within these arrayed transduction systems, hearing remains fixed in predatory mode, entrenched in Euclidian space, and fostered by localizations. Roped into those circuits are vast territories of the surroundings preordained to definitions of conflict. Tap into any one of the signals in those arrays with a basic telephone receiver to hear the particular turbulence of our times: there within the chaotic tremble of a single molecule of air or water brushing against the transducer, the abstractions of vast globalized human practices, modulated by shifting climates, turn up in tactile proximity with the listener.

When not in conflict, tactical methods of hearing turn up elsewhere in projects where waves are drafted to survey, surveil, or control such as hydrocarbon exploration or monitoring thawing permafrost. Modes of hearing come and go, on the other hand the techniques and armatures of listening perpetuate. And along with them inbuilt calibrations migrate in the architectures of apparatuses and listening protocols. Calibrations in those initial circuits are paramount for the range of appearances thereafter. Audio devices are filled with such latent polarizations, of forgotten histories and bygone attentions, detached from their initial contexts yet operative in the carry-over to other attentive circuits. At times the biases dissipate, taking on other characteristics. Other times they remain active, absentmindedly colonizing perceptions and foreclosing experience.

Sounds rendered as localized objects, frozen spectrums, or closed communicational channels enforce material impressions of sounds as fixed detached things. Sounds abstracted from their inherent motions and removed from their conditional binds have much in common with predominant mindsets integral to the current impasse, namely, impressions of surroundings reduced to itemized stockpiles; an existence crammed with material resources, subject to extraction and circulated in hermetic loops. Closer scrutiny is

45 The agency of situated practices are strikingly apparent when factoring in mounting evidence of non-genetic inheritance, experience-dependent neural plasticity (recalibrations of perceptual registers throughout an organism's life cycle), phenotypic plasticity (malleability in an organism's characteristic behaviors *and* morphological features responding to dynamic environments), gene-technique coevolution (e.g. human dairying practices and genetic traits for lactose digestion), niche construction (evolutionary responses incurred by organism modified local environments) and the prevalence of symbiosis, all underscoring the *combined* agency of environmental structures, electro-chemical structures, processes and behavioral patterns, in their place-assembling as well as future-making capacities. Recent literature in evolutionary theory and biosciences blur boundaries between organisms and environment as well as calling into question the unified nature of the organisms themselves. Titles such as "*A Symbiotic View of Life: We Have Never Been Individuals*" (Gilbert et al., 2012, pp. 325–341) or sentences such as "[b]ehavior is seen as a driving force in evolution, and an adaptation to the environment is understood as the result of an interactive construction of *self* and the *environment*. [...] Organisms are not just actively engaged in the business of being alive [...] they are at the same time creating the pre-conditions for evolution, and actively shape the evolutionary process." (My emphasis, Stotz, 2014, p. 11) exemplify transforming notions of both organisms *and* environments in biota studies.

46 If obsessions with sound localization persist, humans may end up growing a third ear. Though unlike the mythical third eye, the additional ear would merely serve to complete the function of spatial triangulation.

required to determine the manners in which these and other closed-in anthropic circuits may be performing the *conditions* of separateness. Human impression of surroundings also has its contextuality and intensifications of attentions that disconnect, extract, and amass, are self-evident components in the current crisis. Surroundings only begin to 'surround' when the observer is rendered detached.

There are other options for hearing environments that spread out rather than localize and embrace the cacophony rather than closing in on telltale tones. Sounding events are wonderfully haphazard affairs with trails pointing every whichway. Hearing can learn something from sound just by following more closely the complex currents interweaving its presence. Taking notice of interlinks rather than privileging its subjects opens into that flutter. Oscillations enact continuities in which existence provides an abundance of transport. Attending to that which is always entering or escaping our frames of hearing, links those sounds to other sounds and their inherent spaces of action and energetic itineraries, and back into the comings and goings here, on earth.

Hearing Bias

Every act of observing entails a cascade of entanglements that establish relations. Observations produce spaces and times, sharpening outlines of certain entities while diffusing the presence of others. Hearing is integral to that cascade, and as such can never be unbiased. Every instance of hearing is also limiting, the narrowing of fluctuant plentitude into tangible entities is innate to the process. Hearing is doubly constrained, first by the structural properties of organs (and listening devices) and second through the techniques, practices, and haphazard locales that situate and orient listening and sounding. Both aspects – morphological limitations and perceptual registers – are moving targets, their configurations and orientations are only metastable.

The coevolution of sounding and hearing in animals suggests that bias itself may evolve as an integral component of attentive circuits. Sustained attentions enforce biased modes where sounding-hearing recursively tune towards advantageous characteristics in the circuit: male mosquito hearing tuned to the frequency of female mosquito wing-beats.[47] (Mayer, 1874, pp. 15–18)

Cricket hearing sensitivity peaks at the frequency of its own chirp. (Popov, 1990, p. 301) Human hearing excels in the vocal range of speech. Hydrophone arrays tune to signature propeller sounds.

One can only listen so far into hearing before reaching its own limit, because hearing itself is part of the same circuit listening attempts to overcome. No matter how broad-banded, technologically aided, or exotically named a solitary listening practice may be, it can never capture the entirety of intersecting sound worlds. Inclusive hearing only happens collectively, as the cumulative effect of countless attentions (organic and inorganic) bumping up against one another in the same energetic expanse. Attending to that discordant pluralism helps keep biases in check. Adopting a vigilant, proactive listening, that embraces difference, resists dominant modes and remains open to other influences, keeps the dynamic in motion. Moreover, a shift towards other hearing is not only possible, it is inevitable and actively pursuing other attentions gives a bit of a head start. Shifting attention alters future sensations that are importantly not fully ours to behold. Listening to the expansiveness of earth-bound sound, through the lingering reptiles in our ears and sloshing primordial oceans in our heads, may provide some provisional grounding in attentions-yet-to-come.

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47 Mayer's mosquito experiment of 1874, demonstrating evolutionary traits of mechanical resonance, then gets applied just a few years later in his invention of the Topophone (1880). The device, designed to assist in ship navigation through fog, utilizes enhanced binaural hearing as a method of detecting differences in phase of distant foghorns, notably by applying two resonators attached by tubes to a listeners ears, presumably tuned to the sounds of the trills. Mayer applied frequency calibrated tuning forks to numerically quantify mosquito wing beats, building on de la Tour's Sirène experiments of 1819 that definitively quantified numeric relations between air frequency fluctuations and musical pitch (as well as mosquito pitches). The siren was named by de la Tour for its ability to produce pitches underwater, employing perforations that worked both in air (with air pulsations) as well as underwater (with pulsed water flow).

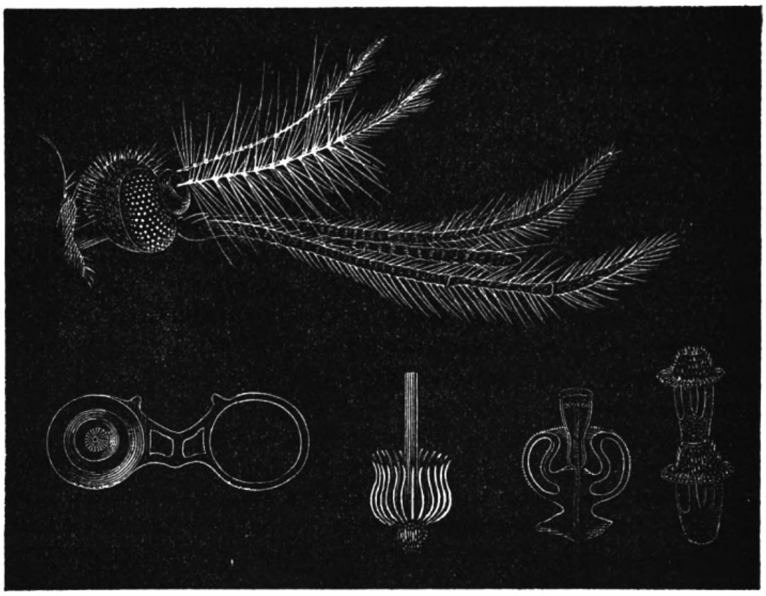

Figure 5.43 Air vibration-sensing hairs on antennae of a male mosquito. Illustration, from Mayer, Alfred M. Researches In Acoustics (The American Journal of Sciences and Arts, vol. 08, no. 05, Aug, 1874), p. 20, Fig 02.

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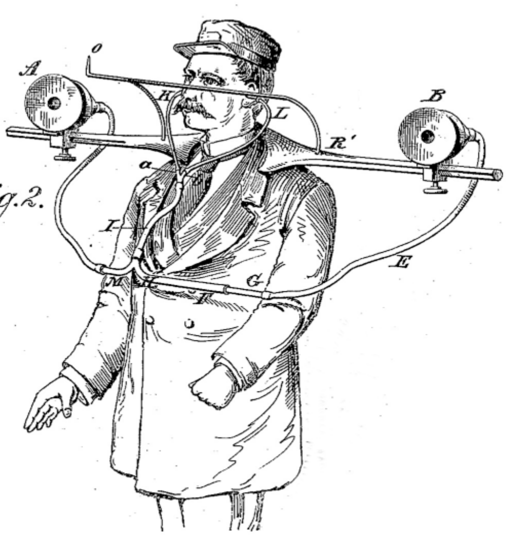

Figure 5.44 Topophone binaural listening apparatus with adjustable armature and resonators, invented by Alfred Mayer in 1880 to facilitate 'safe navigation of a vessel in a fog'. Illustration from US patent No. 224199, 1880.

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Chapter 06

Baku's Sirens: Circuits of Industrious Attention[1]

This year (2022) marks the one-hundredth anniversary of Arseny Avraamov's urban sound orchestration *Symphony of Sirens* (Simfoniya gudkov, Гудковая симфония) that took place on November 7th, 1922, in the expansive urban surroundings of Baku, Azerbaijan. During the performance the entire city was activated as a colossal symphony of sounds, combining voices from spectator-choirs, hydroplanes, flotilla foghorns, train whistles, artillery batteries, a steam-whistle machine, and an abundance of sirens sounding from factory towers and speeding emergency vehicles criss-crossing the city.

Avraamov's state-sponsored experimental anthem celebrated the ousting of the Russian Tsar at a critical geographical node of expanding Soviet interests. This text is not meant as a commemoration nor a critique, but rather a calibrated refraction of expansive sounds passing through that site a century ago, whose oscillations partially carry over into the present, inhabiting vestiges of contemporary attentions in alternate locales. In order to hear the ongoing oscillations, Baku's *Symphony of Sirens* is examined in terms of its sonic-contextual continuities, rather than its currency as a stationary anomaly in the historical avant-gardes. By tracing its *contexts,* back through a tangle of petroleum infrastructures, political turmoil, revolutionary agitations, evolutionary and utopian musical imaginations and techniques of geo-spatial sound localization, one can access the various attention circuits it inhabits. This text attends to those continual dynamics.

Modes of Hearing Baku

The city of Baku served as an unlikely staging ground of an experimental city-wide sonic spectacle in which four coinciding modes of hearing (and related materialities of sound) can be observed: hearing urban hubbub *as* music; hearing *social progress* in sirens; hearing *synchronization* through blasts; and hearing the *metabolisms* in the liveliness of the metropolis. All four modes are not native to Baku, their circuits are prepared elsewhere, coming into prominence over the first half of the 20th century and are momentarily actuated through conditions of that event. Other nascent oscillations from Baku had to wait nearly a century to become audible, such as the after ringing of sounds linked to infrastructures of industrialized petroleum production that were the backbone of the event.

Baku's edition of *Symphony of Sirens* lasted only one day, though it arguably activates, and partially makes audible, a myriad of transformations that were underway in spatial-sensory attentions at the time, notably a dynamics of attention linked to fluid ontologies of media that participate in expansive, turbulent infrastructures. Due to its limited duration, remote location and scant documentation (no recordings of the event are currently known) its sounds mostly live on though repercussive commentaries in printed media. Despite the nearly mythical status associated with this gargantuan acoustic event, its sounds seem to do a better job of propagating once transduced into words, diagrams, images and imaginative audio reconstructions. Curiously, more of the event seems audible today, mostly heard through non-acoustic means, not only through published commentary but also by way of its murmurs whose contexts have sharpened over time. Such secondary hearing provides an auxiliary listening to diffuse, contexts that were nascent, and for the most part inaudible on-site the day of the event.

Sounds in Transition

Pronounced sonic transformations taking shape around the time of the event are linked to changes

1 An abbreviated version of this text has been published in Ganchrow, R., "Baku's Sirens: Circuits of Industrious Attention." In *The Derailment of the Usual*, edited by Paul Devens and Eline Kerstens. Liège: Hématomes Éditions, 2023.

in the functions and meanings attributed to mechanically produced sounds, especially sirens, optically synthesized sounds, as well as phonographic recordings. Synthesized sounds of the mechanical (sirens) or optical (sound on film) variants challenged norms of musical expressivity and intensified debates surrounding tonal polychromatic as well as non-tonal approaches to music production. Notably in post-revolution Russia, mechanical sounds were displaced beyond their tonal horizons and into social-political agency of emerging propaganda machines.

A more obscure category of transitory sounds appears as a *fluid-energetic* ontology of revolution, manifest in *tactile-emotive* meanings circulating through cultural and political facets of revolutionary thinking. These *waves* of *affective agitation* facilitated unprecedented energetic exchanges between diverse facets of a society in the midst of rapid restructuring. Cacophonous sounds of uprising galvanized social momentum, its specific sonic textures were noticed, harnessed, and strategically prolonged. Since the acoustics of the palace storming in Petrograd (current day St. Petersburg) – culminating the Russian Revolution – were limited in geographic scope, printed words, images and phonographic sounds sought to elicit further agitations pushing outwards to the edges of the former empire. Early descriptions of the revolution likened it to a natural force, such as an avalanche (Leon Trotsky) or deluge (Vladimir Mayakovsky), physically sweeping across the landscape in swells of nationalizing momentum. Revolutionary flux travelled by way of railway (and later wireless telegraphy and radio broadcasting) infrastructures, deploying printed, photographic, phonographic and theatrical replays of the momentous events in its wake. The traveling media was geared towards actuating further political thrusts at their destinations.

Media Agency

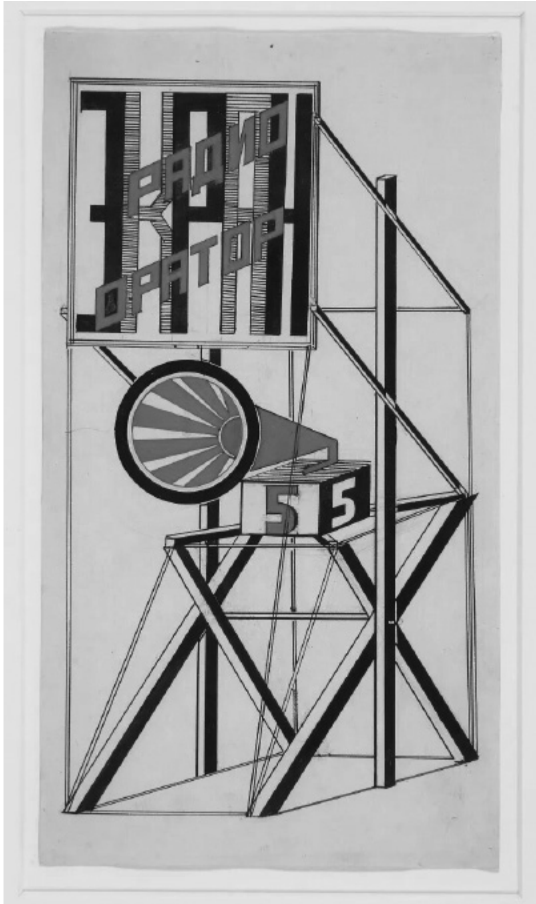
6.1 Gramophone employed in Bolshevik agit-train propaganda and agitation practices. Film still from Dziga Vertov's film Agit-Train (1921)

Energetic swells accumulating along national infrastructures, harness affordances of preexisting transportation and communication arteries as well as utilizing literal energy infrastructures of urban electrical grids and networked transport of coal and petroleum.

If one thing can be said of this early socialist media attention is that it embodied environmentally active functions intent on producing senses of the new collectivity in which the instrumentality of images and speech were central. In same year of the Baku performance, Gustav Klutsis designed a series of mostly unrealized agitprop kiosks integrating phonograph megaphones, film, text and graphics for deployment in urban settings in commemoration of the revolution.

Audio recordings, spoken words and imagery were particularly important in conveying new meanings to illiterate sectors of society that accounted for a large percentage of the post-revolution population. Bolsheviks, knowingly and instrumentally, applied principals of media affect to brightly coloured and technologically laden agit-trains (initially with decorated designs by the likes of Kazimir Malevich, Vladimir Mayakovsky and El Lissitzky), agit-boats, agit-trams and agit-kiosks put to use from 1918 and into the 1920s. Part experimental vanguard, part educational infomercial, part propaganda machine, the agit-apparatus took upon itself to propagate waves of revolutionary agitation (the term 'agitrop' derives from combining the words 'agitation' and 'propaganda')[2] from urban epicentres to dispersed peasantry in the far corners of the former empire. Railway infrastructures in particular served as extensions of social realist theatrical machinery spreading through the landscape. Agit-trains included on-board cinemas – a medium that many rural populations were experiencing for the very first time (Taylor, 1971, p. 569) – and distributed printed matter such as posters, pamphlets and books. They also contained the means for further media

6.2 Crowds gathered around a Bolshevik agit-train, central to post-revolution 'agitprop' practices (contraction of 'agitation' and 'propaganda'), incorporating emerging technologies such as phonographs and motion pictures as means of transmitting revolutionary 'agitations', along railway infrastructures, from the urban centers to rural peripheries. This still image reappears, filmed into motion, in Dziga Vertov's film Agit-Train (1921). (Photo by Shalgin A.)



6.3 Gustav Klutsis' design for an agitprop kiosk (No. 5, 1922) integrating phonograph text and graphics for deployment in urban settings in commemoration of the revolution.

production such as a photographic darkroom, radio transmission and reception facilities and on-board printing press. The Bolshevik director Aleksandr Medvedkin developed an entire film-production train, complete with darkroom facilities, editing studios and projection room, equipped for traveling Russian rural backwaters, producing films in collaboration with local communities en rout. Trotsky installed his Red Army headquarters on-board one such train, traveling between critical flashpoints of the emerging state.[3] The train included, among other amenities, armoured wagons, a library, an electrical generator wagon, a telegraph station, a radio station and printing press. Trotsky later reminisced how his texts and thoughts, issued on the journeys, were directly coupled with creaking mechanical sounds of wagons in motion:

2 Richard Taylor points out in his book *The Politics of The Soviet Cinema 1917-1929*, distinctions in the original Russian meaning of the words where 'propaganda' involves print technologies and 'agitation' employs spoken word. Agitation belongs to a practice that is more direct and immediate in its tangible affects. Taylor, Richard. *The Politics of the Soviet Cinema, 1917-1929*. International Studies. Cambridge [Eng.]; New York: Cambridge University Press (1979). pp. 27-28
3 For a discussion of Agitprop tactics see Kenez, Peter. "The Birth of the Propaganda State: Soviet Methods of Mass Mobilization, 1917-1929." Cambridge Core. Cambridge University Press, November 1985. Pp. 58 – 59. https://doi.org/10.1017/CBO9780511572623.

'In those years I accustomed myself, seemingly forever, to writing and thinking to the accompaniment of Pullman wheels and springs.'[4] (Trotsky, 1930, p. 325)

The train churned out copies of a newspaper titled *En Route,* produced exclusively onboard, interleaved with commentary from radio communication with Moscow as well as monitored transmissions from Nauen (Brandenburg) and the Eiffel Tower (Paris). According to Trotsky 'These articles were simultaneously transmitted to Moscow by direct wire, and radioed from there to the press of the entire country'. (Trotsky, 1930, p. 328)

Large-scale coordinated propaganda parallels later fascist practices, though also contrasts the pronounced transparency characteristic of early Bolshevik operations. The agency of media that circulates and distributes by way of rivers, rails and later radio (Lenin considered radio 'newspaper without paper and distance' (Vertov, 1925, sc. 07:36-07:43) likely expanded on the strategic role that publishing (and mobile theater) already had as tools for social-political change in the days leading up to the ousting of the tsar. The binding of printed (as well as image and sound) media to transport infrastructures is the logical outgrowth of pre-revolution Bolshevik propaganda dissemination tactics. For example, the clandestine harnessing of the Nobel Brothers' transnational oil transport infrastructures, originating in Baku, Azerbaijan, for the dissemination of revolutionary propaganda that also originated in Baku. Prior to the October revolution, ten thousand copies of Lenin's political newspaper *Iskara* were smuggled into Russia via the Nobel's oil infrastructures. Propaganda flows eventually reversed their direction, though the harnessing of empire-wide oil transport channels to parcel out revolutionary printed media can be seen as muted pre-verb for the pronounced agit-transportation agendas of post-revolution media tactics (Tolf, 1976, pp. 152–153). So too is the emphasis on the political dimension of printed matter dissemination, reflected in the post-revolution forced literacy policies and campaigns. For Lenin, literacy was a prerequisite in forming a political subjectivity, that is also the foundational step in preparing a subject's susceptibility to coordinated political manipulations: 'An illiterate person stands outside politics, he must first learn his ABC. Without that there can be no politics'. (Vladimir Lenin, 1965)

6.4 Baku's oil worker union newspaper Gudok [Siren], edited by Joseph Stalin, including a factory steam whistle in the logo. Image from edition No. 28, April 21, 1908 that included Stalin's editorial 'The Oil Owners on Economic Terrorism' defending the role of printed media in the coordinated struggle against worker oppression. (Photo by author)

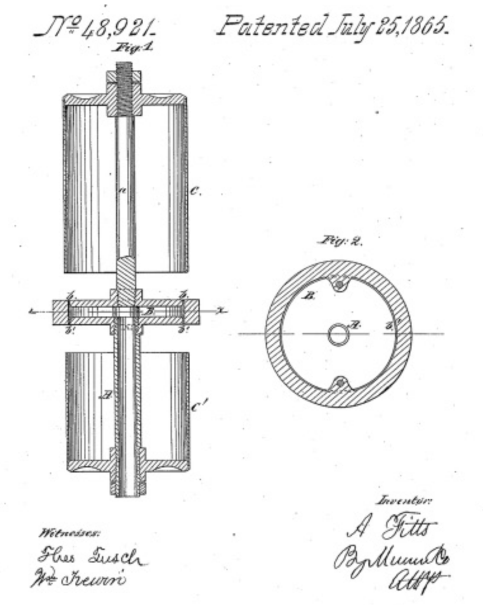
At the turn of the 20th century, workers made up 20 percent of Baku's population, a contributing factor to its reputation as *the* revolutionary hotbed of the Caucasus. Clandestine printing of Marxist literature

4 Pullman wheels were specially designed vibration dampening railway carriage wheels primarily installed on dining and sleeper wagons.

destined for the Nobel Brothers transport infrastructures were produced in basements of Baku's old-town (Tolf, 1976, p. 153). The local oil union-run newsletter – incidentally named *Gudok* (*Siren*)[5], with a factory steam whistle in the logo – was edited in 1907 by the young Joseph Stalin, who settled there with his family after an Imperial Bank convoy heist in his native Tiflis, Georgia (Sebag Montefiore, 2007, p. 186). It was in Baku that Stalin honed his thuggish tactics in the company of disgruntled industry labourers, oil barons and ethnic conflicts. Residency in Baku likely also facilitated an understanding of the geopolitics of energy, particularly the importance of carbon-rich territories in the broadening geological scope of industrial production, spanned the Carboniferous (coal) to Mesozoic (oil & gas). Living amongst spewing oilrigs must have made the links between geology and oligarch power tangible, possibly even providing a preliminary roadmap out of what the Bolsheviks considered the agrarian backwardness of rural territories of the empire. Once in power Lenin focused on electricity and transportation infrastructures through it was Stalin who inaugurated the nation-wide Five-Year Plans, consisting of forced rapid industrialization fueled by coal and gas from Donbas and Baku.

Trill of Transformation

Printed words can at times function as transducive sediments of past listening attentions. Industrial vibrations have been discerned an integral aspect of urban modes of hearing since at least the Victorian era.[6] From the start of industrialization, mechanical vibrations have been productive of multiple perceptual significations. The particular acoustics of mass production: the clunks, crashes, vibrations and rhythms, experienced in reverberant acoustically un-treated factory halls, to which worker populations were becoming increasingly accustomed, were also the sounds that significantly linked up with sentiments of modernization, the promises of progress and socio-economic change that contrasted more critical hearing of oppressive dehumanizing work. Functional acoustic infrastructures such as whistles were also built-in to the exterior of factories, combining with sounds emergency vehicles, where sirens, mechanical horns, steam whistles and electronic bells served as keynotes of communication, alarm and time-keeping functions of the city.



6.5 Left: Multi-tone steam whistle mounted on the exterior of an industrial facility in the Donbas region. Film still from Dziga Vertov's Enthusiasm: Symphony of the Donbas (1931), incorporating experimental audio montage of recordings from steal and coal processing facilities of Ukraine's Donbas region promoting Stalin's 5-year plan of rapid industrialization. Right: Dual-tone 'signal-gong' steam whistle, sectional drawing from Fitts' US patent No. 48921, July 25, 1865.

5 The word *Godok* in Russian denotes a specific class of sirens, mostly installed in factory infrastructures as a means of communicating the start and end of workdays.

6 See Shelly Trower's convincing survey of material transformations and related vibrational attentions underway in Victorian England in *Senses of Vibration: A History of the Pleasure and Pain of Sound*. New York: Continuum, 2012.

6.6 Factory with steam siren (gudok) signaling infrastructure on the opening page of the first edition of USSR im Bau (USSR in Construction, vol. 01, 1930). The journal, published from 1930 – 1941, was a large-format magazine, designed by El Lissitzky, Sophie Lissitzky-Küppers, Alexander Rodchenko, Varvara Stepanova and others, with editions in Russian, French, English, German and Spanish (from 1938) centered around photographs and dynamic layouts depicting rapid Soviet modernization during the five-year plans and the nation's transformation to a formidable industrial power.

Sirens

From this complex cacophony of production, one sonic category stood out in particular: the siren. In the Russian context, the poets Vladimir Mayakovsky and Alexei Gastev called for an embrace of the spatial territorializing aspect of music in general, and factory sirens in particular, calling for a new form of proletarian music released from its chambered confines and projected over entire districts, likened to trills of factory sirens (Fülöp-Miller, René, 1927, p. 183). In Gastev's book *Poetry of the Worker's Blow* (1918) (Поэзия рабочего удара), a poem titled *Horn-Siren* transposes the mythical Greek siren into Russian current affairs. The poem describes an aquatic singing siren that climbs out of the river Neva and into the Russian sky, spreading red dawns of revolution across the former empire to the trill of an all-encompassing sound. From St. Petersburg to Moscow, above the Ural mountains, through the Donets Basin coal mines (Ukraine's Donetskyy Baseyn, parts of which are currently under Kremlin siege) and over the Caucuses, igniting starry twinkles and northern lights in her wake:

> 'Red tides will rise and flare up the sky, dawns will be engaged in songs […] Up to the azure hills on the raging waves a rebellion-siren will fly for the last, for the overhead, for alarming, merciless, flaming horns!' (Gastev, 1918, pp. 13–16, author's translation.)

In the early days of the revolution the siren came to embody a collective yearning: the desire to hear a materiality of social transformations, invested in a material ideology (Marx's historical materialism), channeled through the physical territorializing agencies of the siren. What was heard in the wavering spatialized pitch were tangible expressions of modernization that were also components in a larger attempt at skewing public perceptions towards a collective, politically scripted, shared form of identity. The role of sound includes hearing socialist rearrangements of labour as musicalized liberation of the workforce. Moving from an oppressive manual labour to emancipatory collective production.

Meanings and uses of factory sirens – integral to infrastructures of industrial production before air-raid sirens found their way into city infrastructures – were being actively warped towards other ends. Siren calls for progress are formalized in Dziga Vertov's first feature-length sound film *Enthusiasm: The Symphony of Donbas* (1931) that artfully edits and montages factory and machine sounds including one extended section shot at an industrial facility edited to the sounds of a factory steam siren that is cut up, repeated, slowed down and sped up in the soundtrack. *Enthusiasm* was filmed onsite in the heavily industrialized coal and iron zone of the Donbas region in eastern Ukraine and aimed at documenting and celebrating Stalin's Five-Year Plan. The film is structured in a symphony in three movements and is notable for its incorporation of in-situ industrial sounds 'in a setting of din and clanging, amidst fire and iron, among factory workshops vibrating from the sound' with portable recording equipment weighing in excess of one tonne, specially designed for the task (Michelson & O'Brien, 20, pp. 108–109).

Soon after the 1917 revolution, Avraamov started working on a city-wide siren-based commemoration of the raucous uprising:

> 'Suddenly, in the evening - an unforgettable evening - a Red Petersburg was filled with many thousands of sounds: sirens, whistles and alarms. In response, thousands of army lorries crossed the city loaded with soldiers firing their guns in the air. [...] At that extraordinary moment, the happy chaos should have had the possibility of being redirected by a single power able to replace the songs of alarms with the victorious anthem of The Internationale. The Great October Revolution! - once again, sirens and work in the cannon, the whole of Russia without a single voice unifying their organization'. (Buatois & Lopez Angriman, 1992, pp. 19–20)

Sonic reenactments call upon a mute past to perform a revived energy in the present. Avraamov's desire to re-hear the past in terms of a 'future music' may have been aided by other proclamations, for instance those of the poet Alexander Blok, to whom the sounds of uprising embodied '[…] the spirit is music […] With your whole body, with your whole heart, with your whole consciousness – *listen* to the Revolution.' (Blok, 1918) Blok was attending to the social transformations inherent to those sounds and '[…] kept hearing — I mean literally hearing with my ears — a great noise around me, a noise made up of many sounds (it was probably the noise of the old world crumbling).' (Figes, 1997, pp. 784–785) The moment those sounds ceased for Blok; his writing too fell silent, eventually succumbing to rheumatic fever. Leon Trotsky, in his book *Literature and Revolution* (1923), later attributed the stoppage to Blok's untuned musical ear:

> '[…] one has to have a different training, a different faith in the Revolution, an understanding of its sequential rhythms, and not only an understanding of the chaotic music of its tides.' (Trotsky, 1925, p. 108)

For Trotsky, the homogenization of hearing, in the Russian revolutionary sense, apparently starts with a chaotic catastrophic event that eventually folds into a neat and steady pulse:

> 'The Revolution, which descended on the poet like a hail of facts, like a geologic avalanche of events, refuted or rather swept away the pre-revolutionary Blok [...] It drowned the tender, gnat-like note of individualism in the roaring and heaving music of destruction.'(Trotsky, 1925, p. 107)

Fluid-tactile ontologies of revolution dovetailed with an interest in elevating the materiality of everyday surrounds summed up in the film director Sergei Yutkevich enthusiastic embrace of the siren as a rallying call to end figurative and representational art, to move into a realism constructed of actual sounds of everyday lives in cities and factories.

'[…] the electric siren of Contemporaneity bursts with a mighty roar into the perfumed boudoirs of artistic aestheticism!' (Yutkevich, *Eccentrism Manifesto*, 1922 cited in Taylor & Christie, 1994, p. 62)

According to some accounts, this new-found musicality included staging 'factory concerts' employing steam whistles, turbines and sirens as industrial instrumental ensembles (Figes, 1997, p. 738). By the late 1920s machines and factory ambiences were symphonically mimicked in Russian music and sirens occasionally turned up on stage at the concert hall.[7]

Aptitude for hearing the noises of industry culturally were no doubt partially prepared by readings of Luigi Russolo's 1913 Italian Futurist manifesto *The Art of Noises*, translated soon after to Russian. Mayakovsky's poem *Noises, Noises and Noises* (1913) echoes Russolo's fascination for urban hubbub where 'Noises carry through the echoes of the city on the whisper of soles and on the thunder of wheels'.[8] (Vladimir Mayakovsky, 1955) One year later *The First Journal of Russian Futurists* (No. 1-2) (Vasily Kamensky, 1914) was published in Moscow, including poems by Mayakovsky and other Russian futurist writings and imagery. Vasily Kamensky's contribution to the volume includes a poem titled *Ba-ku-ku* curiously honed on industrious sounds of distant Baku:

[Oil] is transported in tank cars from Baku
across the vast expanse of smoky thoughts
in the forest forging kU-kU-shka KU
Spring oil smells noise
26 seats in the ruby bus
nearby. It is above the trembling of the window
No. **147**
shakes the highway
past days
telegraph poles With
white cups
WIRE OF COPPER HOPES
March 4th (To her)
GEOGRAPHICAL MAP IN MY HEAD

Avraamov's Baku symphony embodies these shifting ontologies of the siren and musicalized production at a crucial source of post-revolution industrialization. It also addressed the challenge of performing an acoustic commemoration of sounds still echoing in living memory of St. Petersburg residents to other locales. The goal was producing an organized cacophony that aimed at mimicking aspects of the turbulent political events at the winter palace grafted onto Baku's civic structure. Avraamov imagined an urban symphony, where the city, its infrastructures and collective inhabitants momentarily constituted a spatialized, experimental, national anthem. *Symphony of Sirens* had several iterations, in Nizhny Novgorov (1919), Rostov (1921) and Moscow (1923) (Alarcón, 2008, p. 19). Though, the most substantive realization

7 See for example Vladimir Deshevov's piano work *Rails,* Op. 16 (1926) mimicking trains, or Alexander Mosolov's factory ambience conjuring symphony *The Iron Foundry*, Op. 19 (1927). In Dmitri Shostakovich's Symphony No. 2, Op. 14 (1927), commemorating the 10th anniversary of the October revolution, sirens harmonize with instrumental crescendos in the final section of the work.

8 Russolo writes: 'Let us cross a large modern capital with our ears more sensitive than our eyes. We will delight in distinguishing the eddying of water, of air or gas in metal pipes, the muttering of motors that breath and pulse with an indisputable animality, the throbbing of valves, the bustle of pistons, the shriek of mechanical saws, the starting of trams on the tracks, the cracking of whips, the flapping of awnings and flags. We will amuse ourselves by orchestrating together in our imagination the din of rolling shop shutters, the varied hubbub of train stations, iron works, thread mills, printing presses, electrical plants, and subways.' Russolo, The Art of Noises: Futurist Manifesto, 1913, reprinted in Cox & Warner, eds. *Audio Culture: Readings in Modern Music*. New York: Continuum, 2004. p. 12.

took place in 1922 in Baku for the occasion of the Fifth Anniversary of the October Revolution. It included a massive citizen choir, steam locomotives, boat horns of the entire Caspian flotilla, airplanes, hydroplanes, two batteries of artillery guns, infantry regiments (including a machine-gun division), and a panoply of sirens. Avraamov also designed a steam-whistle machine dubbed the ‘Magistral’ containing 50 steam whistles played by 25 musicians following text scores (Smirnov & Kloptsov, 2017). The device could be attached to a variety of steam-producing facilities such as a factory boiler, boat chimney or steam engines. For the Baku performance, it was fixed to the engine of the destroyer *Dostoyny* moored in the harbour – a decommissioned Russian empire Baltic ship that was moved south, along with other battle vessels, to enforce the Caspian Fleet based in Baku since 1867.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тябрьскому торжеству, и даем здесь инструкцию по организации „симфонии гудков“ применительно к различным местным условиям.

После удавшегося опыта это уже нетрудно: нужна лишь инициатива и энергия.

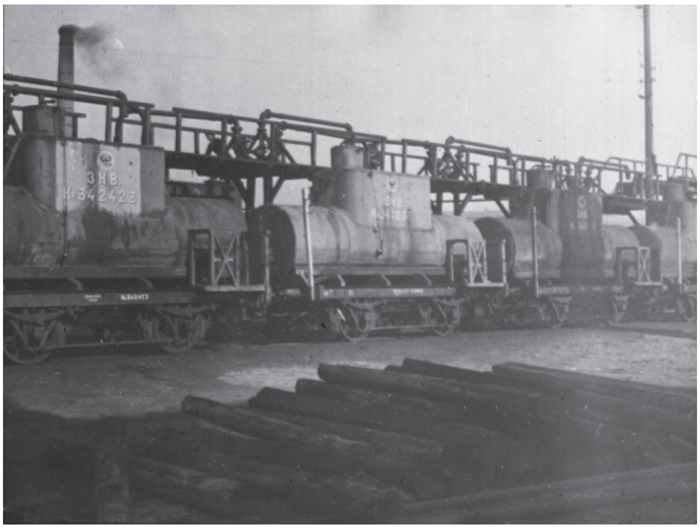
МАГИСТРАЛЬ.

Одним из важнейших условий удачного исполнения является предварительная постройка паровой гудковой магистрали.

Магистраль устанавливается либо на удобном по месторасположению заводском котле, либо на паровозе или пароходе (в Баку была установлена на миноносце „Достойном“). Преимущества подвижной магистрали очевидны: в различные моменты торжества она может быть подана в тот или иной пункт города и даже продемонстрирована самостоятельно в окрестностях.

Устройство магистрали очень несложно: на общую трубу навинчивается от 20 до 50 гудков (преимущественно цилиндрических: их легче перестраивать). Трубе придается та или иная форма, в зависимости от места установки: прямая, полукруглая, двух-трехколенная, безразлично — с точки зрения звучания. Важно лишь, чтобы подача пара была в центре, а на концах устанавливаются спускные краны или клапаны, для отлива воды перед исполнением,—иначе вода будет выбрасываться через клапан гудков и ритмическая точность исполнения утрачивается. Настройка гудков производится укорочением воздушного столба в надставном цилиндре любым способом: поршневым, либо просто вколачиванием деревянной чурки сверху с последующим закреплением ее на даннной глубине. Дерево нужно выбрать наименее гигроскопичное, иначе разбухание его под действием пара нарушит точность настройки уже после 2-3 репетиций. Стаканные гудки перестройке поддаются очень слабо (лишь в пределах одного тона, самое большее—терции) путем подкладки шайб и, следовательно, удаления нижней окружности стакана от паровой струи: значительное изменение высоты будет в ущерб тембру и силе тона. Если нужны высокие тона, которых имеющиеся гудки не дают, можно деформацией

6.7 Page from Avraamov’s essay Symphony of Sirens depicting the multi tone steam-whistle machine, mounted on a locomotive’s steam mechanism. (From Avraamov A. Simfoniya Gudkov [Symphony of Sirens], Gorn, No. 9, 1923, p. 110)



6.8 Barnobel oil cartel (Nobel Brothers) railway tank cars and petroleum loading dock, Baku oil district, 1903 (Photo by A.W. Cronquist)

Symphonic Cities

Analogies between the life of cities and structures of normative music assist in calibrating modes of hearing cities musically. A series of experimental filmic city portraits from diverse, populous, urban hubs in the 1920s are expressive of these sentiments: Mikhail Kaufman’s *Moscow* (1927), Walter Ruttmann’s *Berlin: Symphony of a Great City* (1927), André Sauvage’s *Études sur Paris* (1928), Dziga Vertov’s *Man with a Movie Camera* (1929) define the ‘city symphony’ genera of early cinema though all of them are produced towards the end of the silent era, so orchestrations were primarily constrained to an optically conveyed aurality. Their imagery is saturated with mechanized city infrastructures (harbor machinery, trolleys and railways, communication and postal systems, printing, industrial production etc.), reveling in the pulsating dynamism of increasingly systematized urban milieus. When considering these films shared sensibility, the post-industrial city itself manifests as an abundance of coalescing and colliding dynamic patterns.

Urban Modes of Hearing

Cities acting as unconscious laboratories for sensory stimulation themselves provide a kind of playback to which citizens are admitted simply by way of habitation. In sensory terms, built environments can be considered forms of reciprocal media, acting upon, and reproductive of, patterns in human attention that in the case of the post-industrial metropolis emerged as an expansive, indeterminate, perceptual apparatus. Curiously though, this heightened urban sensuality coincides with the rise of mono-sensory public buildings such as museums, libraries and music halls where specific sense faculties are housed in dedicated public functions. The fragmented, functionalized, paradigms in urban planning parallel modern ontologies of the human body understood as a collection of discrete sensory apparatus rather than a cohesive multi-sensory whole. Such understandings are mirrored in depictions of urban infrastructures, especially belowground illustrations of plumbing, sewage and subway systems, drawn in cutaway sections, resembling anatomy book depictions dissected human bodies. Fracturing the senses into discrete functions are also mirrored in a transition from holistic multi-sensory experiences of the pre-modern Zoroaster rituals at the Surakhani fire temple of Baku into regimented sensory modalities of museums, libraries, theatres and symphony halls during and after Baku's oil boom.

However, cultural expressions – such as the city symphonies – suggest more complex narratives that include hybridizations and coexistence of contrasting sensory worlds. Participating in city cycles, frequenting patterned frequencies fosters and calibrates sensations. Some of those patterns escape the hubbub by way of their observers, reemerging as shared sensory modalities that then materialize and sediment in printed text, images and arrangements of sounds. Its in that sense that the emergence of the city symphony genera is *symptomatic* of more pervasive shifts to every-day attentions incurred by urban restructuring of sensory orders (rather than the other way around) in diverse locales that then take on particular agency within the early Russian avant-gardes in general and Avraamov's symphony incorporating city and siren infrastructures in particular.

Urban Acoustics

Impression of resonant cities were also prepared by audible transitions in the patters of air pressure incurred by changes in building materials, city infrastructure and increasing population densities. The urban milieu was increasingly stratified with flows of people and transpiration along with nonhuman flows of liquids, gasses, steam, sewage, communication and electricity with their integral hums, rings, beeps, hisses and sloshing. The modern metropolis *sounded* different than earlier city structures, especially at the interfaces of façades and street life. Integrations of acoustically unregulated mass-transport, railway, traffic and other sonorous city systems along with an increasing civic density of high-rise construction and the introduction of highly sound-reflective glass façades meant cities had distinctive, yet comparable sounds across various capitols of the industrialized world. The historian Emily Thompson has attended to the acoustic modernity of such settings, particularly the context of New York City's roaring twenties exemplified in Midtown Manhattan's Rockefeller Center complex – a series of buildings explicitly designed for audio and acoustic programmes. The centre, housing performance halls, radio studios and the offices of broadcast giants such as RCA and NBC, was almost exclusively financed by oil revenue from the Rockefeller's operations in Baku (Blau et al., 2018, p. 17).

Urban Symphony Halls

Equivalences between symphonies and factories can be applied either way. The American historian and sociologist Lewis Mumford, points to that parallels in terms of their shared infrastructural morphologies:

> '[...] with the increase in the number of instruments, the division of labor within the orchestra corresponded to that of the factory: the division of the process itself became noticeable in the newer symphonies. The leader was the superintendent and production manager, in charge of the manufacture and assembly of the product, namely the piece of music, while the composer corresponded to the inventor, engineer, and designer, who had to calculate on paper, with the aid of such minor instruments as the piano, the nature of the ultimate product—working out its last detail before a single step was made in the factory.' (Mumford, 1934, p. 202)

Diversification of the typologies of public space goes hand in hand with increased urban complexity combined with shifts in demographics and social structure. The emergence of dedicated spaces for listening, from the 18th century onwards, help define the city as a site for musical productions. Incidentally the rise of dedicated spaces for hearing (such as music rooms, concert halls and later radio houses) coincides with the emergence of dedicated spaces for gazing (museums and galleries) as well as multi-modal sensory spaces such as opera houses, theatres and cinemas, all of which build on an expanding middle-class coupled with increasingly rationalized city planning and transport infrastructures, nationalized power grids not to mention an increasing rationalization of the human sensory apparatus.

By the end of the 19th century the grand symphony hall (that built on the civic music halls of Leipzig and London of the 18th century) had become a feature of public life and a fixture of public space. With the political annexing of Baku into the Russian Empire in the mid 19th century, international oil commerce imprinted itself in stone-clad Baroque and Renaissance styled buildings in the city.

6.9 View of Baku's Baroque-styled city hall (City Duma), completed in 1904, with newly erected telegraph-line poles along the boulevard.

Baku had one such philharmonic hall (Azerbaijan State Academic Philharmonic Hall, opened in 1912) and opera hall (Azerbaijan State Academic Opera and Ballet Theater) catering to the cultural needs of a growing, affluent, international urban elite linked with the oil boom as the city morphed into the so-called Paris of the Caucuses.

At the time the philharmonic hall was constructed Baku's exports accounted for more than half the world's oil production (Wendel, 2012, p. 550). Baku's oil boom architecture such as the opera hall had a typical double-layered enclosure prevalent in music hall designs that followed Leipzig's Gewandhaus layout of 1781, acoustically isolating the halls interior from urban hubbub by way of an encircling foyer. Baku's Baroque-styled city hall, designed by the city's chief architect Józef Gosławski and completed around the same time, featured an excessively reverberant meeting chamber deemed ill fit for speech had to be remedied with carpets and heavy curtains (Äbdülrähimov & Abdullayeva, 2013, p. 223). In all three cases Baku's civil engineer Nikolai Bayev tended to the sonic treatment of the interiors with meager empirical tools or acoustic theory. Unbeknownst to Baylev the systematization of architectural acoustics was well underway at Harvard University's physics labs at the time, under the guidance of Wallace Clement Sabine, though it would take another half century before architectural acoustics became common practice.

Oil Infrastructures

6.10 Left: View of urban Baku with telegraph-line pole (Photo by K.W. Hagelin). Right: Interior view of the post and telegraph office of Baku c. 1900 (Photo by P. Sinelnikov).

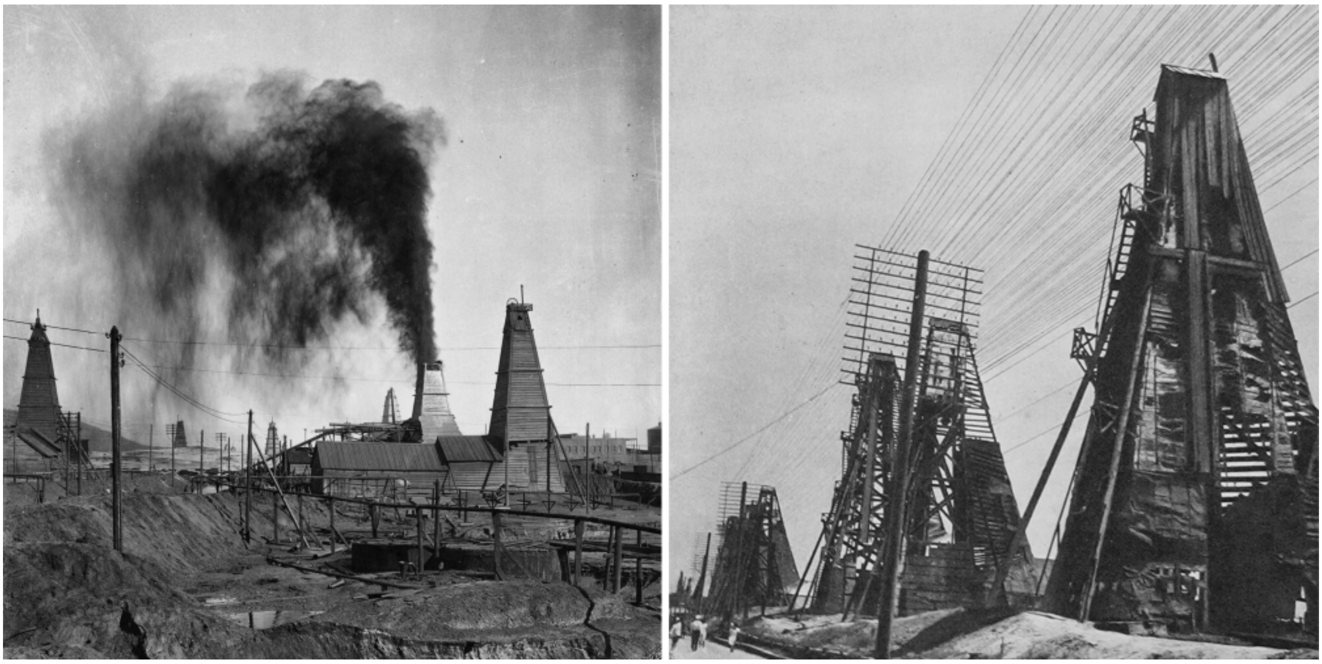
In the last three decades of the 19th century, Baku's population grew 15 fold, at a faster rate than New York City at the time (Blau et al., 2018, p. 25). Approaches to urban planning derived from industrial culture, coincide with Baku's oil-boom expansion with an emphasis on the city as a series of infrastructural circuits, functional systems and assembled urban units.[9] This urban approach was especially visible in areas like Black Town, named for sheer density of sludge spewing oil rigs interlined with tangled railway tracks, housing shacks, warehouses, tank storage facilities, refineries and open oil pits. Baku was the largest oil supplier worldwide at the time, patching the city further afield via pipelines, railways and boats. To assist with logistics of distribution, Baku operated simultaneously in three separate time-zones and was also hooked-up to one of the worlds most extensive telegraph networks linked-up with Russia and Europe.

Baku's oil has been known since antiquity, visibly concentrated in thick black pools at pockets in the landscape. At times they caught fire, producing unending flames. Eerie localized fires were mentioned in Marco Polo's travels and ritualized by Zoroastrian practices originating in the city's Surakhani fire temple. Baku petroleum has been internationally traded and put to use in local heating and healing applications at least since the Middle Ages though it's the arrival of modern industrial practices (such as steam-driven drilling) and foreign oil barons (including the Swedish-Russian Nobels and French Rothchilds) and later the Royal Dutch / Shell oil cartel that gave it pronounced form.

Robert Nobel stumbled over Baku oil in 1873 while seeking walnut for gunstock in the Caucasus. Soon after, Robert and his brother Ludvig, founded the Branobel petroleum company in Baku at the dawn

9 See Eve Blau et al., *Baku Oil and Urbanism* (2018) for an account of the long-term entanglements of Baku's urban developments and infrastructures of global petroleum trade.

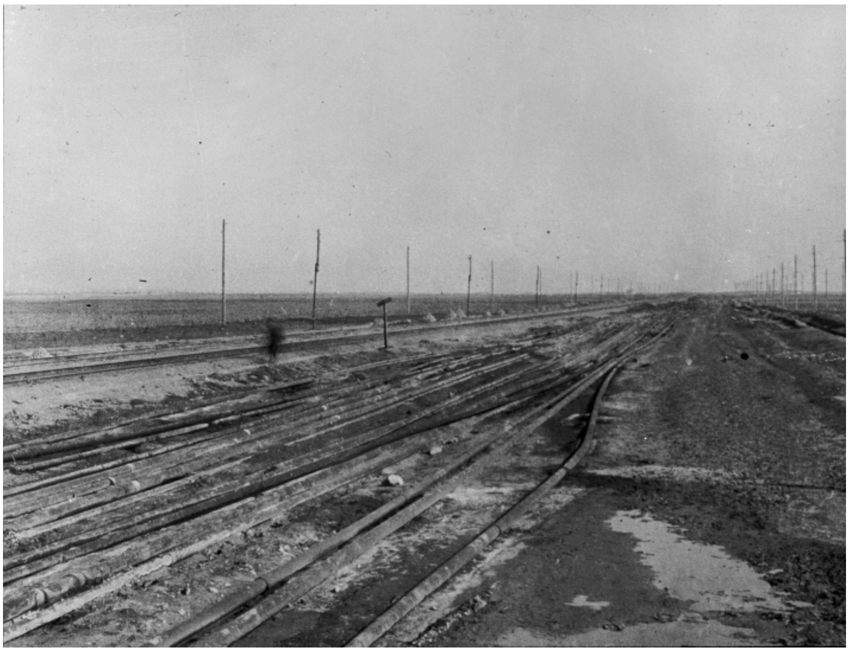
of world petroleum reliance, first through lighting and heating applications, and then combustion engines. Robert and Ludvig constructed refineries and storage facilities and developed oil infrastructures such as railway systems and a trans-national oil pipeline delivering kerosene from Baku to Batumi (current day Georgia). The Nobels owned oil storage sites across the Russian Empire and rented storage facilities as far away as Marseille, Liverpool and Göteborg (Blau et al., 2018, pp. 8–9). The brothers inaugurated the world's first oil tanker, constructed in Sweden and assembled on the Caspian Sea, capable of navigating shallow rivers like the Volga and Neva to deliver Baku oil directly to St. Petersburg (Chapple, 2021). They named it the Zoroaster, a homage to the earlier ontology of petroleum as source of ritual fire ceremonies in the prehistory of extraction.



6.11 Left: View of Black Town with oil gusher and telegraph lines, c. 1900. (Photo courtesy of ETH-Bibliothek Zürich) Right: View of oilfield derricks and newly expanded telephone links as part of the Soviet push for modernization in Baku, in USSR im Bau (USSR in Construction), vol. 12, 1931. (Photo by J. Heartfield)

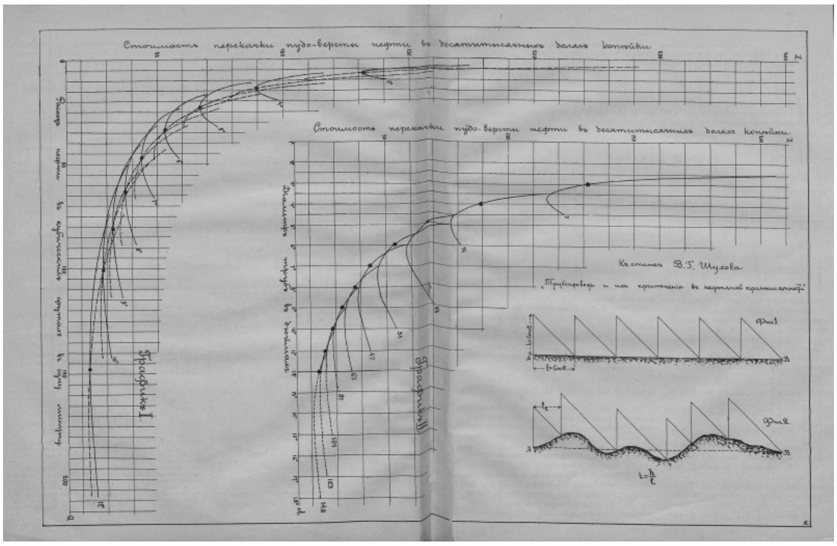
6.12 View of Nobel Brothers oil field at Bibi-Heybat, Baku, c. 1900. (Photo by K.W. Hagelin)

Piped Communication



6.13 View of oil transport pipelines, Baku oil district, 1903. (Photo by A.W. Cronquist)

The Russian engineer Vladimir Shukhov, between 1878–1880, pioneered Baku pipeline oil transport, a crucial development for the regions oil industry. Shukhov was working as chief engineer in Alexander Bari's construction firm 'Bari, Sytenko & Co', managed by Ludvig Nobel, providing services for Branobel and the Russian Tsar. Shukhov's innovations led to the first 10 km long oil pipeline on the Absheron Peninsula from Balaxanı (near Baku) to Black Town in 1878. When the Baku-Batumi pipeline (also designed by Shukhov and laid along side the railway line) connecting Baku to the Black Sea was completed in 1906, it constituted the world's longest kerosene pipeline.



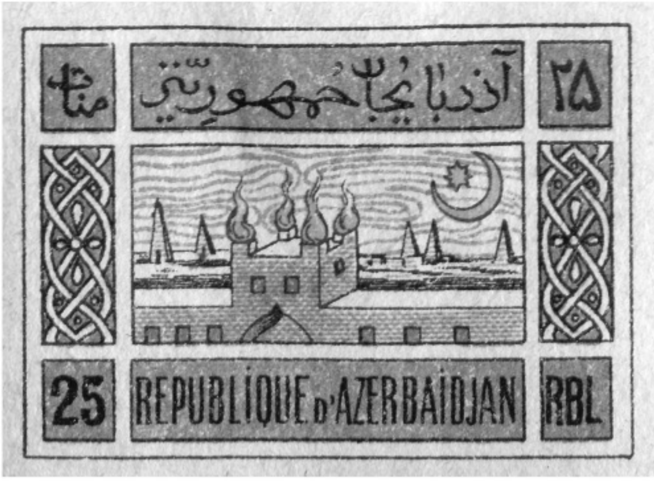
6.14 Chart from the Russian engineer Vladimir Shukhov's pipeline hydraulics book for calculating oil transport through pipes, in *Pipelines and Their Application to the Oil Industry*, Moscow, (1895), p. 20.

Shukov also invented several types of oil pumps and cylindrical oil reservoirs (tens of thousands of them constructed by the Bari firm, a design that is now ubiquitous across the globe), however his design possibly most remembered for the design of the iconic Moscow radio tower, crucial for post-revolution communication and radiophonic imaginations. Half a century before Claude Shannon hatched the mathematical model of communication at Bell Telephone Laboratories (1948), Vladimir Shukhov imagined the oil pipeline a *communication channel* consisting of two stations (a transmitter station and receiver station), interlinked with a pressurized transport channel (pipeline). Shukhov discovered that heated oil pumps more smoothly and devised mathematical formula for determining relations between crude oil temperature; pressure; pipe length and pipe diameter organized into a series of charts that are still in use today. In other words Shukhov hatched a method for *mathematically modeling* the forces of anthropogenic-oil-in-motion. By 1890 an estimated 25 pipelines, designed by Shukhov and others, totaling over 300 km in length were servicing the Baku oil fields.

Baku Sounding

The 1920s marked a turbulent period of transitions in Baku in which the industry was undergoing a process of Russian nationalization morphing into the state-run company Azneft. After a brief moment of independence where the region was known as the Azerbaijan Democratic Republic, the Red Army took control of Baku in May 1920 with the industry in shambles. The city underwent extensive development, overhauling oil fields, factories and workers settlements; the city itself became the site of an expansive Soviet experiment. The historian Rebecca Hastings aptly describes Baku at that time as '[…] one of several urban-industrial sites on the periphery of the country that in the early 1920s acted as 'living laboratories for urban experiment' (Lindsy-Hastings, 2020, p. 137). Experiments included approaches to urban planning, oil techniques as well as constructing the emerging identity of the socialist citizen. Nevertheless authorities decided to retain the geographic oil regions of the previous era following the six main oil production districts of Ramani, Surakhani, Balakhani, Sabunchi, Binagadi and Bibi-Eibat. Besides coal from the Donbas powering Soviet factories, Baku was the central source of oil revenue for the Soviet economy. Myakovsky, who had first visited Baku in 1914, is so enamoured with the Soviet urban transformations that he dedicates a poem to the city, simply titled *Baku,* portraying it as a post-religion site of proletariat pilgrimage:

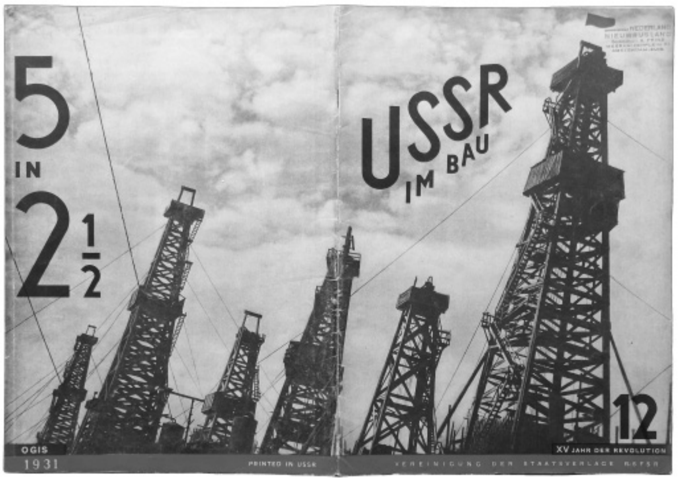
Baku.
City of fires.
[…]
Baku.
Leaves - soot.
Branches are wires.
Baku.
Brooks -
oil ink.
[…]
what attracts the dervish to Tibet,
Mecca - the faithful,
Jerusalem -
Christian
on a pilgrimage.
For you
machines sigh
billions
pistons and wheels.
Kiss
and again
kiss without stopping
oil,
oil,



6.15 Left: Democratic Republic of Azerbaijan postage stamp issued in 1919, depicting Baku's ancient fire temple in Surakhani illuminated with petroleum fires. Right: Azerbaijani postage stamp circa 1922 featuring Baku's Soviet coordinated petroleum industry after the Red Army invasion.

Much of the sounding infrastructures Avraamov drafted for *Symphony of Sirens* were already in place, implemented in Baku's urban-industrial hybrid layout. Infrastructural features of Baku's oil industry, served as a backbone for sections in Avraamov's orchestrations of urban space: the opening section includes sirens on military and oil trade vehicles speeding from peripheral positions at Zych, White City, Bibi-Heybat and Bailov towards the central train station; section five of the symphony commences with a choreographed sounding synchronized sirens of Black Town's two districts (on outskirts of town); section ten cued in sirens of Azneft, the offices of the Azerbaijani Oil Administration. Ironically this commemoration to the birth of nationalized-Marxism is grafted over the material armature of trans-national capitalism. In a sense, Baku's native sounds were already part of the early soundtrack of globalization. Overtones of that irony intensified along Soviet assembly lines where rapid industrialization was partially modeled after North American Fordist and Taylorist paradigms. More subtle, but growing in intensity, is the prolonged after-ring of Baku's spatial ping that only starts making sense to ears listening one century later: unbeknownst to Avraamov, the inadvertent sounding of the origins of global petroleum trade tends to render its sounds through infrastructures of alarm.

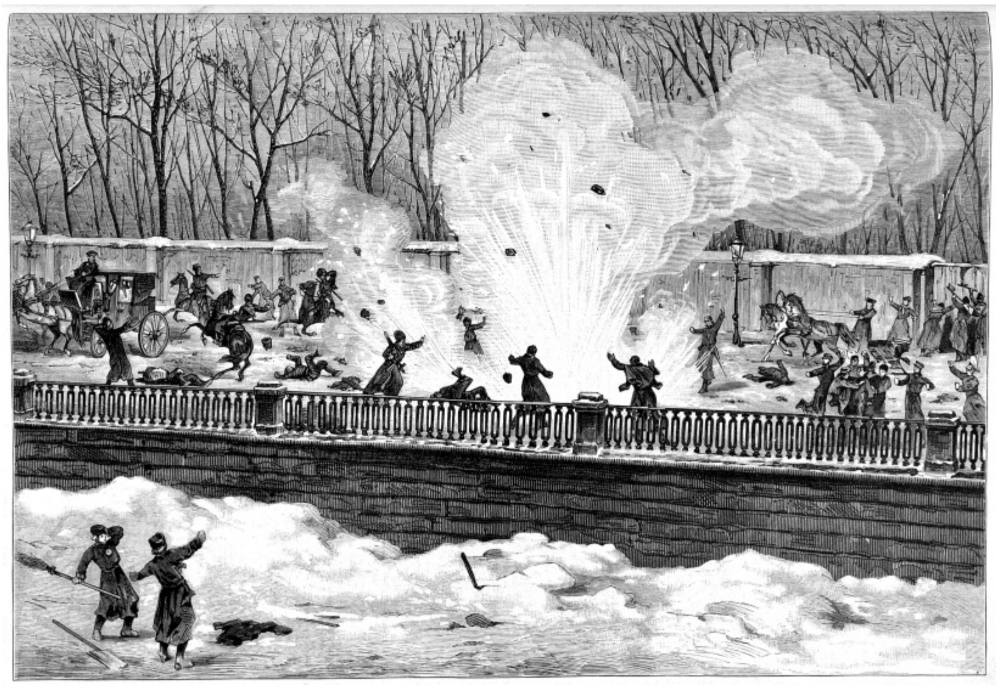
6.16 Open petroleum retainer pools and oil derricks at Balakhani, c. 1890. (Photo by K.W. Hagelin)



6.17 Cover of USSR im Bau (USSR in Construction, vol. 12, 1931), featuring Baku's revised oil infrastructure in the 1930's.

Explosive Chronometry

Immanuel Nobel, the Swedish businessman and arms manufacturer, had a workshop in St. Petersburg supplying black-powder based explosives to the Russian tsar during the Crimean war of the 1850s.[10] Nobel's munitions staples were artillery shells and mortars, however it was the design and innovation of sea mines, brandished with the English-language inscription 'Infernal Machines', that secured the tsar's sovereignty over key strategic ports of the empire, especially in gateways to the Black & Baltic Seas.[11] Immanuel's third son Alfred, best known for his invention of dynamite, briefly studied chemistry in St. Petersburg during the Nobel's residency there. Though at the time dynamite was patented, the Nobel's had already moved back to Sweden. Alfred's dynamite – nitroglycerine based explosive molded into stable cylindrical sticks – was central at the time for developments in mineral extraction, advanced warfare as well as the rise of terrorism.[12] Some years later dynamite was the substance of choice in attacks aimed at destabilizing the monarchy targeting the imperial train, the winter palace and ultimately the assassination of Tsar Alexander II on the banks of St. Petersburg's Catherine Canal in 1881, when a dynamite stick was thrown under his carriage. All three bombings were carefully timed, synched to clocked schedules. In the palace bombing, a timing device was incorporated on the dynamite charge itself, set to detonate under the dining hall at dinnertime.



6.18 Assassination of Tsar Alexander II in St Petersburg, March 13, 1881.(From A. Baldinger, Vsemirnaya Illyustratsia [World Illustration], Vol. 25, No. 12, March 14 O.S., 1881, p. 220)

Links between explosions and chronometry is possibly the longest standing mode of hearing that turns up in the Baku performance, stemming from 17th century musket blast experiments of timing the speed

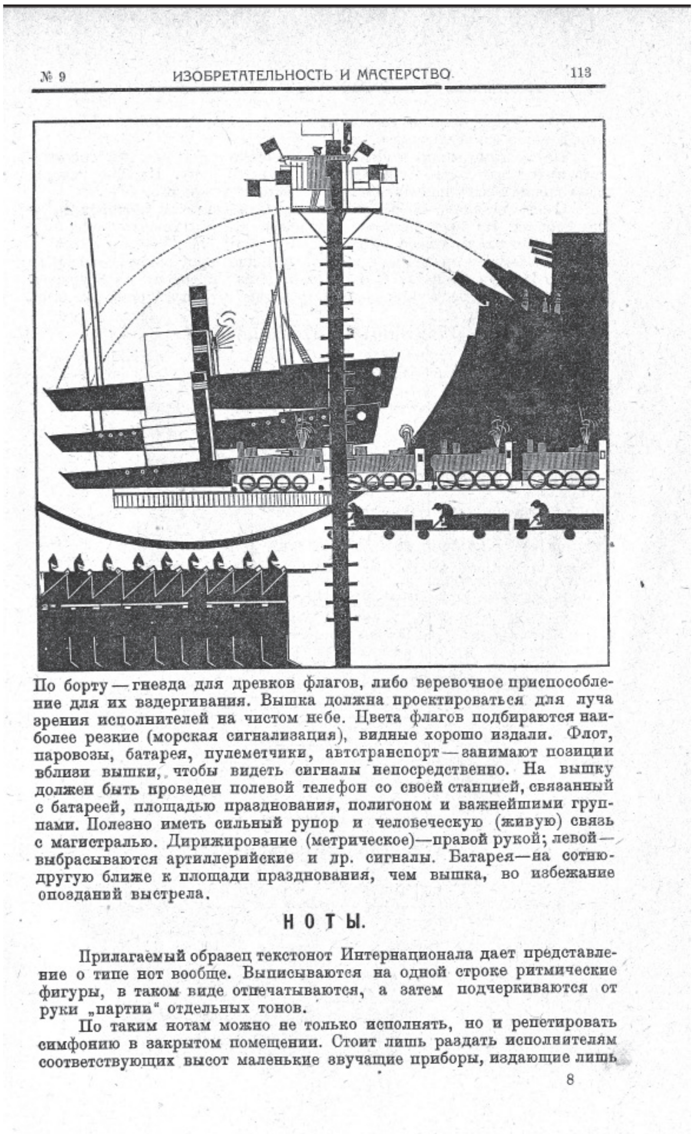
10 The tsar eventually lost the Black Sea fleet mooring rights after prolonged confrontations with an alliance of Ottoman, French and British forces concentrated on the Crimean peninsula. NobelPrize.org. "Immanuel Nobel." Accessed February 11, 2022. https://www.nobelprize.org/alfred-nobel/immanuel-nobel/.

11 The 2014 annexing of Crimea is a replay of Sevastopol harbour affordances as a maritime gateway to unfolding power shifts in the Caucasus and Middle East in the wake of Russian expansionism. Turkish control of battle ship passage in the Bosporus and Dardanelle straits along with the Russian attacks on Odessa and other Ukraine ports in 2022 increases the global geopolitical complexity of that region. See Tonolli, Frédéric, *Putin: Return of the Russian Bear*, France, 2021, broadcast on Arte, February 2022.

12 For an account of links between the invention of dynamite and explosive-based terrorism see Merriman, J. M. *The Dynamite Club: How a Bombing in Fin-de-Siècle Paris Ignited the Age of Modern Terror*. New Haven: Yale University Press, 2016.

of sound in air that carry through into 20th century atmospheric analysis synched to thermonuclear blasts.[13] In Avraamov's siren symphony, city-wide synchronization was attempted through explosive blasts from twenty-five cannons, cueing in various sections of the piece. The first shot initiated sirens on military and oil trade vehicles speeding procession from peripheral positions at Zych, White City, Bibi-Heybat (where the world's first oil well was drilled in 1846) and Bailov towards the central train station. The 25th cannon blast closed the event, wrapping up a simultaneous crescendo of all the city sirens from factories, plants, steam mills, depots and the docks. After a brief silence, a triple chord of sirens from the pier sound a 'hurrah' and then Internationale accompanied by chiming bells of the harbour fleet closed the performance. The cannon blast was imagined as a *gigantic kettledrum* synchronizing the event with its membranous vibration stretched across the city. Or in the case of repeating the blasts, Avraamov imagined shockwaves transforming into a synchronized rhythmic patterns:

> '[...] sirens are scattered around a large area, it is necessary to have at least one heavy cannon for signaling and to fire an artillery shell. [...] A field gun can pass for the 'big drum' effect. Experienced machine gunners (in case they use real ammunition) can do complicated rhythmical figures.'[14]


№ 9 ИЗОБРЕТАТЕЛЬНОСТЬ И МАСТЕРСТВО 113

По борту — гнезда для древков флагов, либо веревочное приспособление для их вздергивания. Вышка должна проектироваться для луча зрения исполнителей на чистом небе. Цвета флагов подбираются наиболее резкие (морская сигнализация), видные хорошо издали. Флот, паровозы, батарея, пулеметчики, автотранспорт — занимают позиции вблизи вышки, чтобы видеть сигналы непосредственно. На вышку должен быть проведен полевой телефон со своей станцией, связанный с батареей, площадью празднования, полигоном и важнейшими группами. Полезно иметь сильный рупор и человеческую (живую) связь с магистралью. Дирижирование (метрическое)—правой рукой; левой—выбрасываются артиллерийские и др. сигналы. Батарея—на сотню-другую ближе к площади празднования, чем вышка, во избежание опозданий выстрела.

НОТЫ.

Прилагаемый образец текстонот Интернационала дает представление о типе нот вообще. Выписываются на одной строке ритмические фигуры, в таком виде отпечатываются, а затем подчеркиваются от руки „партии" отдельных тонов.

По таким нотам можно не только исполнять, но и репетировать симфонию в закрытом помещении. Стоит лишь раздать исполнителям соответствующих высот маленькие звучащие приборы, издающие лишь

8

6.19 Illustration of Avraamov's signaling post atop a 'Swedish tower', conducting Baku's urban sound orchestration Symphony of Sirens also depicting a selected elements from the performance such as boat and train whistles, transport vehicle infrastructures, cannon blasts and marching choirs. (From Avraamov A. Simfoniya Gudkov [Symphony of Sirens], Gorn, No. 9, 1923, p. 113)

13 For a detailed account of the agency of blast monitoring in epistemologies of acoustics and atmospheric sciences see Ganchrow, R. "Earth-Bound Sound: Oscillations of Hearing, Ocean, and Air." *Theory & Event* 24, no. 1 (2021): 67–116.

14 Avraamov, A. (1923) Simfoniya gudkov [Symphony of Sirens], *Gorn*, 9, pp. 109–116, translated to English by Mel Gordon, in Kahn, Whitehead, p. 249.

There is an inherent contradiction to notions of synchronization when taking into account the sheer scale of the event. Avraamov glosses over the fact that blasts take time moving through the air. Ears distributed along the sound's paths of propagations would experience the blast in different time zones. Even if the cueing function of the cannons had been replaced with the simultaneity of radio the event still would have been heard asynchronously due to the accumulation of time lags from spatially separated sounding events (Avraamov conducted the symphony from atop a so-called 'Swedish tower', a tower normally used for radio transmissions, though the one used in the performance had no transmitting capabilities). Each listener's positions in the city occupied a unique auditory perspective with different senses of the temporal relations unfolding at a distance. Furthermore, the accumulation of louder, nearer sounds would have likely drowned out those travelling from further afield. Add to that the fact that the performance itself was a kind of replay of sounds from another place and time (the storming of the winter palace, five years earlier), and it would seem that poly-temporal dynamics enacted that day far exceeded even the three time-zones administering Baku's petroleum trade.

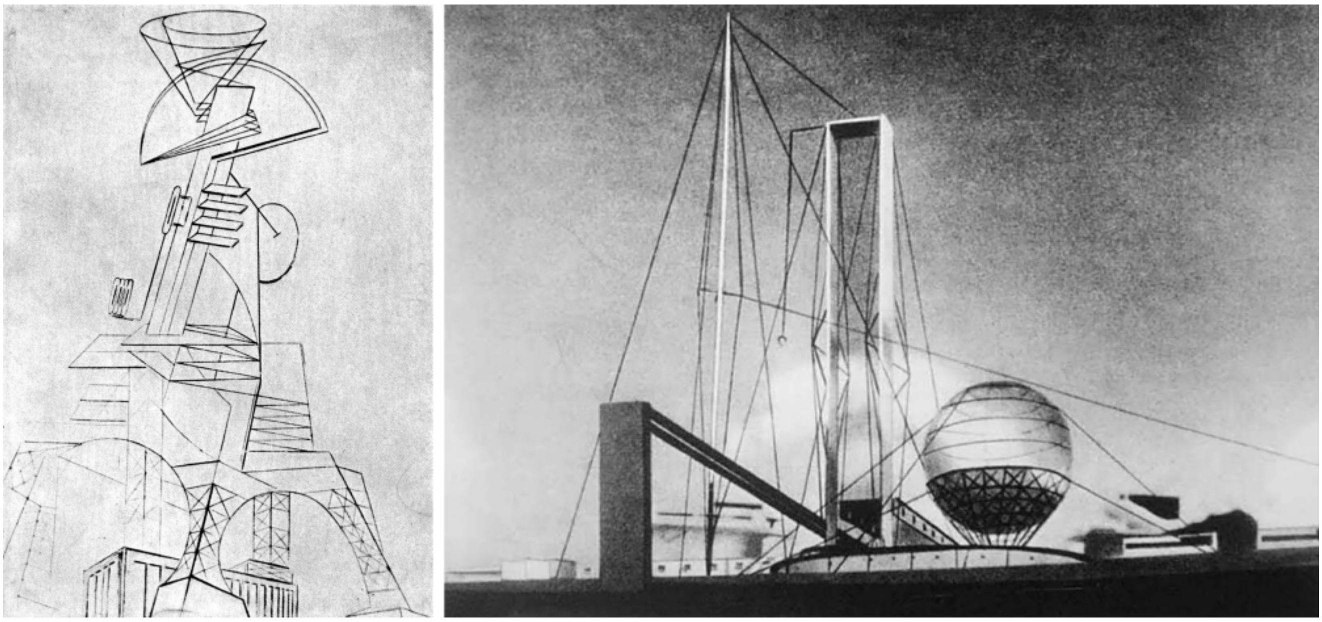
Proletarian Radio

Avraamov also manually orchestrated the spectacle, with the help of colored flags and a megaphone, from atop a specially built tower constructed from tethered telegraph posts. The so-called 'Swedish tower' is a construction method applied to early radio antennas that draws parallels between the symphony conductor and the radio transmitter both serving as a coordinating central relay for dispersed fields of interaction. Although Avraamov's symphony tower did not incorporate an actual transmitter, it did supposedly house a field-telephone, described in Avraamov's Proletkult journal article contribution to Gorn, from which commands could be dial-up simultaneously to disparate sections of the city (Avraamov, 1923).

Electromagnetic agency was central to territorializing strategies of the post-revolution nation building. Early on, radio towers appear integrated into architectural designed in constructivist projects such as the Vesnin brothers competition submissions for Moscow's Palace of Labor, dubbed the 'antennae' (1922-1923) and the Central Telegraph Office project (1925). Although both Vesnin's proposals proved too radical for Moscow planners at the time, the brothers did manage to integrate radio towers into the design of Buku's four Workers' Clubs – the Vesnin's first realized constructivist projects – three of which were completed during the Soviet construction push in the late 1920's and coordinated by the nationalized oil consortium Azneft.[15]

6.20 Film stills from D. Vertov's Kino-Pravda, No. 23, titled 'Radio Pravda' (Radio Truth), from 1925, featuring peasants installing rural radio transmitter/receiver for direct communication with urban centers.

15 For a description of the Vesnin's Baku workers club designs see Khan-Magomedov's Pioneers of Soviet Architecture (1987), p. 436, and Blau *Baku Oil and Urbanism* (2018), p. 134, though neither account for a genealogy of integrated radio towers from the Moscow competitions to the Baku clubs.



6.21 Left: Naum Gabo's Project for a Radio Station (1919-1920). Right: Ivan Leonidov's thesis project at VKhUTEMAS, designed around a central tensile radio transmitter mast, titled Lenin Institute for Librarianship (1927).

Early radio transmissions were environmentally active and susceptible to external electromagnetic influences; experiences of listening to radio back then were saturated with external signal interferences. Presence of activities in the surroundings at times became distinctly audible, especially when electromagnetics from passing trams or ignition sparks of motor vehicle were active in the vicinity of radio receivers. Signal fading was also commonly experienced as signals interacted with weather and physical properties of urban structure. Such experiences no doubt transform material notions of urban vibrancy crisscrossed by electromagnetic emissions from radio. It is precisely in that *radiant material* guise of energetic emission that one should read El Lissitzky's 1920 tribute to radiophonic urbanism:

> 'We have set ourselves the task of creating the [new] town. The centre of collective effort is the radio transmitting mast, which sends out bursts of creative energy into the world. [...] Therein lies the answer to all the questions concerning movement. This dynamic architecture provides us with the new theatre of life and because we are capable of grasping the idea of a whole town at any moment with any plan the task of architecture – the rhythmic arrangement of space and time – is perfectly and simply fulfilled for the new town. [...] The new element of treatment which we have brought to the fore in our painting will be applied to the whole of this still-to-be-built world and will transform the roughness of concrete the smoothness of metal and the reflection of glass into the outer membrane of the new life.' (El Lissitzky, Suprematism in World Reconstruction, in Bowlt, 1976, pp. 155–156)

Documentary footage of Dziga Vertov's Kino Pravda film No. 23 (1925) depicts transformations of a rural community through the introduction of radio infrastructure to the village. Support for the antennae is gathered by felling trees and a cottage is adapted into a functioning transmitter station. The film's visual narrative integrates instructions and circuit diagrams underlying the technical functioning of the facility that could be applied as blueprints for subsequent adaptations. The materiality of film here differs from the illustrative position film occupies in later Soviet avant-garde productions where the media expresses a self-awareness of its support materials and means of production (i.e. film frames and film strips appearing as protagonists in *Man With a Movie Camera* (1929) and *Enthusiasm* (1931)) that allude to the significance of Marx's heightened awareness of the links between material conditions and the conditions of social justice. Vertov's instructional approach in these early newsreels reveals utilities of film, along with anticipated functions of radio, in their *operative* dimensions. This approach, still in its nascent state, expresses an awareness of the manners in which media entangles the quotidian and is capable of shaping features, as well as future, materiality.

Radio indeed played an increasingly important practical role in administering Soviet life, especially in organizing the collective farms of the 1930's (Kenez, 1985, p. 13). Though it's the avant-garde's radio imagination that gives radio its most radical formal expressions. For example the unrealized constructivist radio towers of Naum Gabo (1919-1920) and Anton Lavinsky (1921). Not to mention Ivan Leonidov's iconic thesis project at VKhUTEMAS, titled *Lenin Institute for Librarianship* (1927) sporting a slender transmitter designed to directly relay, and disseminate, discoveries from the institute to distant corners if the union. Moscow's Shukhov Radio Tower (1920-1922) – a radio-tower project from the same period that was actually built – took a more structural approach, though its transmissive agenda was equally ambitious. The colossal tower, for which Lenin took a personal interest of completing, aimed at providing continual communication with other republics. The tower is prominently featured in the closing sequence of Mikhail Kaufman's city symphony film *Moscow* (1927). Two years after its completion, pan-global radio was featured in the opening sequence of the first Soviet science fiction film *Aelita* (dir. Yakov Protazanov, 1924), with reception of a mysterious wireless telegraphy message, originating from Mars.

6.22 Film stills from *Aelita: Queen of Mars* (dir. Yakov Protazanov, 1924), simultaneous global reception of a mysterious wireless telegraphy message, originating from Mars.

Metal supplies for constructing the Shokhov radio tower in Moscow, were diverted from munitions production supplies during the Russian civil war, underscoring the centrality of electronic communication infrastructures in the burgeoning federation. In 1920 Lenin called for further radiophonic measures such as the investment in small and medium range spark gap transmitter production for wireless telegraphy, as well as the redevelopment of stations in Moscow, Odessa (Ukraine), Omsk (Siberia) and Tashkent (Uzbekistan). As one senior Bolshevik Party member put it 'when our entire national economy was in ruins, [Lenin] laid the foundation of the wireless in the land of the Soviets and predicted its considerable significance in the future.'(Gorbounov, 1934, pp. 29–32 Lénine et la radio)

In the midst of the push for soviet radio, Trotsky reiterates an earlier political anxiety stemming from scientific discoveries into the coupling of energy and matter that posed a potential threat for Marxist materialist thinking:

'[…] there used to be atoms, elements, which were the basis of matter and of materialist thinking, but now this atom has come to pieces in our hands, has broken up into electrons, and at the very beginning of the popularity of the electronic theory a struggle has even flared up in our party around the question whether the electrons testify *for* or *against* materialism.'(Trotsky, 1957, p. 167)

In the quote, Trotsky is specifically referring to Lenin's polemic against fellow Machist Bolshevik *dynamic materialism* approach. Before the revolution Bolshevik's were embroiled in fierce debates over the nature of materiality in its relation to politics. In the midst of disputes, Lenin published a book-length critique of the Machist's, and their exponent Alexander Bogdanov's ideas regarding energetic materiality, in a volume titled *Materialism and Empirio-Criticism* (1909).

6.23 Left: View of the radio transmitter tower in Moscow, designed by Vladimir Shukhov, shortly after completion c. 1922. Right: Film still from the closing sequence of Mikhail Kaufman's city symphony Moscow (1927) featuring the Shukhov tower.

Ironically, by the time of Trotsky's commentary, the utilities of electricity in general, and radiant radio in particular, were proven key ballasts in unfolding materializations of modernization, socialist identity and centralized state coordination and control. Trotsky's talk, delivered at the *First All-Union Congress of the Society of Friends of Radio,* in 1926 under the title *Radio, Science, Techniques and Society*, reimagines radioactivity in an analogy of radio-activity where the electrons circulating the nucleus of an atom resemble tangles of communication binding together the vast socialist federation.

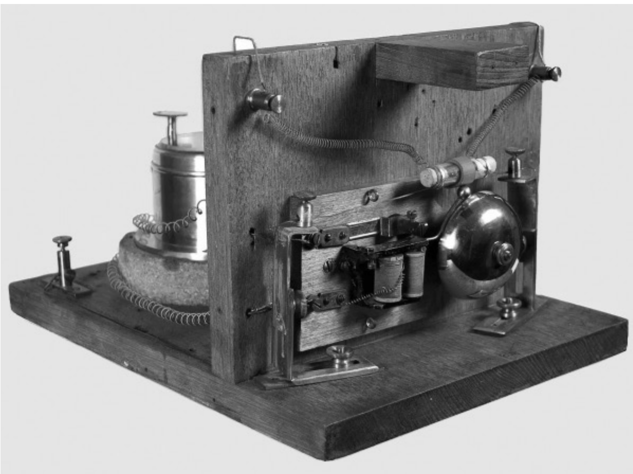
'What is the relation between radio technique and the social system? […]
How is a country transformed into a single economic and cultural whole? By means of communications: railways, steamships, postal services, the telegraph and the telephone – and now radio-telegraphy and radio-telephone [...] We cannot seriously talk about socialism without having in mind the transformation of the country into a single whole, linked together by means of all kinds of communications. In order to introduce it we must first and foremost be able to talk to the most remote parts of the country, such as Turkmenistan […] For direct and immediate communication with all points in the country, one of the most important means is radio […] every village not only should know what radio is but should have its own radio receiving station […] Each province should set out to conquer the countryside with a definite programme of radio development. Place the map for a new war on the table! From each provincial centre first of all every one of the larger villages should be conquered for radio.'(Trotsky, 1957, p. 168)

At the same time Trotsky asserts the materiality of energetic emission itself, where radio meets up with the penultimate powerhouse of nuclear fusion:

> '*Wireless* does not at all mean *non-material* transmission [. . .] these are phenomena of matter, material processes – waves and whirlwinds – in space and time [...] The phenomena of radio-activity are leading us to the problem of releasing intra-atomic energy. The atom contains within itself a mighty hidden energy, and the greatest task of physics consists in pumping out this energy, pulling out the cork so that this hidden energy may burst forth in a fountain. Then the possibility will be opened up of replacing coal and oil by atomic energy, which will also become the basic motive power.'(Trotsky, 1957, p. 168)

At the close of the 19th century, before radio communication was invented, the world's first atmospheric radio receiver was presented in St. Petersburg, to the Russian Physical and Chemical Society in 1895. Its inventor, the physicist Alexsandr Popov, presented a device that could sonify faint radio emission from lightning, by relaying the lightning signal to an electronic bell. The device was based on Oliver Lodge's coherer circuit, an electromagnetic pulse detector. Though Popov's innovation allowed for *durational* observation of successive pluses and could be applied as a means for weather monitoring (Fahie, 1902, p. 205). One year later Popov successfully demonstrated building-to-building wireless telegraphy transmission at St. Petersburg University, with an apparatus capable of distinguishing Morse code. The received message read 'Heinrich Hertz', honoring the German physicist's pioneering spark gap experiments that had recently confirmed Faraday's radio wave predictions. Popov's innovations were contemporaneous with, and largely independent of Guglielmo Marconi's radio experiments, though the latter's name remains synonymous with the invention of radio communication. Marconi filed his British patent for radiotelegraphy — the antecedent of practical radio techniques — less than three months after the Popov's university demonstration.

The question who invented radio depends on how one defines the category 'radio', though the debate remains tainted with political posturing (Marsh, 2020). The annual *Radio Day,* celebrated in the federation since 1945 (and in some regions until today), enshrines Popov's May 7th transmission demonstration and asserts Russia's radio birthright. A commemorative USSR *Radio Day* postage stamp, issued in the midst of the Cold War, closes additional circuits with Shukhov's Moscow radio tower, an orbiting sputnik and tactical naval aviation maneuvers that by that time had become dependent upon integrated radio technologies.

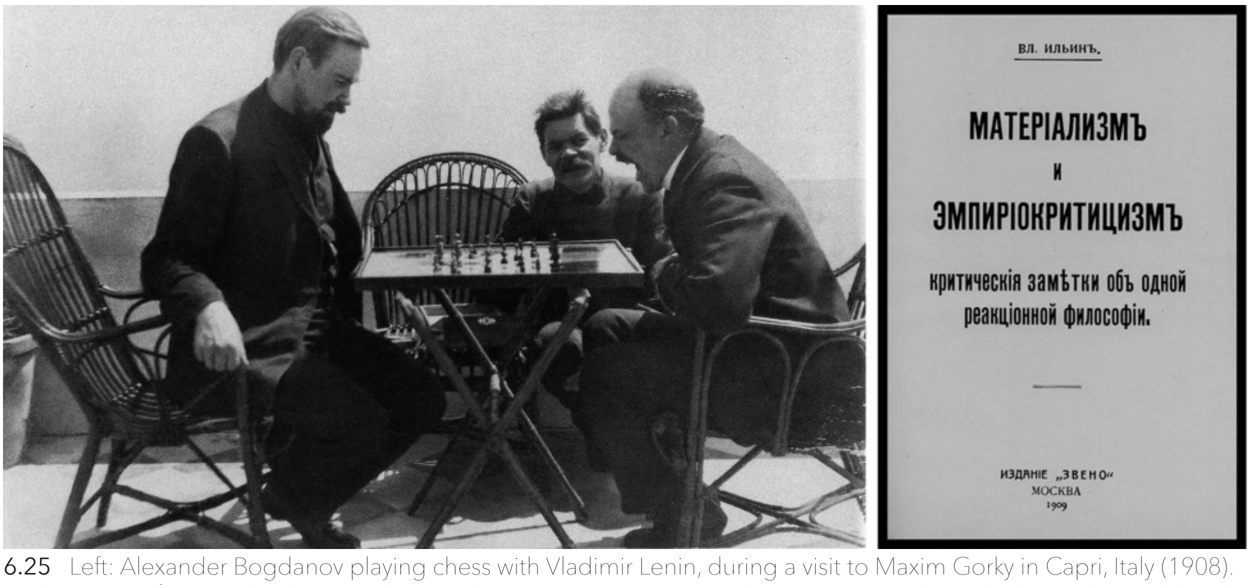


6.24 Left: Alexandr Popov's lightning detector of 1895, a device that converts electromagnetic lightning emissions into bell rings based on Oliver Lodge's coherer pulse detector circuit. (Photo: A.S Popov Central Museum of Communications, Saint Petersburg) Right: Commemorative USSR Radio Day postage stamp, issued in 1958, celebrating Popov's radio inventions closes additional circuits with Shukhov's Moscow radio tower, an orbiting sputnik, a megaphone and tactical naval aviation maneuvers, at a time when electroacoustic communication had become an inseparable component of Cold War strategies.

Cultural Enlightenment

Cultural groups that combined art and politics as a means of social mobilization were aggregated after the October revolution under the state subsidized experimental arts organization Proletkult (Proletarian Cultural Enlightenment Organizations). Co-founded in 1917 by Alexander Bogdanov (b. Alexander Alexandrovich Malinovsky) who served as Proletkult's intellectual ballast, the organization advocated a new proletarian culture based on experimentation at the intersection of art, science, technology and society. Proletkult was imagined as the cultural branch of the revolution endowed with the task of an art-based restructuring of everyday percepts, mobilizing aspects of Bogdanov's 'tektology' and 'emperiomonism' theories. Specifically, the notion that the shift to other social formations is facilitated by rearrangements of *perceptual fields* – sounds, images, architectural forms, words – fields of everyday lived experience in which the perceiving masses are immersed. The approach was based on the assumption that proletarian experience was to be fundamentally different than any existing social structures, such that proletarian culture should be actively constituted as a *dynamic system of perceptions*, thus enacting the new worker order.

Bogdanov's social-transformative function attributed to culture was meant to remedy Marx's crude notion of art as a 'simple adornment of life' (Bogdanov, 1984a, p. 48). In Bogdanov's take, art was understood as media conduits capable of exerting sensory influence and galvanizing social aggregation. Art constituted a diverse set of sensory formats with which to experiment towards perceptual amalgamations of an imagined future society. The approach was not so much a call for a 'new' art (Russian Cubo-Futurism was well rooted before its application in Bolshevik politics) as much as it pointed towards an understated *operative* dimension in *all* cultural production. Art – as an element of social conciseness – does not merely reflect reality, but instead actively partakes in it's structuring. During and after the revolution, cultural activities were consciously steered towards perceptual recalibrations of collectively shared sensory circuits. The emphasis was on art's ability to calibrate perceptions, in other words *organizing* the sensory dimensions of everyday life, shared across individual perceptions and nurtured into a collective social space. In Bogdanov's words 'an artistic idea serves as a living means of rallying the collective toward a unity of perception, feeling and mood.' (Bogdanov, 1984a, p. 03) As the scholar Zenovia Sochor aptly points out 'Proletkult, in fact, should be viewed within the context of the first attempted cultural revolution, embodying Bogdanov's concept and standing in sharp contrast to those of Lenin' (Sochor, 1988, p. 10). Several hundred cultural societies, avant-garde organizations and individual artists participated in Proletkult that also served as a haven for creative forces escaping authoritarian tendencies of the Soviet regime. Shortly before it was dissolved in 1923, membership numbered in the hundreds of thousands (Sochor, 1988, p. 8). *Symphony of Sirens* project was facilitated by Proletkult.



6.25 Left: Alexander Bogdanov playing chess with Vladimir Lenin, during a visit to Maxim Gorky in Capri, Italy (1908). Right: Cover of Lenin's book Materialism and Empirio-criticism (1909) that attempts to discredit the Machist Bolshevik's (headed by Bogdanov) dynamic-energetic materialism known as Empiriomonism.

Competing Materialisms

Prior to the revolution, Bogdanov co-authored the Bolshevik movement, together with Vladimir Lenin, named the Russian Social-Democratic Labour Party (RSDLP) until a bitter dispute over philosophical and tactical issues, lasting over two years, resulted in a Bolshevik split. At the peak of disagreements, Lenin published his *Materialism and Empirio-Criticism* (1909) a book entirely dedicated to demounting Bogdanov and fellow Russian Machists vibrant take on materialism. Especially ideas developed in Bodanov's three-volume work *Empiriomonism* (1904–1906) that had targeted Plekhanov's outdated materialism.

In the run-up to revolution another struggle was raging within Bolshevik circles over definitions of materiality and the revolutionary potentials of various interpretations of materialism. On the one hand there was the orthodox atomistic, static, interoperation of Marx's materiality advocated by George Plekhanov (considered the founding figure of Russian Marxism) and supported by Lenin. While on the other hand, a progressive sensory-energetic materiality, advocated by Bogdanov and fellow Machists (named after the Austrian physicist / philosopher Ernst Mach), incorporating the latest insights from science and philosophy, not least Einstein's discovery of the energy-matter paradigm.

Machist Bolshevik interpretations included a marked critique of atomist materiality, picking up on trends in the natural sciences that were shifting from the emphasis on classification of substances towards the study of energy and material dynamics. In the orthodox material interpretation of Marx, a fixed set of relations are ascribed between oppressed subjects (the working-class majority) and fetishized commodities (material expressions of hoarded wealth and authoritarian power). Those collective relations constitute fundamental, immutable, building blocks of social injustice. In contrast, for Bogdanov, the atomistic approach simply reflected certain structures in human cognition, which gained prominence at particular historical moments, but were in no way an expression of a universal material truth. In other words for Bogdanov the atomist materiality was one option between many other shared sensory-environmental formations. Conditions Marx had described were historically and geographically situated, they also happened to be the predominant materiality experienced by individuals in his times as well and thus sustained conditions of widespread oppression. For Bogdanov and the Machists, materials and consciousness were taken to be one continual zone of interactions in which energetic formations were at the core. Perceptions of materiality were outcomes of those dynamic interactions.

Machist emperiomonist approach intended to remedy Marx's blunt materialism by infusing it with temporal agencies of the observer that combined aspects of the German-Swiss philosopher Richard Avenarius's empiriocriticism with Ernst Mach's neutral monism, to arrive at this novel form of *Marxian thermodynamics:*

> '[…] 'energetics' is in complete harmony with the basic tendencies of Marxism [...] The principle of the transformation and conservation of energy is the ideological expression of the essence of *machine production*, consisting […] in the application of a *quantitatively-given* supply of energy for the goal of labor through the *transformation* of that energy into new forms.' (Bogdanov, 2020, p. 284)

Ultimately it was Lenin's atomistic materialist branch, that eventually took charge of tactical operations during the revolution. It seems that for Lenin it was easier to launch an attack on the solid ground of material determinism – a concept providing traction – instead of the slippery dynamics of Bogdanov's observer-dependent material indeterminacy.

Energetic Tektology

Empiriomonism had a double objective, the political twist on Mach's monism intended to work in both directions on one hand to remedy Marx's rudimentary historical materialism by infusing it with observer-centric agency while at the same time opening up Mach's abstract phenomenalism to situated social-historical causality. An outgrowth of that approach was Bogdanov's 'tektology', a cross-disciplinary science that attempted to grasp experience and knowledge of the world in its totality, defined in terms of successive organizational formations. Tektology – that shares aspects with later developments in cybernetics and systems theory – contains distinctive process-philosophy traits in its emphasis on *dynamically organizing formations*. The science was envisioned both as an observational lens and as an applied method for transitioning social structures from one formation to another.

Tektologic temporality also has marked sonic overtones. Rhyme and rhythm were understood as essential tektological agents for organizing aspects of the emerging proletarian art by synching to the pulsations of labour and other rhythms of nature and consciousness (Biggart, 2021, pp. 230–231). These aspects were also identified as general ordering principles linking workers to situated practices that also scaled-up into larger dynamics Bogdanov termed *Labor Causality*. Bogdanov energy-causality approach to perception suggests that sensations are always, in some way, determined to get work done. For example human material attentions are accounted for in their spatial-organizational structures relating to labor and exchange – something he termed *Labor Causality* – that was worked out in evolutionary, tooled and industrial narratives in the writings. An example for this was language and thinking, which Bogdanov believed were consequences of mental images coalescing with practical onomatopoeic utterances. Examples for context-specific work-utterances include 'European workers, when they need to lift a heavy weight together, cry out 'hop' or 'hop-la' at the moment of collective effort, sailors cry 'ho-hoy' when raising an anchor, and Tunisian bridge-builders cry 'ai-a' when swinging their heavy mauls down on rocks. Russian barge haulers on the Volga cry 'ukh' when they pull on a cable in unison.' (Bogdanov, 2016, pp. 15–16)

At a lecture delivered on Oct 29th, 1921 at the *Russian Academy of Artistic Sciences* [RAKhN] – an institute Kandisky was involved in setting up in Moscow – Bogdanov argues for a social utilitarian basis of all arts, with sound in a pivotal role:

> 'The beginning of music lies in labor noises with their rhythm; the meaning is the same. Among savages, a military dance, like a war song, is a tool for the preliminary organization of the forces of the collective, its "spirit", for the upcoming struggle; […] In the future, singing, music, and dancing remained and remain an instrument for organizing everyday ties, bringing units of the collective closer together in different household cells, an instrument for their emotional mutual understanding, on which the cohesion of the collective in life depends.'(Alexander Bogdanov, 1921)

In Tektological terms, social-political structures were understood as natural, evolving, formations made up of amalgamations of bodies and substances, undergoing energetic exchange. The process-oriented theory was steeped in universal principles of oscillation, pulsating with collectively experienced 'waves of attention' (Bogdanov, 1984a, p. 10):

> '[…] periodic oscillations or "waves" are the most widespread method in nature of preserving or restoring equilibrium. This is a kind of general model for innumerable processes of the inorganic universe from the […] waves in the air; heat vibrations in hard bodies; electrical, light, and "invisible" rays ranging from Hertzian waves to x-rays; and at the other end of the universe, the "rotation" of the heavenly bodies, can all be conceived as complex periodic *oscillations* […] this model is also applicable without limit to the realm of life; almost all of the life processes are of the periodic *oscillating* type. Such are the pulse and breathing, work and rest, and the vigilance and sleep of organisms. The replacement of generations represents a series of *waves* superimposed one upon the other*;* it is the real "*pulse of life*".' (Bogdanov, 1984a, p. 09, my emphasis.)

Hearing cities (along with their social-political structures) as naturally pulsating metabolic formations is a theoretically informed mode of listening that may or may not have been present in Baku during the *Symphony of Sirens.* Even if it was, that mode must have dissipated quickly with the onset of dogmatic material determinism. After Lenin's death in 1924, Plekhanov's dull materialism finds its ultimate expression in the hollowed-out monuments of socialist-realism whose unambiguous narratives, forced optimism, delusional idealism and monolithic presence can only be understood as static material watchdogs, installed in public space to ward off ideological decent.

The study of Tektology was discouraged under Stalin and eventually forgotten. And maybe for the better, as the second edition of book (Moscow, 1921) opens with an emphatic, yet highly questionable, evolutionary trajectory culminating in a celebrated human domination of nature exemplified in armies of coordinated workforces collectively applying energy-conserving principles of universal organization. Utopian expression of *Labor-Causality* in material formations (Bogdanov, 1984a, p. 01).

Blood-Red Star

6.26 Left: Alexander Bogdanov's science fiction novel Red Star (1908) describing a visit to a utopian socialist society on Mars, with advanced scientific and technical knowledge such as rejuvenating blood transfusions, capable of doubling Martian life expectancy. Right: Propaganda poster for blood donations with the caption "To be a donor is a great honor for the patriot!" (1941).

One year prior to Lenin's publication of *Materialism and Empirio-Criticism,* aimed at demounting the Machists, Bogdanov published his own Bolshevik book titled *Red Star* a science-fiction novel describing a highly advanced socialist Martian society on Mars visited by the astronaut Leonid who is caught up in the pre-revolutionary socialist struggle on earth. The socialist utopian fable — set on the red star Mars — casts the Martian landscape as a trip to Russia's imagined distant future after a successful social and advanced scientific-technical revolution.

In the novel, the traveller Leonid, confronted by experiences of the revolutionary ultra-organized, technologically-driven utopian society on Mars, eventually succumbs to mental shock, much in the same way the actual revolution impacted the poet Blok. Contrary to Block's diminishing hearing, Leonid's trauma was accompanied with acute auditory (and visual) hallucinations, hearing fellow humans calling back from a distant, absent, earth:

> 'I had been bothered for some time by a noise in my ears, but now it became so constant and loud that it interfered with listening to phonograms and deprived me of the little sleep I was able to get at night. From time to time the noise would become more articulate and I would distinguish familiar and unfamiliar human voices. At times someone seemed to be calling me by name, sometimes I thought I heard conversations but could not make out the

> words above the noise.' (Bogdanov, 1984b, pp. 89–90)

At times, auditory hallucinations intensified, materializing as snippets of urban hubub:

> 'A passenger would haggle with a cab driver, or a salesman would urge a customer to buy some cloth; once I found myself in the middle of a noisy university lecture hall, and I could hear the voice of an administration official telling everyone to quiet down, because the professor would be there any minute.'(Bogdanov, 1984b, p. 91)

Compassion from a Martian named Netti, and ample rest, eventually cured Leonid's paralysis. Medication could be administered due to differences between human and alien physiology though Leonid took a keen interest in advanced alien health treatments, especially a procedure involving rejuvenating blood transfusions, doubling Martian life expectancy. Leonid's temporary paralysis was not only the result of psychological duress but also physical circumstances stemming from inabilities of his earthly body to properly regulate fluids in the extreme planetary conditions. Martians on the other hand were fluid experts, knowledge they applied to pioneering methods of blood transfusion.

Some years after the actual Russian revolution, Bogdanov founded the Institute for Blood Transfusion, housed in the former merchant mansion (Igumnov House) in Moscow where he, his wife and son also took up residence. The institute followed up on certain hemoglobin intuitions laid out in the novel *Red Planet* also appearing in later theoretical writing. The book *Essays in Tektology* describes a toxin cleansing blood transfusion procedure understood in terms of a tektological contra-differentiation approach. The chapter titled *The Tektology of Struggle Against Old Age* concludes that 'an interchange of blood must lead to a deep cleansing and refreshment of the organism, to a liberation of the organism from specific internal poisons harmful to it' (Bogdanov, 1984a, p. 156). The practice involved infusing the elderly with youngster blood.

Bogdanov subsequently died of kidney and liver failure in a botched blood transfusion, during a rejuvenation experiment he performed on himself, involving blood from a 21-year-old Moscow University student harboring an inactive form of tuberculosis.[16] However, some scholars maintain it was a premeditated death, similar to the services provided in 'suicide rooms' also described in the *Red Star* book chapter titled 'Hospital'. The Institute for Blood Transfusion eventually morphed into the National Medical Research Center for Hematology, while the merchant villa where Bogdanov performed the initial experiments is now home to the French Ambassador to Russia.

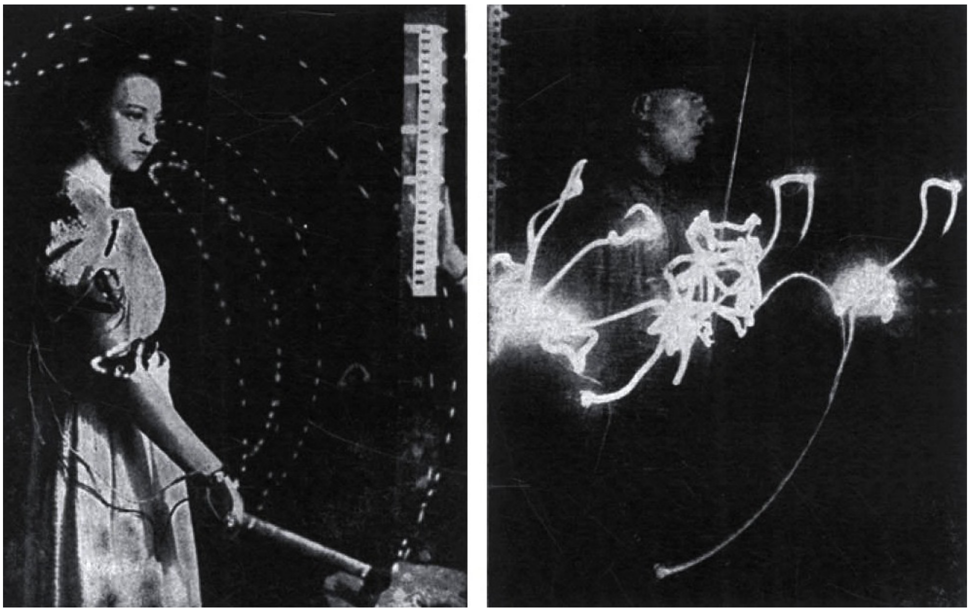
Crossfade

Wails of factory sirens across Baku signaled the opening and closure of the performance. The city was engulfed in sounds. Citizens were called to participate in the spectacle marching and singing en masse, though just how much participants heard that day, or comprehended what they were hearing, remains a matter of debate (Schwartz, 2020, p. 64). The din also intended to silence ethnic diversity – a diversity that was characterized by intermittent outbursts of ethnic violence, especially between the Azeri and Armenian populations – through imaginations of shared industrious futures. The ethnic diversity of audience-participants, mostly workers from refineries and the oil trade, consisting of Armenians, Georgians, Azeris, Iranian Azeris and Russians, was momentarily homogenized under the trill of Soviet might. Hearing industrious cities as cacophonous unity exposes an understated ideological dimension in Soviet listening that was expressed in nascent form in dialogue of Mayakovsky's *Mystery-Bouffe* during the first anniversary of the revolution: 'We don't have any nations. Our labor is our homeland.' (Mayakovsky, 1918)

By the time the Baku performance took place, Alexei Gastev's meandering mythical siren from the

16 For a detailed discussion of Bogdanov's socialist blood imagination see Krementsov, N. *A Martian Stranded on Earth: Alexander Bogdanov, Blood Transfusions, and Proletarian Science*. Chicago, IL: University of Chicago Press, 2011

Poetry of the Workers Blow (1918) had morphed into pragmatic Laban-like choreographic notations of actual factory workstations in his illustrated 1923 book titled 'How to Work'. Gastev's enthusiastic embrace of American Tylorism and Fordism (supported by both Lenin and Trostky) translated to meticulous analysis of assembly-line worker movements through photographic and drawing techniques borrowed from Etienne-Jules Marey body-motion studies of the late 19th century, applied to specific Soviet manufacturing needs. Moscow's Central Institute of Labor (TsIT) (Центральный институт труда), founded and headed by Gastev in 1920, was dedicated to improving industrial efficiency through analysis and modeling of workplace motions such as the pounding of blacksmith hammers (Gastev himself was a skilled blacksmith) but also motion analysis of cello and piano performers. Vertov's film *Enthusiasm* includes intercut footage of choreographed worker movements developed by Gastev's Central Institute of Labor and actual coal miner movements at work in Ukraine's Donbas mines. One section in Gastev's book 'How to Work' compares the assembly line muscle training of that of musicians, dancers and athletes and goes as far as proposing workforce muscle training commence at the tender age of two, through specially designed children's games incorporated in preschool educational programs (Alexey Gastev, 1923, p. 52).



6.27 Worker motion efficiency studies c. 1924, conducted at the Moscow's Central Institute of Labor (TsIT), founded and headed by Alexei Gastev in the early 1920's, a few short years after the publication of his Poetry of the Workers Blow (1918). The institute was dedicated to improving industrial efficiency through biomechanics studies and approaches to human-machine hybridization. Analysis and modeling techniques of bodies-at-work were borrowed from Taylor and Gilbreth's time and motion studies of American industrial production applied to specific Soviet manufacturing needs, such as the pounding of blacksmith hammers but also motion analysis of cello and piano performers.

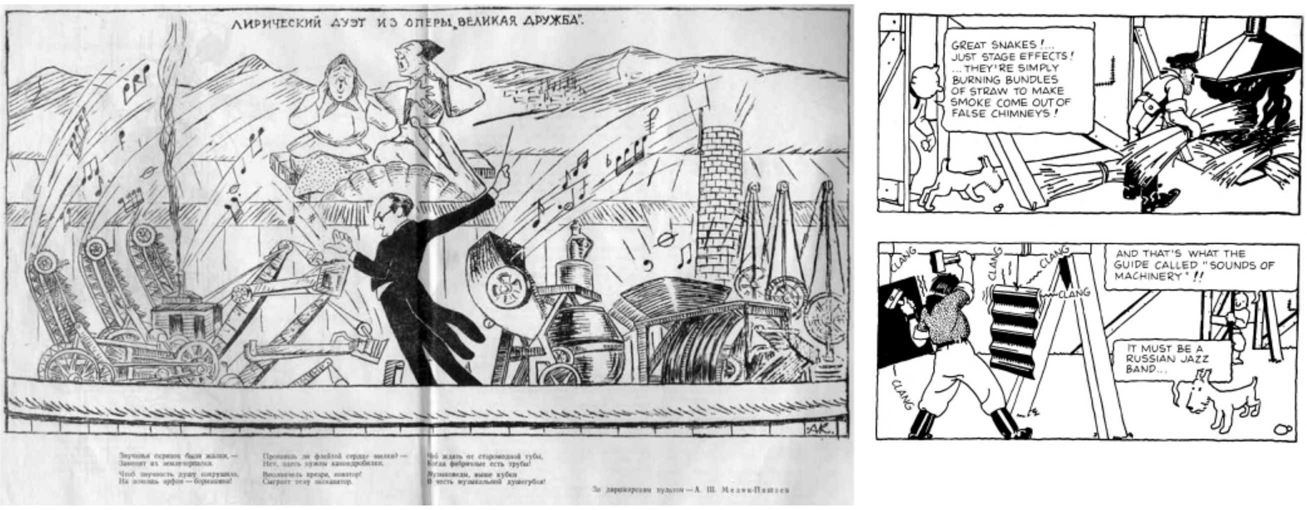
In Gastev's strict interpretation of American Taylorism, the slam of the hammer was no longer heard acoustically but rather as a mute gesture that participates in a larger score of movements choreographed by Soviet production. Hearing the intangible collective gestures of nation-wide synchronized working bodies is a totalizing expression of the human-machine-culture sentiment as it gets systematized and institutionalized by means of centralized control.[17] By that time the recourse to factory music is all but gone from the narrative. What are left are trajectories of productive motions as a means and ends in themselves.

Sounds of labor subsumed in a general rule of energetic efficiency recalls an earlier Bolshevik preoccupation with 'energetic' theories the German chemist / philosopher Wilhelm Ostwald who elevated the 'law of conservation of energy' to an evolutionary status. If developments in organisms stem from efficient use of energy, then the history of civilization could be understood as advances in coordinated

17 For an account of how culture is entirely subsumed in a narrative of labor, see Alexei Gastev's 1924 publication *New Cultural Setting*, http://www.togdazine.ru/article/1996, accessed Feb 6, 2022

administration and application of energy.[18]

By the time of Vladimir Lenin's death in 1924, functions of the siren were again in flux, morphing from music into expressions of public grief during. During Lenin's funeral the trill of nation-wide factory sirens and steam whistles accompanied the traditional cannon and gunfire shots reserved for the departure of public dignitaries. Lenin's expansive burial moan was discontinuous and fragmented over the vast scale the Soviet Union. Its cumulative sound, like Gastev's totalizing sounds of production, could only be heard ideologically. Each set of ears, confined to hearing proximal acoustics, had to imagine the rest of those sounds extending into an incomprehensibly vast, and politically homogeneous, space (Figes, 1997, p. 805).



6.28 Left: Lyrical duet from the opera The Great Friendship. Cartoon in Sovet-skaya muzika magazine, No. 1, 1948. "Violin has no choice – It is replaced by dredger's voice. / To break a soul with sonority A drill extends the harp's authority. / No flute will pierce the darling's heart without stone-crusher's stab. / Despise the cello, innovator! The theme be played by excavator. / What to expect from old tubas, When plants and factories have hooters? / Hey musicologists, lift up your cups, For the musical mass-murder-bus!" (Illustration reproduced in Smirnov, "Generation Z : Renoise", CTM Festival exhibition, Berlin, 2014). Right: Excerpt from Tintin in the Land of the Soviets (1929), the first volume in the comics series by Belgian cartoonist Hergé, where Tintin and Snowy uncover the sounds of Soviet industry as a sham.

By the 1930's celebratory factory sounds had become a clichés, heard outside the Soviet Union with increasing skepticism. In a series of illustrated panels published in the children's edition of the conservative newspaper *Le Vingtième Siècle* the Belgian illustrator Hergé depicts the strip's hero Tintin unmasking the symphony of factory sounds as a sham. Inside an empty factory hall, the industrial soundtrack is revealed as cinematic foley, performed live by an 'experimental Russian jazz band'. Propaganda sounds were understood as smokescreens, diverting attention away from unfolding realities of poverty and hardship under Soviet leadership.

Russia's administration was also showing signs of aural fatigue. Tensions around the misplaced musicality of experiments with industrial sounds came to a head in April 1948 when the 'Resolution of the Political Bureau of the Central Committee of the Communist Party' published a scathing review of The Great Friendship, an opera by the composer Vano Murdadeli, in the newspaper Pravda deeming the piece anti-artistic formalism. Andrey Zhdanov a vocal member of the Political Bureau likened the music of Sergei Prokofiev and Aram Khachaturian to sounds of a dentist drill or a 'musical murder bus'. Soon after the congress of the Organizational Committee of the Composers' Union communist party functionaries replaced key positions, hand picked by Stalin and Zhdanov. The general secretary chosen at that time held his post for 43 years until the collapse of the Soviet Union in 1991 (Smirnov et al., 2014, pp. 68–69).

During Stalin's totalitarian rule, cultural experimentation – of the kind witnessed in the early days of the revolution – had become a personal liability. By that time cultural enthusiasm with sirens have been displaced by functions of civil defense especially after the introduction of aircraft and ballistic warfare

18 See Bogdanov, A. *The Philosophy of Living Experience: Popular Outlines (1923)*. Historical Materialism Book Series, volume 111. Leiden ; Boston: Brill, 2016, p. VIII and Ostwald, Wilhelm. "The Modern Theory of Energetics" *The Monist* 17, no. 4 (October 1, 1907): 481–515. https://doi.org/10.5840/monist190717424. pp. 510-511.

6.29 Propeller-driven sirens fitted on the main gear legs of the Luftwaffe dive-bombers, widely known as Jericho-Trompete (Jericho trumpet), accentuated plane dives with a distinctive wailing noise that become the signature sound of the German Blitzkrieg. Similar mechanical sirens can be found today in early-warning air-raid systems common to city infrastructures. Film still from a Luftwaffe dive-bomber sequence in The Battle for Oil (dir. S. Legg,1942), National Film Board of Canada.

where an unrealized airborne siren project of Avraamov's titled 'Topographical Acoustics' (1923) (Smirnov & Kloptsov, 2017) morphed into the terrifyingly real Jericho-Trompete sirens of Luftwaffe dive-bombers over the Ukraine during the Third Reich's failed push for Baku[19].

Geospatial territorializing functions of blasts as well as sirens continue circulating earlier artillery ontologies of sound intersecting with a particular historical moment and locale. The incorporation of socio-political sounding techniques into cultural agendas is part of that moment. So are the shifting ontologies of the siren, phonograph and radio, diverted from their initial calibrations and taking on alternate agencies markedly different to their normative functions elsewhere. At the urban scale, momentous city sounds encapsulate shifting relations between geopolitics, systems of social governance and an emerging aestheticization of politics common to communism and later fascism and other totalitarian regimes. In the example of Baku, the staging of a city-scale avant-garde spectacle outside the typical hubs of the historical avant-gardes underscores agencies of the orchestration: the celebration of communist advancement, in the midst of a rapidly modernizing urban hub at the periphery of the Soviet Socialist Republic at a time when Socialist expansion was focused on strategic peripheries. The intersection of the Caucasus Mountains and coastal territories of the Caspian Sea was a critical node at the time, reenergized by the global oil trade, in a city whose commercial and strategic relevance extends back to the days of the Silk Route as the gateway to Asia and the Middle East. In perceptual terms, the event demonstrates Bolshevik avant-garde modes of hearing sirens differently. But also importantly closes circuits with previous tactical modes of hearing as well as broader perceptions of hearing the musicality of modernizing cities.

In a more general sense, Baku's symphony tests the acoustic potentiality of large-scale social/political orchestrations and the role of the *city*, as a form of collective media, capable of facilitating a variety of cinematic, political and festive formats with equally diverse performative outcomes.

Globalized Pressures

Fast-forward to February, 2022. The Kremlin commenced a large-scale offensive on neighbouring Ukraine, closing in on Kyiv, Kherson and Mariupol with brutal force. Across the country, air-raid sirens sounded the alarm. In an eerie replay from Bogdanov's book, passing through a complex tektology of post-Soviet repercussions 'the command of the most insignificant individual has directed millions of people into an unprecedented hell of iron and dynamite, of murder and destruction.' (Bogdanov, 1984a, p. 02) Nearly

19 Siren infrastructures are integral to modern built environments, functions that carry-over from airborne warfare and other threats from above. Their territorializing agencies are still audible today when tested on a regular basis. Civil defense air-raid sirens sound every first Monday of the month in the Netherlands & Finland and first Wednesday of each month in France & The Czech Republic. In Austria a 15-second siren tone is played every Saturday at noon. In Israel the air-raid network sounds every Friday, ringing in the Sabbath.

concurrent with the incursion, Storm Eunice swept across mainland Europe, with hurricane-force winds and record-breaking gales wreaking havoc in its path.

What is increasingly heard today are double commotions, stemming from polarized political rhetoric and unprecedented outbursts of precipitation, playing out in a variety of urban locales. These seem to be the noteworthy urban sounds of our times: globally distributed social and political unrest interleaved with the sounds of environmental turbulence. The emerging sonority of flooding promenades, tree crumpled cars, bursting riverbanks, brushfires, rattling shingles and corrugated roofs, suburban mudslides or swarming courtyard insects, all of which get amplified on the backdrop of petrified cities in pandemic lockdowns. This emerging flood of sounds, that was partially ignited by the now inaudible emissions from Baku pump-towers, is a far cry from Mayakovsky's allegory of revolutionary Deluge (*Mystery-Bouffe*,1918) or Gastev's 'red tide' metaphor (*Horn-Siren,* 1918) – that has since descended from the sky to form actual red tide blooms of toxic ocean algae. Listening today requires a different hearing. Not of revolution but instead a listening tuned to the complex, multi-scalar, poly-temporal coevolution.

6.30 Fallen trees in the wake of Storm Eunice, Amsterdam, February 19, 2022. (Photo by author)

Fluctuant Futures

Paying attention to this emerging urban sonority is a way of physically becoming acquainted with pressures of these times. Pressures arriving simultaneously from anthropocene weather and political precipitations, intimately striking emotive chords that reflexively veer towards trepidation. But there is another, more fundamental affordance in listening to these pressures that needs to be approached with calm resolve: adopting a listening that actively seeks to unsettle pervasive attentions tied up with bankrupt sensations of materials and surrounds that have accumulated in the current impasse. For example disrupting universalized material perceptions linked with impressions of sovereignty and extraction, and fostering instead, situated attentions of contextual reciprocities. On that front, alliances with specific models of materiality still matter (as they did a century ago) and what has become increasingly apparent is the urgency of materialising more interlinked, interdependent, porous, fluid-energetic, reciprocal impressions of subjectivity and surrounds. Adopting other ways of listening can assist, though inevitably the experimentation persists. It is an unending reaching towards the other spaces and unknown agencies of evanescent surrounds. Accommodating the incoming pressures and fostering intimacies with their complex relational realities, attends to aspects of that dazzling dynamics where observers, sounds and surrounds, always, each time differently, emerge simultaneously entwined.

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Chapter 07

Sound Operation Circuit

Sound Operations

Every sound already manifests meandering interlocking trajectories of spatial agency and contextual dynamics.[1] Curiously though, those itineraries are not readily apparent in the sounds. In order to observe sound's activities requires sounding its *qualities*, taking its manifestations as *sites* and observing its operations as *circuit*s. Sound circuits provide access to semblance domains where the dynamics of entities-in-the-making can be observed.

Sound's spatial-material appearances reveal its *situated operations*. By focusing on the contextual circuitry of sound an entirely different *dynamics* opens up, far exceeding the motions constrained to its waves. To observe sounds actions requires converging with its flows, following diverse travelogues of context.

Operational sounds are circuitries of the extant.[2] Each instance presents its own unique case with quirks and dazzles that cannot, and should not, be generalized. On the other hand, there are tendencies of action and behaviours of dynamics that recur in sound circuits. Closer observation of the mechanisms and infrastructures of sonic eventfulness provides guidance for reading sound's particularities. This section of the thesis attempts to open up some traits of sonic agency and in doing so provide tools towards more robust, detailed and inclusive accounts of sound's being. Unpacking sound's *operational spaces*, *contextual agency* and *terrestrial circuitry* are paramount to that approach. The list is far from exhaustive, but it aims to provide some foothold into sound's operational expanse.[3]

In the current epoch there is a growing urgency of attending to interlinked, interdependent, porous, fluid-energetic, reciprocal conditions of terrestrial milieus. Observing spatial-material qualities of sound and tuning into its contextual infrastructures provide crucial interlinks.

Sound Circuitry

When attempting to qualify a sound, one shouldn't ask what it *is* but rather what it *does*. Sound operates. Its operations involve contextual circuits. These circuits are integral to the processual extant. Sounds are movements with qualities that persist, seemingly escaping the motions bringing them about. This is not a contradiction but rather a central *mechanism* through which sonic spatial-material specificity comes about.

Every sound already arrives with distinctive spatial-material features. Its attributes are conditional of its appearance. Sound circulates agencies through qualitative specificity. Sonic qualities are expressive of circuit operations where its shifting qualities perform dynamic assemblages of context. Qualities operate. They reflect intricacies of the circuit and sense their operations. Identities, qualities, spatial characteristics observed in sounds are real, though their properties remain tightly bound with more expansive interlinked movements. Situated qualities are also calls to action, ensuing further operations in the expanse. Nothing escapes this ongoing dynamics. Anything and everything may participate in sound's circuitry from forces and signals to materials, artefacts, subjects, places and knowledge – just as long as they circulate along interlinking pathways that give rise to subsequent movements, and their configurations are productive of discernible

1 Throughout the text, the plural 'dynamics' is used to highlight the diverse relational interactions that give rise to a variety of dynamic categories associated with qualities of the extant. The singular 'dynamic' implies a single overriding principle, which is not the case in mechanisms of the manifest. Instead, the text argues that the diverse formations of sounds occur in the draw of contextual constraints, exhibiting a variety of arrangements with differing dynamic traits.

2 The word 'extant' aims to provide a synonym for existence that emphasizes the dynamics *in* presence, hence the noun-ing of the adjective.

3 The word 'expanse' denotes the full reach of intermixed movements in processual actuality, with emphasis on its expanded and emergent spatiality.

effects.

Attention circuits foster spaces, materials and times through ever-changing currents, augmenting agencies of flux. Appearances that mediate also participate in the characteristics they dynamically bring about. Their forms perform. Materiality is a habitat for actions. Not all of those materializations are accessible to the incidental observer, and sentience is not always the addressee. Yet some of the ongoing exchanges escape their primary spaces of action resurfacing in incidental resonances or in the general radiance of a locale.

The collective movements of events, energies, vibrations, sounds, impressions, ideas, and residues are heterogeneous territories of shifting, interweaving dynamics perpetually active in the extant. Observing sound's spaces of action and the related contextually circulating attentions provide glimpses into that dynamics.

Spaces of Sound

There are multiple spaces in an auditory event: in the relations between subjects and objects, between vibrating air molecules, between sequences in an oscillation. All these spaces somehow manage to wrestle themselves loose of their initial agitations, yet each example seemingly resides within its own independent, mutually exclusive, relational space. However, there is no common 'vibrational space' from which sonic dimensionality emanates and to which sounds eventually return. Sounds materialize and propagate through a broad range of spaces — besides acoustic territories — such as audio mechanically transduced onto vinyl or travelling over copper wires and fiber optic cables. Some sounds even propagate silently, through written text, without ever budging from the space of a screen or page. Written sounds also sound, though in manners that cannot be monitored on audio technologies.

Commonplace definitions of sound as a series of longitudinal pressure waves propagating through compressible media (e.g. air, liquids, solids), no doubt present a space where vibrations can reside, though the rise to prominence of *that* specific sound-space has its historicity. Calculable wave-space is tied to universalized presumptions of matter, scaled up through technical and tactical industrial production that should be approached with a measure of caution. Otherwise, how are we to understand the multitude of other interlinked movements, materially and anecdotally involved in adjoining spaces of sound, such as redistributed human-made minerals in earth's crust directly tied with the universalized wave-space modelling of sound? Minerals such as piezoelectric crystals, ferrite, and rare-earth neodymium magnets, central for production of vibration-coupling transducers such as sensors, loudspeakers and microphones that today more than likely outnumber the sum total of human mouths and ears on earth. The cumulative force of abstract universalized wave-space may in fact be empirically measureable through a stratigraphy of anthropogenic transduction deposits across worldwide landfills.

A key to sound's ontological pluralism is that it always *specifically* appears (haecceity) and furthermore that such specificity is *always* nested in implicit material, spatial and possibly temporal confines. Diversities of sound's manners of appearance also hint at its myriad ways of being. Variations in perceived extensity of sound reveal differing spatial ontologies of fluctuation. Sounds open into polyphonic, at times discordant spaces reflecting concurrent and potentially incommensurable worlds. Space in general — and sonic spaces in particular — are emergent *properties* of relations they involve. And those relations can be many in sound. Complicating things even further, once emplaced, sound's forces get diverted elsewhere, on alternate pathways, through alternate agencies manifesting in other movements of disparate domains.

Sound-Space Context

Sonic-spatialities are heterogeneous, intermittent and *contextually* constituted materializations of sound. Context is sound's circuitry. Far from being inert backdrops, contexts produce dynamic fields of agency actively present in every moment of hearing. Contexts *conduct tendencies* of movements in the expanse, providing space for sounds' operations. Each contextual dynamic spawns slightly divergent spatial characteristics. For example, the space of *acoustic waves* versus the space of sound's *perceptual* identities present two contrasting spaces sharing an energetic expanse. Context is hard to pin down in the abstract as it can only be gauged in relation to its operations. When entangled with observations, its clustering contexts often cut across diverse subjects and domains.

Sound-Space Scale

Spatiotemporal materialities of sound organize their operations. In other words, every qualification of sonic materiality is already spatialised within the limits of its operational scope, keyed on actions in its corresponding surrounds. The catch is: sound's spatial determinates are themselves indeterminate due to the instability of the processes through which they arise. As contexts cluster and recombine — an essential property of sound's becoming — determinates determining 'determined space' continually evolve, especially in the social milieu. So do relations amongst, and presence of, various subjects active in a circuit.

Operations provide spatial *scales* and agency in context. To understand a scale of a given sound-space, one must first grasp the scope of its context. Refracting sounds back at their features provides hints of their formative contexts. Sound-spaces do not express linear scale progressions common to geometric or quantized space (e.g. small-to-large, slow-to-fast) but rather scale to their situated configurations. Temporality, too, likely synchronizes with agencies of a context, beating time in rhythm with native domains. Scales and rates of sound-spaces mirror their territorial responsiveness.

Relational Spatiality

Sounds are inherently relational, they have influence on, and are shaped by, the contexts within which they operate. Sounds provide armatures for endured relations: of the frictions providing them structure; of the mediums they traverse and waymarks encountered along the way; of the entities they relationally bind; of substances they activate and attentions they bind. Sounds never occur in isolation, and when they appear as such it's due to constraining factors of their circuits (such as propagating through anechoic chambers). In other words sound is not ever a thing in itself but are rather roadmaps of situational orientations and dynamic configurations.

Acoustic sounds exhibit relational spaces through the correlation of frequencies, distances and environments. The propagation of acoustic waves is closely related to the physical dimensions of the frequency, which are influenced by the properties of the propagation medium and environmental conditions. For instance, a single frequency cycle of the note 'A' (the sixth note of the C major diatonic scale oscillating 440 times per second) is 78 cm long when measured at sound's conventional speed in air of 343 m/s.[4] However, in seawater, this note expands more than four times to a length of 341 cm due to the increased propagation speed of sound in the ocean.

In fact, even in the open air, the note 'A' is not typically encountered at its standard 78 cm textbook definition due to fluctuations in temperature, humidity, wind, and elevation, which are inevitable outdoors. The speed of sound in a medium is dependent on the density of the material, which in turn depends on the temperature, all of which are deeply relational to terrestrial constraints, which are again relational to the speed and position of an observer, when determining a resultant pitch.

Spatial Qualities

Sonic qualities emerge from eventful in-situ processes. Space is one such quality. Space denotes directions and operation. The spaces and materials heard in sound are domains of situated relations. Sound is relational to the extent that it entails interactions among various components of a circuit. To 'hear' is to participate in relations and in doing so also assist in making them other. Hearing engages movements and also partially alters their courses of action. Conditions of sound endowed with material qualities, spatial properties and temporal dynamics indicate diverse relations as well as ascribed territories of action. Contextual

4 440 Hz corresponding with a 78 cm length is calculated at sea-level with an ambient temperature of twenty degrees Celsius.

circuit operations inform sonic properties, providing sounds with signature qualities. Those qualities in turn perform agencies that feed back into movements of the extant, potentially giving rise to other contexts and other spatial-material emanations. Sensory attentions sustain contextual flows. They are vortices in vast circulatory configurations, such that when attention shifts so do the contextual assemblages. As energies traverse terrestrial expanse, encountering interfaces of *refraction-transduction*, their sounds multiply and with them the spaces and contexts of operation.

Sounds do not reside *in* space, sounds *are* spaces taking place. Sounds *produce* space dynamically. Sound-spaces are characteristically tactile, malleable, fluctuant and occasionally pulsed. There is no vacant sound-space, when a sound ceases so does its space. Spatial configurations, orientations and extents reveal sound's *operations*. There is no containing space for sounds, no singular native 'acoustic space' where vibrations dwell from which the rest of sonic spatiality can be derived. Instead, there is rich heterogeneous agglomeration of overlapping, nested, complementary or contradictory sonic spaces reflecting equally dazzling contexts and sensations at play.

Fluctuant Emplacement

Locational properties of sound arise from in-situ interactions; there is no generalizing sound's emplaced formations, no guiding principles to the inexhaustible manifestation of sound-space. Space outlines sound's possible relations and potentials in its surroundings suggesting fields of activity, courses of action and manners of movement. Just as other spaces, sound-space imposes relational logic embedded in tectonics of its formations, permitting certain movement-logics to take precedent over others. Sounds provide a wide-range of spatial typologies, spanning from quasi-Newtonian object-retaining spaces to turbulently elastic shape-shifting wonders.

Some of that spatial diversity can be corporeally inhabited. When listening to an echo, sounds appear distinctively separate. Sound-things travelling about *inside* seemingly enclosed empty space. On other occasions, when listening to resonance, structural features of discontinuous objects seemingly melt into one another, producing an interlocking presence challenging their disconnected optical confines. Imagine a distant airplane rattling a nearby windowpane. Occasionally space itself seems to emanate form within undulations of ongoing oscillations as experienced when walking through the palpable, pulsating, fluid architecture of standing wave interference patterns taking shape inside buildings. Each configuration responds to differing spatial logics, providing varieties of movement and sustains.

Participating in sound's spatial diversity — observing echo, merging with resonance or swaying with oscillations — transforms perceptions of an event's locale while also subtly reconfiguring subject/object divides. Attending to sound's spatial logic provides partial mapping of its operational extent as well as a roadmap towards possible modifications.

Attention Circuits

Perception often has been mistakenly portrayed as a one-way flow, where energy passes on from stimulus to receptor to the perceptual apparatus, the final destination, within which impressions then arise. If, on the other hand, perception is taken as a *circuit of relations,* linking subjects to surrounds, then an entirely different impression of perception arises, understood as a *system* or *environment* of reciprocal exchange. Sensed sounds are not an endpoint of perceptual representation, barricaded within an isolated subjective space, but rather essential components of subsequent mobile and lively interactions. Impressions seemingly belonging to an object are in fact neither fully contained *in* the object nor sealed off in impressions of the mind. Their qualities are rather *relational agencies* of *contextual conductivity* native to a given attentive circuit.

Features that attract attention are nascent action-functions in search of conductive pathways through their native milieus. Attentive qualities are endowed with agency that invites future motions. Qualities function as connective relays, providing situational conductivities and spatial orientations in activated circuits.

Physiological structures in the organism, electrochemical biological pathways, conscious and unconscious meanings, environmental features and affordances are all part of a continual, malleable interconnected *terrestrial circuitry*.

Modes of Hearing

Repeating attentions engrain and recursively enhance anticipated perceptions. Attentions tuned to resonate are akin to resonance modes of physical systems, though perception's modes are malleable. Modes of hearing express repeating attentions often adopted in shared social domains. Modes facilitate categorizations and grouping of sounds based on perceptual consensus pertaining to discerned commonalities. Shared modes demonstrate cohabitations of contextual sound circuits, activating rehearsed attentions (conscious and unconscious), patched through selective meanings, modulated by expectations and often ballasted by dedicated technologies and techniques. Configured modal attentions can include listening practices, historical moments, technological and geographical constraints as well as subjective topes, coalescing in distinctive manners of hearing sounds in categories of meaning. Configurations in a mode of hearing are conditional to their circumstantial appearances. Like sounds themselves, modes are essentially situational and inexhaustible. Hearing tends to cling to familiar modes in the same manner that habits cling to routines. Breaking a hearing habit opens paths to discovery of sounds unheard. Hearing in multiple simultaneous modes provides numerous vantages onto fluctuant events, opening up differing aspects of eventful surrounds.

Urban Modes of Hearing

Modes appear in conscious as well as unconscious states of attention, resonating nascent attributes so that they stand out from other respective qualities. Some modes are carefully fostered, as for example, diagnostics modes practiced amongst physicians and car mechanics. Other modes appear haphazardly, as if the environment itself practices its inhabitants. Vibration-shaping landscapes, resounding geographies as well as built environments produce complex *aural agencies*. Cities are expansive *audio technologies*, their calibrations manifest incidental resonances, at times appearing unexpectedly, notably in musical practices.

Ambient Selective Attention

Sentient attentions are borne in tangles of mechano-tactile and electro-chemical nervous circuits, interlinking organisms and expanse. Functions underlying electrochemical and transduction circuits of the body can also be found in more general dynamics of the extant. Electrochemical interactions of geobatteries or mechano-tactile piezoelectric mineral transductions suggest that aspects of animal attentions may overlap or coincide with less apparent inorganic or geological attentions.[5] Sensory techniques employ mechanisms native to elemental physical/chemical activities, possibly borrowed from inorganic domains. The use of tools modifies connectivity, repatching linkages of the energetic expanse.

5 A brief passage in Henry Bergson's book *Matter and Memory* (1896) discusses attention in terms of its choosing capacities, a 'force that provokes [specific] reactions', readily observed in plants absorbing selective nutrients from the ground. A similar force was recognized in abilities of hydrochloric acid to 'selectively' pick out the base when combined with carbonate of lime, regardless if it's in marble or chalk (Bergson, 1988, p. 159, orig. ed. 1896). Another example is the attention a copper spool maintains towards electromagnetic fluctuation. The coil's selective attention to frequency nests in its wire and windings. Copper coils tuned frequencies by gliding a conductor along the length of a coil, tapping the windings to dials in a station's carrier frequency corresponding to the coil's resonance properties. Mach argues more general equivalences for physical processes and perceptual states 'our hunger is not so essentially different from the tendency of sulphuric acid for zinc, and our will [is] not so greatly different from the pressure of a stone'.(Mach, 1919, p. 464 orig. ed. 1883)

Sensation Clusters

Inorganic Sensation

Sensations are conditions through which qualities arise. If qualities present the features and specificities of an event, then sensations denote underlying *connective configurations* producing particular effects.[6] Sensitivity is a fundamental principle of the extant, possibly more general than motion. Embracing a broadened organic-inorganic approach, sensation processes are understood as *tendencies* of the extant, emerging where fluctuant interchanges abound.

Interference patterns found in vibrational phased-space (the locale of acoustic waves) may be an example of pre-auditory sensation complexes, through the manners in which molecules engage and imprint traces of traversing flux. Schlieren photography opens spaces into that remote fluid dynamics. What are Chladni patterns if not snapshots of qualitative states, organically inert, yet intricately featured unfolding sensation complexes?[7]

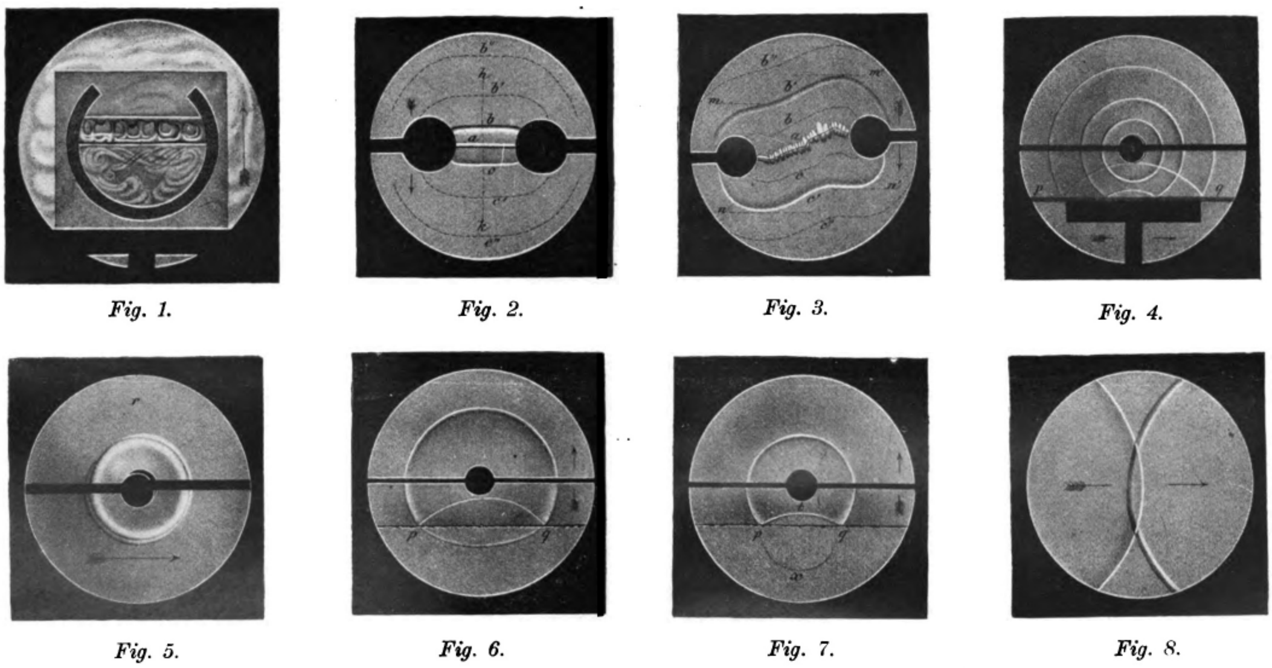

Figure 7.1 Pressure-wave interactions from spark-gap discharges in various reflection/refraction configurations. Images produced by Schlieren photography, a method developed by the German physicist August Toepler to visualise fluid dynamic in mediums such as air. Sequence from A. Toepler's book Beobachtungen bach der schlierenmethode (1906).

Aspects of perception share commonalities with other features of the extant by providing temporary habitats for energies and agencies traversing the expanse. As vibrations carry-over they accumulate incidental sensations, joining in on the travel. The terrestrial expanse is saturated with crisscrossing negotiations escaping their locales, all nesting within one another. Shared sensations transform attention, eventually altering features of the extant. Coevolution is a prime example that performs aspects of expansive sensations intermingling.

Hearing Long-distance

When attending to sounds from great distances — rumbling infrasound transmitting halfway around the globe, or, the tangle of earth's telluric currents — their signals arrive saturated with additional presences.

6 Ernst Mach briefly brings up the question of inorganic sensations but then diverts by stating that it is a questions without scientific significance (Mach, Ernst, 1914, pp. 243–244). Arguably, if such questions *were* asked, then other manners of empiricism could take shape.

7 For a more detailed discussion of acoustic phased-space as a category of inorganic sensations see (Ganchrow, Raviv, 2010, p. 188).

Distant sounds interleave multiple encounters cohabiting the same expanse. The remote listener, often unknowingly, shares senses with other places and times, enacting immediacy from the nonlocal and diffuse. Hearing takes part in those ongoing conglomerations of intermingled being. The paramount question is what's kept in attention? And how does attention corroborate with the distant and remote?

Noisy Signals

Noisy signals are quintessential domains for hearing ambiguity. They demonstrate pluralist milieus. By attending to their multiplicities, qualitative outlines keep shifting presence, skipping from meaning to meaning. Ambiguity imparts relational interactions occurring simultaneously in overlapping contextual circuits. Attending to convoluted sounds, especially noisy signals from activity-saturated environments or signals from afar, explores the many interlocking, multi-spatial presences a single stream sustains. On closer scrutiny, when honing into any one of the presences, the details tend to fray and resolve into corresponding motions. Repeating loops and eddies piling up in patterned resonances, their internal movements laced with the contradictions and paradoxes of appearing.

The annals of communication are a sustained attempt to *suppress* the cacophony. Insisting on the determinacy of messages-in-transit. Communication models unambiguously, and effectively, relegate comingling environmental noises to the status of disturbance. Environments agency downgraded to signal distortion. Ironically, the tensions between sensation (what *could* be heard in a signal) and perception (what *is* heard in a signal) seem to increase symmetrically with lengths of communication cables spanning oceans and land.

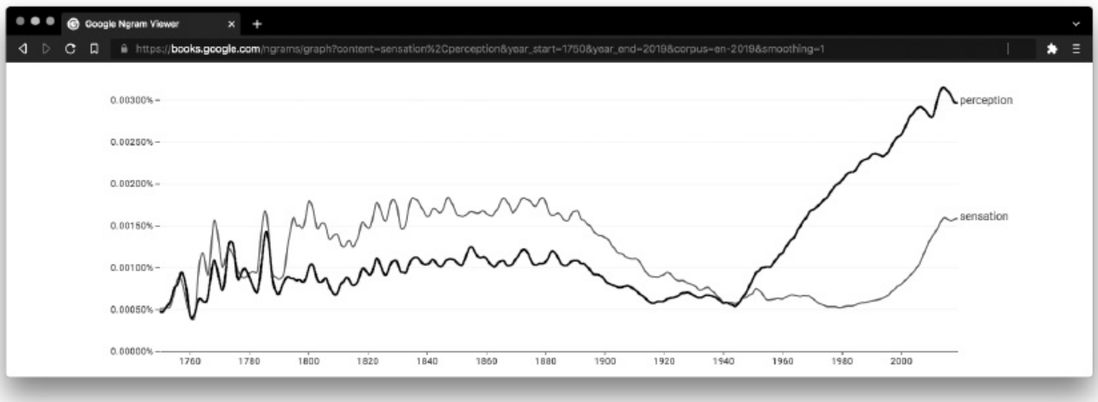

Figure 7.2 Waveforms plotting the frequency of 'perception' versus 'sensation' (ngrams) on Google's corpus of English language books (1750-2019). Graph illustrating the frequently of occurrence over time (x-axis publication years and y-axis frequency of occurrence).(Source Google Books Ngram Viewer, Mar. 26, 2023)

Plotting frequency waveforms for both words — 'attention' and 'sensation' — recounts a more nuanced narrative. Use of both terms, in English language printed matter, swells in the 19th century corresponding to trends in the natural sciences at the time, with sensation clearly in the lead. By the early 20th century, interest wanes and trends reverse. Both waveforms intersect only once, in the early 1940's, at the time when Harvard's anechoic chambers were tactically active. In the padded chambers, human sensations were tested for functionality as integral components in hybrid bio-electro-mechanical combat circuits (Ganchrow, Raviv, 2016). Since that time the primacy of *perception* has been experiencing a steady incline, on its way to current battlegrounds of *perceptual meanings* in post-truth politics (Ngram, 2023).

Even when senses are functionalized and signals seemingly de-cluttered, folded into themselves and piped-through insular channels, their transmissive propagations exert extraneous pressures, inducing haphazard sensation along their paths of propagation. Inorganic sensations are omnipresent in conjoining flows. Radio signals picked up in conductive minerals of geologic formations or oscillations from national power-grids intermingling with native telluric ground currents demonstrate the degrees to which anthropic expressions permeate the surrounds.

The birth of radio also signals the domestication of lightning. The crude form of emission in spark-gap transmitters (the origin of radio transmission techniques) has audible characteristics that exceed the semiotic function ascribed to it by wireless telegraphy. In its most elemental appearance, the spark is more of a feature of matter than a proper signal. Its ambiguous status in the circuit pathway, as a natural rather than synthetic phenomenon, draws kinship with earth's other circuits. It also points out an inbuilt *terrestrial* component in naturalized circuits such as electrical signaling in plants, electrocommunication in honeybees, or within the human nervous system. The co-evolution of minerals and life on earth may also be that of electrical and sensory circuits.[8]

Physicality of Sense

Energetic behaviours of the expanse combine and collide, refract and transduce in a variety of manners giving shapes and contours to unfolding sensation complexes. Imprinting sensations sometime appear on the surface of things, like patterns in the ocean. Combining currents of wind and water are *sensed* in undulating surface tensions through perturbations of conjoining ocean-atmosphere relations, or in tangles of dendritic electrical relays signalling through minerals in rock and soil. Seismic motions in the earth's crust induce electricity into ground-based telluric currents by way of micro-fracturing piezoelectric rocks, especially along tectonic faults. Do mountains, participating in seismic fault lines, sense a pending quake? That's not to endow geology with anthropomorphic wonders, rather the reverse, to propose that aspects of perceptions themselves may be borrowed from pre-existing proven configurations of the extant.

If organic consciousness is situated stuff, stratifying aspects of physical matter, a converse statement could also be proposed: that the physical universe *itself* be considered a form of expansive consciousness.[9] Strong nuclear force, clumping together the contexts of physical matter would then present altogether different *magnitudes of attention*. But the term 'consciousness' is too vague and broad a category for examining materializations of sound. Its potential anthropomorphism is equally troublesome. Suffice to say that every portion of existence bisects many endured actions of which sounds are important constituents. Sounds are *tendencies* in those ceaseless ongoing processes. Every sonic spatiotemporal-materiality is an eddy in complex torrents of relational interactions. Observable, differentiated qualities materially express traces of situated affordances and contextual actions simultaneously *taking place* as well as *making sense*.

Vibrant Subjectivity

Sound enacts the delays between occurrence and sensation. It resonates relation between attention and context, and in doing so provides partial contours to the *spaces of being*. Subjects undulate and co-evolve with surrounds through turbulent tangles of organic-inorganic sensations productive of myriad agencies and formations. Attentions are not merely functions of an organism's survival but rather coupled interdependencies in complex planetary conductivities, productive of countless effects. To hear is first and foremost to partake in an earthbound ebb and flow of actions and contribute to the intermingling.[10] Demarcations of intensity are recursively pulse-patterned yet also importantly emergent and dynamic. Subjects arise through conditions of sense. Shared percepts delineate continuities and discontinuities between selves and sur-

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8 For an explication of radio's entanglements with the domestication of lightning see Ganchrow's radio work *Knallfunken* (2018) and the contextual compendium https://ravivganchrow.com/page/spark-gap/knallfunken-text.html

9 Exponents of panpsychism —a theory currently gaining traction— hold such statements to be true, as did prominent figures in early experimental psychology (or psychophysics) such as Gustav Fechner and William James. As a young adolescent, the physicist Ernst Mach experienced the surrounding itself as an expansive *sense formation* ensnared with his own immediate impressions (Mach, Ernst, 1914, p. 30). Henry Bergson came to a similar conclusion regarding 'pure perception' as component of the physical universe in his meditations on matter and human memory (Bergson, 1988, orig. ed. 1896).

10 Jane Bennett likens agency to an oscillating, tensional property of the expansive dynamics in which there is a 'pulsating, conative dimension of agency […] engaged in a system of pulses, in an assemblage that links them and forms circuits of intensities' (Bennett, 2010, pp. 80–81).

rounds in perpetual reconfiguration. Adopting listening as a conscious practice exercises those relations.[11]

Distributed Subjectivity

Observations close situational circuits, circulating both distinctive object qualities as well as a subjective stance. In the example of sonic experience, hearing becomes a site whereby attention, surrounding, and subjectivity are mutually conductive. Acts of listening emplace subjectivity and situate eventfulness. To hear a 'place' implies internalizing oscillations and negotiating limits of the self. Subjectivity breathes in tandem with shifts in the limits of its objects. No form is invariable. Redistributions of subject are reminders that the subjectivity was never fully contained in the first place. The elusiveness of subjectivity is inherent in distributions of self that is as much inside the body as they are spread over its *territories of action*. The organism is a crucial node in that distribution as it is where the possibilities of immediate action are concentrated.[12] Making sense involves dynamic extensions of conductive traces through elements of an attentive circuit. Refractions glean out from events those aspects the conductive medium is capable of influencing. However, since actions *of* the body are never fully *in* the body, corporeality is always scattered in orbits of its subject. Distributed subjectivity includes cumulative attention circuits, conscious and unconscious, active at any given moment in various overlapping domains.

Observer-observed subjects, traced back through their action-temperaments, disperse and are rediscovered within curious formations and incidental conditions structuring the quotidian and geological expanse. This complex dynamics, crossing human/non-human and organic/inorganic divides, opens up numerous relational interconnections, reacquainting the subject with terrestrial heritage at large. A geological subjectivity actively seeks manners of sensing relational reciprocities. An awareness of being at once located and distributed in multiple places and times, finding aspects of the subject in agencies of the surrounding and vice versa, finding terrestrial dimensions in corporeal milieus.

Transverse Flows

Just before lightning strikes, intense electrical build-up and ionization of air causes human hairs to stand on end, as if the hairs themselves reach out to participate in conductivity of a nascent bolt. Extreme energetic situations induce polarizations where the subject becomes a composite of minerals and chemicals forming conduits of exchange in circuits exceeding human domains.[13]

Postures of reaching-out-opening-in are expressions of acute connectivity that are also temporary paralysis, where the intensity of sensations short-circuits comprehension. Excesses of energy at times over-intensify sensations in manners that bodies can no longer sustain. Extreme conditions of terrestrial energetics in which mineral provides support often also spell the organism's demise. Conductive properties of extending hairs seem to *welcome* such corporeal transgression, like the sloshing of calcium carbonate otoliths (earstones), trapped in the inner ear, longing for ocean returns. Occasionally fossilized otoliths and tympanic bulla wash ashore, dredged up from sediments of extinct whales swimming in palaeo-oceans.

Sound, Earth-bound

Interlinking Sounds

Sonic attentions, the circuits they maintain and materialeties they sustain are integral to dynamics of the extant. Sounds are only ever determinate in relation with contextual conductivities to which they correspond. But circuits never occur in isolation. Circulations are inevitably tied into countless other movements,

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11 For a discussion of the psychological, ethical and philosophical implications of listening as a practice of self see Kleinberg-Levin's *The Listening Self* (Kleinberg-Levin, 1989).

12 There is an essential pragmatic underpinning to sensations that are always oriented towards operations. Bergson recognized that aspect in the organism's poise to actions (Bergson, 1988, orig. ed. 1896). J. J. Gibson's ambient psychology of 'affordances' is another example.

13 An account from the vicinity of a bolt strike at Morro Rock (Sequoia National Park, August 20, 1975) describes altered spatiotemporal perceptions including the expansion of time and temporary weightlessness (McQuilken, Michael, 2013).

of other spaces and times and *their* related agencies and interlocking worlds.

Figure 7.3 Fossilized whale inner ear (tympanic bulla), c. 18 million years, South Carolina. (Photo by author)

By placing the human sensorium in circuit with other terrestrial processes, hearing along with the spaces ballasted in sounds, endures a cascade of relations, blurring distinctions between cultural/natural, bisecting other times, locales and processes that encroach on the immediate chambers of hearing. Once in-circuit, the spaces of sound appear formatted with multi-layered, heterogeneous, poly-temporal *agencies* incorporating diffuse and discontinuous fields of multi-scaled relational interactions. Sound's diverse material presences and spatial logics reflect that interlinked multiplicity.

Attention Sediment

Vibration sensing and acoustic sounding features of biota (trembling vocal chords, resonating cavities, undulating membranes, swaying cilia) are physical sediments of vibrant co-evolutions that integrate substances and forces native to developments of the planet. The term paleohistoricity can be coined to describe deep-time components embedded in sensory organs. Sensory morphologies are shapes that are also manners of operation, slowly yet persistently recalibrating their limits and sensitivities in ongoing phylogenic processes. If historicity describes contextual constraints of a sensory circuit, paleohistoricity scopes the geological temporality of sense calibrations transitioning intermittently and across multiple generations.

Organism physiology is also an existential technique; morphogenesis expresses the coalescing of actions *and* energetic attentions combining with surrounds. The natural history of substances and structures involved in sensory circuits cannot be decoupled from the fluctuations they endure and sustain. Spaces and places come in tow of multifarious processes.

Organisms, mineralogy and geography collectively evolve in periodicities of milieu. Subterranean organisms evolved in tactile contact with perpetual substrate vibrations and their various sensing and sounding mechanisms are shaped by, and contribute to, categories of ground motions. Plant roots respond to, and grow towards, vibrations from moving subterranean water (Gagliano et al., 2017). At the same time, dendritic root structures dissipate sounds on sloped terrain by knitting topsoil in place, alleviating rumbling landslides. In turn, vibrational properties of substrates alter with life and mineral compounds inhabiting their domains.

Other terrestrial forces, unrelated to vibrations, also imprint in morphologies of ears. Vestibular systems, present in inner ears of all vertebrates, perpetually tether organism moments to earth's gravitational pull. The system, most commonly comprised of three semicircular canals oriented in Cartesian XYZ-axis, coordinate body movement with balance. Palaeo-ear evolution in hominins sets the rise to two-legged locomotion — unique to humans among living primates — at approximately 1.8 million years ago, mirrored in the shapes of vestibular canals (Spoor et al., 1994).

Environmental Frequency

The ground is permanently traversed by 54 min long waves — the strongest signature in earth's resonant modes — continually ringing with microseism oscillating at around 0.0003 Hz (Park et al., 2005). Steep topography such as alpine ranges, have their own signature resonances. It was recently discovered that Switzerland's distinguished Matterhorn mountain has a fundamental frequency of 0.42 Hz due to structural properties of the massif (Weber et al., 2022). On larger timescales, terrestrial sonority potentially demonstrates vast recursive feedbacks, inaccessible to sounds accumulating in the lifetime of a single listener, of sounds informing structures imprinting sounds informing structures imprinting, et cetera.

Substrate vibrations sensing abilities through soil and foliage, widespread in animals, evolved several times independently in various locales. Snakes developed ground-conductive hearing, sensing feeble soil vibrations (Friedel et al., 2008). Mole-rats employ it for burrow-to-burrow signalling (Narins et al., 1992). Conversely, general tendencies of ground vibrations are conditioned by animal presence, most recently noted in an abrupt drop of 'background noise' on seismograph readings during global pandemic lockdowns (Gibney, 2020). At planetary scale, tendencies for earthquake frequency and magnitudes themselves seem to be coupled with cycles of life on earth, with ocean sediments lubricating earth's plate subductions in a feedback circuit of ecosystems, climate and movements of tectonic plates (Behr & Becker, 2018).

It's been recently discovered that much of terrestrial life happens underground, where the collection of archaea and bacteria is estimated at nearly twice the volume of all Earth's oceans (Watts, 2018). Some of those micro-organisms live for millennia, barely moving except with shifts in tectonic plates, their lived worlds progressing in cycles of geological time. Surface dwelling organisms as ourselves, cannot grasp sensations of the depths. Microorganisms of the substrate, on the other hand, may be the best qualified to comment on the experiences canyons endure.

Poly-temporal

Energetic events refract and transduce haphazardly through the extant. Their circulations follow interweaving principles of refraction and shape-shifting transductions. Refraction entails territorial contortions altering orientations and rates of change as well as relational *transformations* within a given terrain. As splayed and warping rates meet up with one-another, they express their time-slip, thickening the present tense. Every locale contains multiple rates unfolding simultaneously, only some of which seemingly address the clocks of biological time.

Temporality is an emergent *quality* of processes, as is space. Time variance appears with transformations in quality, like the red-shift in light travelling over great distances or Doppler pitch shift of relative motions. Polychronicity is the accumulation of multiple times packed into the now, but also importantly times *shifting* and *shearing* in relations to one another. Delay is a persistence of the past that carries-over into the present just as pre-delay is a nascent state of the future also active in present, operating simultaneously with differing rates of becoming. Every sound circuit synchs and scales to operations in its context, presenting its own temporal manners and ways of becoming.

Dynamics Future-tensed

Spatiotemporal qualities of sound are features of agency. Sonic qualities aggregate and condense eventful pasts as much as they facilitate follow-up states. The vibrancy in material presence is also a call for future actions. Sonic spaces remediate events, preserving and prolong motions to facilitating further interactions. If the past persists in the present through refractive-transductions, tendencies of the future also potentially manifest.

Fragments of future-states can also be found in anomalous wave behaviours of the extant, as the tensioned 'anticipation' air experiences, becoming nearly a vacuum just moments before a shockwave passes through or the reverse reverb that ends in a crescendo of ocean echoes traversing the deep sound channel (Hamilton, 1949). Likewise, the shoreline slowly recedes, sometimes for several minutes, before the arrival of a tsunami as approaching waves temporarily pull water away from the shore. Both wave retreats, and the reverse echo playback, are possibly forms of inorganic recoil, pre-delays anticipating future-impacts.

Refraction-Transduction

Temporal Shapes

When approaching dynamics of the expanse, principles of *transduction* and *refraction* provide useful guidelines, especially in accounting for transformations of orientation, spread and temporality integral to circuitries of sound. Both terms are applied in a broadened sense, denoting *processes* and *movements*, typical of energetic behaviours of processual actuality. Both refraction and transduction have pronounced *spatial* traits in their movements exemplified in refractive *fields* and *arborescent* transductions respectively. Many terrestrial oscillations can be traced back to ur-transductions of chlorophyll (photosynthesis), approximately 3.4 billion years ago, that send radiant sunlight circulating in a host of emergent chemical, gaseous, organismic and tectonic pulsations.(*Timeline of Photosynthesis on Earth*, 2008)(Rosing et al., 2006)

Transduction is useful for observing circuit propagations weaving through and bridging over material distinctions, where transference of energy is not only in type (standard transduction) but also potentially transference between *systems* (context transduction). An example of *standard transduction* is acoustic energy transferring to electrical energy when passing through the ear or a loudspeaker. An auditory event transducing into descriptive words and gestures is an example of *context transduction* (movements transferring from a milieu of gasses to movements in the social milieu). The frayed meander of sounds, transducing along media pathways, is possibly more instructive of context transductions.

Waveforms

Storage mediums of sound (and other energetic phenomena) function as refractive-transductive delays. Media containers alter an event's rates of becoming. Recordings on vinyl, invisible patterns on magnetic tape, waveform diagrams, spectral charts, bits encoded in silicone chips are all still part of the agencies of energetic waves, bending, changing directions and velocities when subjected to transduction. Their waves are prolonged, not halted, through sedimentation in media delays. A sound wave embedded in a wax-cylinder is first and foremost a physical transduction, in other words an actual trace of eventfulness still actively performing in other manners what acoustics behaved in air. Although their waves are seemingly inert and captured, they still participate in dynamics of the expanse through their presence as substances, or when closing sensory circuits with unforeseen observers. Knowledge sediments attention, storing latent configurations for future interaction; information stored in media is distinctly context-sensitive in its modes of operation. From the many examples of transduced fluctuations, waveforms in particular have taken on enhanced fields of affect in the late modern era, especially in their activation capacities across diverse contexts when movements render in visual artefacts.

One of the longest terrestrial waveforms charted to date spans 590 million years of sea-level fluctuations, published in 1977 by geologists in the petrochemical industry. The Exxon/Vail curve waveform can be grasped in its entirety in a glance. When loaded to an audio buffer and played back billions of times faster it can even be perceived as an acoustic sound. But the oscillations from which those waveforms project can only really be sensed within the time-scales inherent to their movements, within the ground and rocks to which that particular sloshing relates. A durational accumulation from the last quarter of the waveform is the stuff holding up the white cliffs of Dover, which, incidentally, are also almost entirely composed of calcium carbonate from sinking phytoplankton.

Biominerals such as calcium carbonate (calcite) found in phytoplankton and oyster shells, coral reefs and the eyes of Trilobites, prolong aspects of their agency into processes of the present. Stripped of organic actions their activities persist in follow-up mineral interactions, ballasting the Dover cliffs, participating in zoomorphic limestone cave formations, or contributing to an increased potential force of future earthquakes off the coast of New Zealand (Boulton et al., 2022). Animal bones too refract their pasts, prolonging them into the present. Calcium phosphate is their delay line. Carbon-14 isotopes from plants and animals (applied in radiocarbon dating) measure the time-slip when biological clocks roll back into geological time.

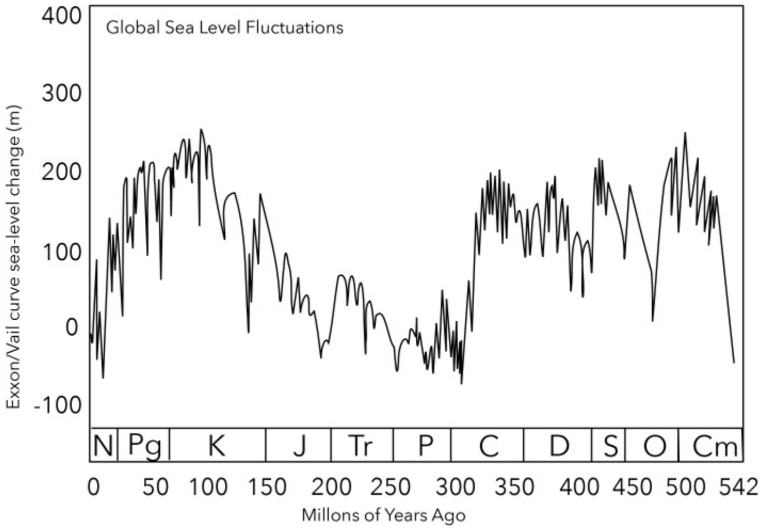

Figure 7.4 The Exxon/Vail curve waveform charting 540 million years of sea-level fluctuations, first time published in 1977 by geologists in the petrochemical industry. (Chart by author)

Discussions pitting linear against cyclic time fall short when observing poly-temporal dynamics of the extant. Rates of change warp and shift continually in physical domains. Ocean floors and glacial mass endure geophysical time; their sediments express intermittent and warping states of becoming. Mountain ranges reveal delays in layered-rock formations. On some occasions stones exhibit waveforms that can even be read like prehistoric seismograms (Mach, Ernst, 1914, p. 236).

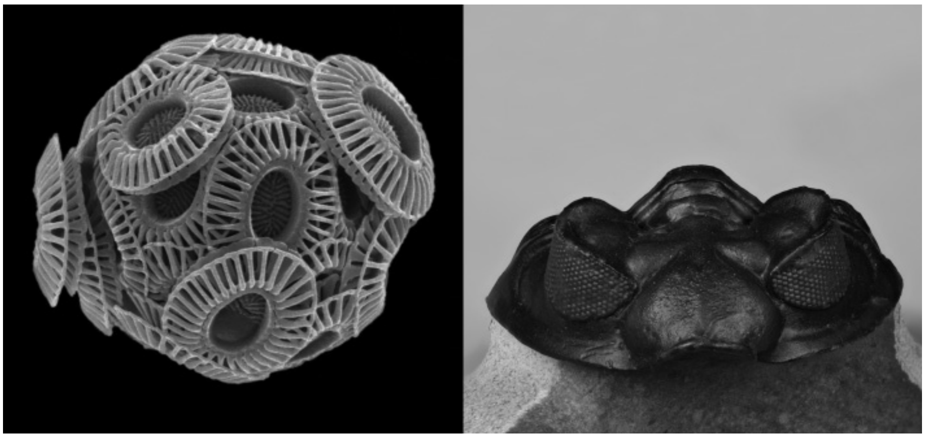

Figure 7.5 Left: Coccolithophores (phytoplankton) capable of forming calcium carbonate (calcite) structures called coccoliths in the process of biomineralization. Right: Compound eyes of a trilobite (genus Coltraneia), made of the rigid mineral calcite lenses. Early Devonian trilobite from Hamar Laghdad, Morocco. (Photo by R. Wilber, CC BY 4.0)

Organisms tune to faster rates, dipping in and out of phase with predominant environmental cycles, synching to earth spin, sun cycles, phases of the moon, tidal motions and seasonal modulations. Predominant geophysical cycles calibrate temporal perceptions that in the case of humans are also potentially clocked to heartbeats (Sadeghi et al., 2023). More hidden, yet widespread oscillations have been discovered in core structures of mammalian and plant cells, with collective emergent behaviors, coordinating rhythms of organism processes in resonance with rhythms of the surrounds (Golden & Strayer, 2001; Schibler & Sassone-Corsi, 2002). Diurnal cycles in organisms were observed linking up with 'master clocks' (housed in neurons), regulating local rhythms of 'slave oscillators' housed in countless peripheral cells and organs (Reppert and Weaver 2002). The mechanisms are notably illustrated in the literature with the electronic oscillator graphic symbol, transposed from electrical circuitry. As is the master/slave jargon that electrical engineering itself absentmindedly transduced from dreadful colonial domains (Ellis, 2020). Importantly, cellular clocks, that generate spontaneous oscillations, are nonlinear dynamic systems radically open to environmental energetic exchange (Kruse & Jülicher, 2005). Clocks synch subjects and surrounds, at time skipping between couplings or re-setting phase in cyclic circadian patterns that according to Arthur Winfree can be accounted for in a peculiar topological space likened to 'crystals of living time' (Winfree, 1987).

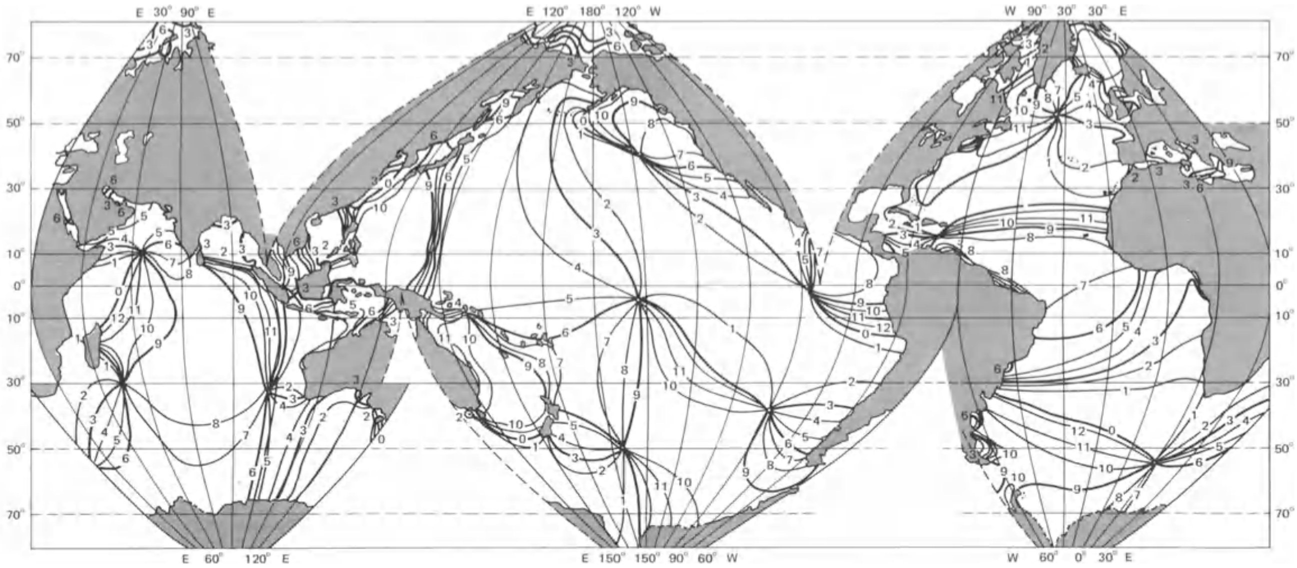

Figure 7.6 Map of cotidal lines along which tides meet, constituting still nodes of oscillation convergence, at each given hour of diurnal oceanic rhythms. (Map from A. Defant, "Physical Oceanography, vol. 2", 1961)

Shared Hearing

Senses inhabit movements without necessarily taking command. Their ethics, politics and aesthetic evolve in-situ, in sway with the contexts at hand. There is an in-built inclusivity to energetic movements indiscriminately bridging sensations, bodies and the milieu. That intrusiveness of uninvited experiences is also potentially its greatest asset. Care stems from taking notice of diverse reciprocities, acknowledging participation and granting access and provisional trust to unfamiliar sways, possibly synching to certain rhythms and following through with consequences of their motions. Hearing diversely is possible, but never all-encompassing, because hearing always synthesizes selectively. Listening, on the other hand, opens the circuit up for unexpected encounters. Experimental modes of hearing can practice and share the discoveries. *Hearing differently is the beginning of becoming elsewise*.

An ethics of listening tests degrees of response-ability conditional to sound's spaces of action, turning affordances into questions that perpetuate discovery. Experimentalizing the ecologies of hearing test what's at stake in shared modes of attention. Every emplacement also entails distinctive orientations and subject distributions. Even the most mundane, quotidian act of hearing already contains understated metaphysical and, by extension, aesthetic and political vectors. When coordinated, they can empower collective force, such as the sounds emanating from public protest, or the growing sonority of thunderstorms, wildfires, flash floods and landslides in the current epoch. Hearing unfamiliar spaces has the potential of redistributing subjectivity towards other courses of action and other ways of being. Geological listening awakens deep-time awareness of ongoing involvements with past and future terrestrial dynamics. Coalescing with sensory impressions and participating in diverse presences foster an unending procession of spaces and formations with unforeseen agencies and actions.

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Chapter 08

Everything Matters

> *'I've been, and still am, in a tangle of gasses, minerals and cumbersome jargon, wading my way through prehistoric hearing. But also tethering the ends to dendrites of contemporary (tekhnētos)listening, namely poly-eared methods of surveillance born in conflict on both sides of the waterline. Arrayed modes of hearing that are currently invading the oceans. [...] There are loads of insect ears and early reptilians in the text to bring out some of the human inbuilt biases of hearing (as well as our own slithering and swimming heritage). Also some minor prods at what you call social zoology to highlight the intrusion of electro-acoustic and human practices (mostly tactical) when humans attend to the hearing of other 'animals' and adjacent life-worlds. But generally I've taken a more technical approach that (intentionally) deflates the poetic potentialities (very few people in the narrative), in order to access the dynamics of contextual configurations and the attentive as well as morphological changes incurred in material dynamics (human ear-minds as refractive indexes and relays rather than proper subjects of interest). The poetics of matching structures (spirals and the likes) gives way to quite a bizarre domain of vastly different, yet coinciding, scales and rates of change (assemblages of amino acids and plate tectonics in a single breath. Literally.) Also some peculiar recurring circuits. One gaping void that has emerged from this strategy is the gap between historicity (shifts in attention) and natural history (morphological changes), maybe due to the temporal biases built into their respective disciplines (attentions clocked at the life-span of organisms and morphologies synched to geological clocks)? I'm trying, at least provisionally and somewhat hastily, to span some gaps because of the immense implications for theories of praxis as well as analysis of material techniques. It seems that everything matters.'*
>
> Sept. 8, 2020[1]

Post-acoustics

Sites of Recent Hearing

When sites of hearing are examined by way of shared materialities, overlapping contexts and recurring themes appear, especially when approaching the sites of modern hearing and listening. Journeys through predominant modes of hearing tend to halt at familiar stations, though each location inevitably enacts hearing slightly differently, interlinking the sites through overlooked pathways. Even ventures into seemingly mundane sites of quotidian hearing reveal complex rabbit hole junctions, patched through seemingly remote territories of technical development such as laboratories and battlefields. Inevitably categories such as the science of acoustics and experimental psychology (particularly since the late 19th c.); military technology (and the politics of surveillance and eavesdropping); recording practices (before and after electronics); listening practices (especially those involving trained techniques); urban and architectural design (keyed on technical infrastructures or established sensory programs); engineering (primarily electrical and optical audio); mineral economies (and their modes of transport), all receive pronounced playback due to their ability to congeal sonic ontologies that, at the same time, perform agencies in the making of the modern hearer/listener.

To access a site of hearing, is to enter the circulatory patterns of operational attentions, engaging the

1 Raviv Ganchrow in email correspondence with Hillel Schwartz, September 8, 2020

properties of sound that enforce sonic material specificity and calibrate spatial dynamics. Sonic sites, comprised of contextual movements, engage multiple interlinked domains shifting in scope and complexity as sounds morph from one presence into another. Sites of hearing combine these contextual circuits in novel and unpredictable manners, inducing territorial fluctuations and distributing over discontinuous fields of action. Every situated quality of sound, seemingly isolated and distinct, is in fact teaming with contexts pointing everywhichway. This rudimentary fact highlights a central paradox in sound: the prerequisite for sound's located appearance is that it also be thoroughly distributed, non-localized and relationally enmeshed. Sounds are as much 'here' as they are always, also, elsewhere. Furthermore, uncovering predominant features of the sonic site involves observer participation that potentially alters subsequent refractions and pathways of qualitative perturbations.

Sound Circuits in the Age of Acoustics

When enquiring about the agency of *spatial sound* in current debates, surprisingly, it's the latter term that requires some unpacking. The discourse of space (and place), aided by developments in the natural sciences, together with the 20th century spatial turn in ethnographic, literary, sociological and architectural discourses has endowed space with pronounced relationality (Einstein, Poincaré) social-political agency (Durkheim, Lefebvre, Foucault, de Certeau, Carpenter, and others), significant sensory-biological dependencies (von Uexküll, Mach, Gibson) not to mention marked theoretical/philosophical currency (Bergson, Bogdanov, McLuhan, Deleuze, Irigaray, and others). Spatial aspects are central to understanding phenomena. There is a general awareness of how the developments of spatial concepts are shaped by experiences and techniques and how, in turn, those concepts influence the acquisition of further experiences and techniques. At this point, the importance of spatial inquiries needs little introduction.

On the other hand normative definitions of sound are taken for granted, their problematic is easily overlooked. Despite the attention sound has been gaining in the past few decades, especially from ranks of historians and sensory/sound studies, sound itself remains largely undertheorized.[2] Besides a few notable exceptions investigating the contexts of electroacoustics (Wittje, 2016), Victorian vibrations (Trower, 2012) and the cultures of noise (Schwartz, 2011) and resonance (Erlmann, 2014)[3] the 'how' of sound remains largely unattended. This could partially due to the effectiveness of acoustic models that tend to halt sounds in the limited confines of vibrational patterns, colonizing radiant multiplicity with standardized utility. Waves held captive in reductionist models, sent propagating through social praxis. In other words why enquire about the metaphysics of sound, if physics has already seemingly provided adequate response?

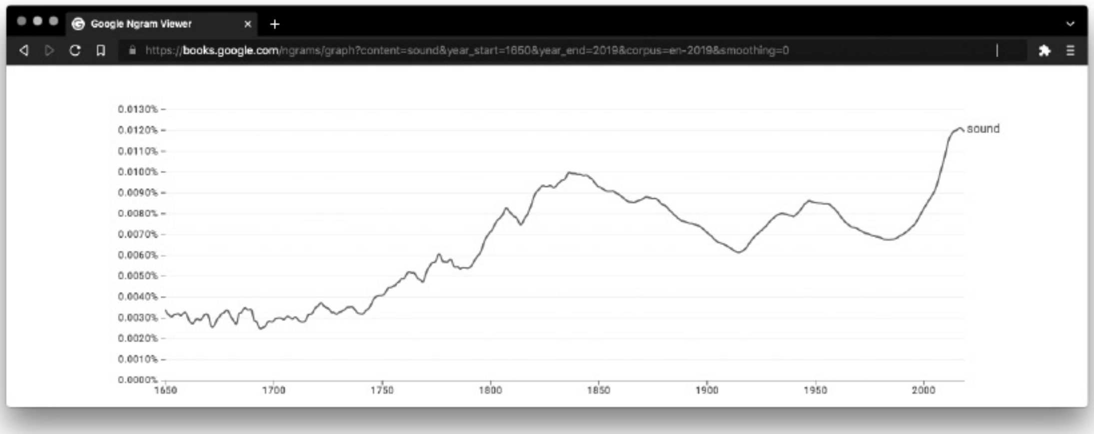
The term 'sound' has come into prominence, especially in Latin-based languages, roughly over the course of the last 300 years, an increase that rises in tandem with the prominence of acoustics and sensory research in the sciences and applied knowledge offshoots taking root in cultural techniques as well as everyday language. The frequency in which the term 'sound' appears in printed matter — in the period spanning 1650 to 2019 — charts an oscillating waveform with a general upward trend. Including two pronounced

2 It should be mentioned that sound's *contextuality* has been gaining traction, though that context is often limited to sound's 'participation' in various social/historic/economic regimes with little attention to the nature of sound's ontology and dynamics. The result is an ever-increasing inventory of examples that provide compelling insights into the material, historical and epistemological conditions yet fail to address the *how* of sound.

3 Notable exceptions include Roland Wittje's book *The Age of Electroacoustics* (Wittje, 2016) that examines shifting interrelations between technical configurations of electronically-circuited sounds and their agencies in science, politics, war, empire and commerce. Shelly Trower's book *Senses of Vibration* (Trower, 2012) examines the rise of sensory attention to physical vibrations tied to processes of industrialization and techniques of domesticity that dovetail with prevalent conceptions of the human body, matter and spirit in the Victorian era. Likewise, Hillel Schwartz's book *Making Noise* (Schwartz, 2011) constitutes a monumental study into vast social and material infrastructures involved in shifting historical attentions to noise across various cultures in distant and recent pasts. Veit Erlmann's book *Reason and Resonance* (Erlmann, 2014) demonstrates how the understanding of the physiology of hearing, and especially the ear's resonance mechanisms, contributes to the matrices of rationality and other key aspects in the making of the modern Western subject.

peaks: around the mid 19th century and again in the mid 20th century.

The first frequency peak roughly coinciding with developments in the science of physiology and acoustics (e.g. seminal work Hermann von Helmholtz on sensation of tone together and John Tyndall's work on acoustics); the second waveform peak coincides with culminations in Cold War tensions, during a period of rapid developments in applied tactical acoustics, when wave-based monitoring techniques were well underway. Curiously, the waveform curves exponentially upwards from the mid 1980's and into the 21st century, possibly mirroring the proliferation of sound-based economies and increasing influence of broadcasting, recording, telecommunication and information industries on everyday life in all corners of the globe.



8.1 Waveforms plotting the frequency of the term 'sound' (ngrams) on Google's corpus of English language books (1650-2019). Graph illustrating the frequently of occurrence over time (x-axis publication years and y-axis frequency of occurrence). (Source Google Books Ngram Viewer, Mar. 26, 2023)

From the vantage of contextual sound circuits, quasi-universal definitions of sound such as 'acoustics' are themselves conditional of particular socio-historical attentions. The utility of situation-neutralized manifestations of fluctuation, seemingly devoid of context and keyed on energetic behaviours numerically resolvable in mathematical equations arises at the specific historical moment when sounds are poised for deployment in tactical knowledge and economic regimes.

Stabilized sounds lend themselves to practical applications, administered through technical protocols and social techniques, enforced and coordinated through dedicated calibrated devices. Homogenizations of acoustics and hearing notably evolve mostly indoors, in laboratory settings or other controlled environments such as anechoic chambers. In isolation, sounds can more readily be split into the separated spaces of acoustics and psychoacoustics, and then developed independently (mirrored in the layout of Harvard's *two* anechoic labs, PAL and EAL).[4] Sounds that are trained to behave consistently and predictably, anticipate the regimented engineering of sounds in the built environment and industry, while also preparing the listening public as an *acoustic consumer*. And if human encounters with fluidity produce socially habituated and historically traceable *manners of time,* then the recent epoch of standardization and audio stockpiling fits neatly into larger dependencies on digitized total recall and Coordinated Universal Time (UTC).

The age of acoustics – spanning roughly from the 19th century until today (Beyer, 1999; Hunt, 1978) – fosters characteristic sonic materialities centred on the molecular vibrations, biased towards air in particular, the primary medium of human hearing and sounding. However acoustics productive neutrality often comes at the cost of diminished attentions to sound's situated specificity. What tactically biased techniques and epistemologies of sound could have carried over into the age of consumer electronics, absentmindedly effecting current material perceptions? Universalized sounds cannot be decoupled from their historicity and

4 Studies of atmospheric and underwater sound are latecomers to acoustics, environmental acoustics are forced to contend with situational specificity but end up doing so through calibrations linked with urgencies of combat. In fact environmental acoustics markedly evades Tyndall's experiments off the coast of Dover. See section *Earth-bound Sound* for more details on early attempts at defining outdoor acoustic propagation.

like other spatial-material manifestations of sound that preceded acoustics too will inevitably be eclipsed by other unforeseen attentions to fluctuant matter while techniques and affordances shift elsewhere.

On the other hand, vibration modalities of acoustics shouldn't be discarded too hastily before attending some of their virtues. When encountered as fluid interactions, wave ontologies, integral to countless techniques, possess an ability to influence shared perceptions. Reorienting manners in which surroundings and events are grasped and folded into quotidian experience. Vibrations working *across* bodies and surrounds make connectivity more tangible.

Every perceptual system implies modalities of substances and subjects, and along with them, immanent models of materiality and subjectivity. Awareness of complex wave dynamics, superimposed on impressions of surrounds, confound optical metaphors of static immutable space (for example those carried over from Renaissance perspective), potentially amending former spatial biases.[5] With the dawn of acoustics, orderly, transparent, geometric space-at-a-distance instantaneously fogs over with tactile temporal immediacy. (Ganchrow, 2006)

If anything, the shift from linear optics to wavering interference patterns challenges the rigidity of geometric edges by confronting assertive outlines with their immanent flipside atmospheres. Ambience thinkers such as McLuhan, Böhme, Thibaud and Morton have taken note of these heightened senses of immersion, arguing convincingly for a metaphysically *active* dimension of inhabiting atmospheres. Ambient tectonics, with its pronounced state of becoming, has the power to dissolve static universals. Though histories of geometry still cast a long shadow, especially in architectural frameworks that are yet to confronted their unquestioned geometric foundation.

In the mean time, acoustic epistemologies continues to colonize waves, and techniques of applied acoustics increasingly stratify the terrestrial expanse: an immense proliferation of wave-based technologies, especially in the wake of auditory observation methods in and after WWI, are found back in a myriad of scientific applications, including tomographic and phased-array techniques such as magnetic resonance imaging (MRI), seismic tomography (mapping magma motions in earth's mantle), acoustic prospecting, ocean acoustic tomography (temperature ocean maps), Sodar atmosphere sounding (meteorological wind profile mapping).[6] Likewise, countless consumer products display a host of waveforms in audio/video editing software, streaming media interfaces, weather monitoring apps, exercise apps and even app-sounding waveform tattoos.

8.2 Soundwave tattoo that can be replayed via a smartphone application. Waveform tattooed on the arm of a Houston resident, recording the sound of his child's voice and dog. Excerpt from a KHOU 11 News (Houston, Texas) report, April 05, 2018.

Today, it is plainly evident that fluctuations, materializing both as waveforms and wave-visualizing pressure gradients, are thoroughly anchored in commonplace experience. However awareness of fluidity does not necessarily induce *fluid awareness*. And in some cases may even produce the reverse, by adding more manipulable things to the stockpile of *material resources* currently cluttering contemporary being.

The unfolding ecological crisis is first and foremost a crisis of shared *material attentions*, exemplified

5 For a conscience genealogy and polemic of McLuhan's concept of Acoustic Space, see Cavell, R. *McLuhan in Space: A Cultural Geography*. University of Toronto Press, 2002

6 Schlieren photography is the 19th c. precursor to phased-array tomographic techniques, a method for visually mapping pressure anomalies of complex in-situ wave dynamics.

in worldwide resource extraction. Extractivist mindsets intensify *point-source subjectivity*, fostered in tactical battleground localizations and extend into models of economic growth. Mindsets that deny preexisting interconnections and relations, replacing them instead with ever-more materially distinct categorizations set to work in anthropic production circuits. A world increasingly stratified with *resources*, raw materials of limitless manufacturing, where acoustic materiality, too, is directed towards eventual transactions. Point source subjectivity ends up extracting the self from its subjects, a condition where both the self and the surrounds materialize mathematically localized, spatially contained and ecologically calculable. Pervasive exctractivist attentions involve recurring material-attention loops, fostered through closed-in social circuits, oblivious of the other *terrestrial circuits* within which they already, inevitably, participate and interact.

However, the task of undoing epistemologies of colonizing productivity-laden materiality is likely more complicated than merely destabilizing the thingness of extractions, desynchronizing measurements, or setting geometries into motion. As a matter of fact, wave-based functions are central techniques in resource extraction. Monitored echoes are paramount in determining mineral and hydrocarbon deposits on land and at sea. Ironically, processes that convert terrestrial conditions into value-laden commodities involve rendering them first through clusters of waves. And when waves are applied to geophysical mapping, the environment paradoxically appears as tangible substances. Encountering these substances within their larger situated circuits illuminates their relations. Tracing those relations back through genealogies of tomographic techniques has the potential of opening up further dynamics.

Overview and Summary of Thesis

This thesis presents a novel approach to sound observed in its contextual dynamics where sounds manifest in spatial-material identities and sonic attention emerges entangled with dynamics of the expanse. The thesis demonstrates that sonic specificity itself is a qualitative outcome of sound's operative circuitry and that emergent space-material-temporality are senses of those operations. Particular emphasis has been placed on sonic *qualitative presence* and its related operational contexts. These aspects have been explored through an application of the operational circuit approach (OCA) to cardinal sites of terrestrial hearing with particular emphasis on sites relating to modern ontologies and epistemologies of sound.

The opening chapters (*Shapes of Time, Hear and There, Perspectives on Sound and Space*) contended with fundamental spatial and material underpinnings of sound. The three chapters constituted an outward movement beginning with the spaces of immediate experience, to that of perception, and onto the environment at large. In all three instances — the site of subjective experience; the site of the human body; and the site of environmental monitoring — differing situated practices of sonic observation were gauged in relation with their correspondingly divergent materializations of sound. The initial chapters demonstrated that sound's spatiality is inextricably tied to its situated contexts.

Chapter four (Phased-space) functioned as a crossfade into the operational circuit approach where categories of sonic materiality give way to more pervasive underlying circuit dynamics, forming an integrative processual expanse where observer/observed/environment perpetually interleave.

Sound's expansive circuitry was developed in the three subsequent chapters (Earth-bound Sound, Baku Sirens, Sound Circuit Operation) where open-ended entanglements, at the oscillating interfaces of geology-organisms-environments, form the basis of sound's vibrant terrestrial dynamics. The operational circuit approach was shown to diminished binary distinctions between natural/technical and organic/inorganic, engaging a more pervasive domain where social-historical, political, technical, biological and geological conditions constitute a continual expanse of circuit interactions. The chapter Earth-bound Sound addressed sound's distributed terrestrial dynamics, across various geological epochs, with particular attention the ways in which humans extend their hearing over the horizon and underwater. Baku Sirens picked up the specific geo-historical context of Baku, Azerbaijan, at the dawn of industrialized petrochemical extraction, in order to observe the social/political/aesthetic/economic/technological vectors passing though situated modes of hearing mechanical sirens. The chapter titled Sound Circuit Operation provides an overview of the central components and mechanisms involved in sound's operational circuitry with particular attention to the spatial-material, as well as temporal and subjective, transformations circuit actions entail.

Originality of the Approach

The originality of the thesis is reflected in the demonstration of sound as situated habitats of spatial, material and temporal qualities productive of operations in territorial agencies of the expanse. It provides an account of sound that clarifies its inexhaustible diversity of spatial-material manifestations and at the same time sound's varying degrees of agency and territorial variability. It presents a novel approach to observation, analysis and writing that participates with its subject matter and performs discernible interlinks.

Sounds are actions taking place within an expanse in perpetual change. Entangled aspects of sonic circuits (with abundant references to the natural sciences) aim to place this account within the scope of material formations (forms-in-process), but also hopes to extend the scope of material activities by accounting for the frames of observation and qualities of appearance as *traceable,* active, components in spatial-temporal materializations and operations. Heterogeneous instances of hearing and listening, linked to specific manifestations of sonic materiality, culminate at particular 'sites' through which junctions of interlinked dynamics are more readily accessible.

One marked challenge in this approach is an awareness that the inquiry operates on the same features it aims to disclose. When describing sound, language and syntax become part of their dynamic, extending their operations by way of textual transductions. In defense of writing as a valid access tool, the overwhelming majority of the ideas developed in this thesis stem from gradually evolving intuitions, over nearly three decades of the author's sonic-spatial practices. During that time, text and language have proven crucial tools for navigating context. Text applied as a tool is particularly productive in historical milieus where much of the early modern sonic ontologies and epistemologies sediment in print media (text/image). Writing has also proven a worthy companion, in prolonging noteworthy observations, while working through incidental thoughts or advancing sonic intuitions.

However in other cases text has proven a hindrance, especially when attempting to navigate non-verbal, tactile-emotive impressions crucial for situated, patched-in, experiences of sound. As such, the ongoing dialogue between explorations of sounding (situated audio and somatic practices) and processes of sense-making (verbal/textual thinking) remain central to the praxis.[7]

Key Findings

OCA's deliberately unbounded approach, necessarily exceeding its subjects, produces a broad range of insights, including some unforeseen in the initial research questions, most notably OCA itself that emerged over the course of site investigations. The following list covers key findings, ranged from insights regarding the material nature of sound and its ambient agency (the entry points of this thesis) to incidental historical and theoretical discoveries uncovered journeying along sound's meandering operational pathways.

> Sounds materialize expansive operational circuits.

> Manifest sounds function in circuit operations.

> Operational circuits demonstrate sonic identity as process.

> Sound's spatiality is a contextually bound quality.

> Spatiality and temporality in sound are emergent material qualities.

7 In the larger scheme of sonic operations, print media accounts for but a small portion of sound's agency. But the efforts of textual mediations are worthwhile, in their ability to locate orienting waymarks, unmaking stagnant attentions or diverting pathways elsewhere. Every perturbation, no matter how feeble or futile, somehow, somewhere, eventually performs effects.

> Auditory experience performs subjectivity.

> Listening recalibrates relations between subjects and surrounds.

> Hearing is a multi-modal, socially, historically, technologically, biologically, geologically and geographically situated affair.

> Sound is a central mechanism in terrestrial transformations deeply involved in organic-inorganic binds.

> Sound operations interlink geologic and biotic processes.

> Knowledge gaps between the 'historicity of senses' and the 'natural history senses' require urgent qualification.

> The invention of audio (mechanical/electrical) increases human attention to sound.

> Audio techniques relay on specific chemical/mineral agglomerations (e.g. piezoelectric crystals, conductive metals, insulating polymers, mineral resisters, diodes and coherers) and energetic ducting (the domestication of electricity).

> Material impressions (epistemological/ontological) in general, and audio techniques in particular, have discernable impact on quotidian senses of self and surrounds.

> Unpredicted intensifications of sound in anthropic circuits, especially over the course of the 20th century, produce divergent effects.

> Many developments in the science of acoustics overlap with, and are historically tied into, tactical advancements.

> All developments in underwater sound monitoring are inextricably bound to military applications.

> There are distinctive parallels between morphogenesis of sensory organs and genealogies of sensing technologies in terms of the transformations they endure and impart upon relational ecologies.

> Global scaled hearing is hatched at the intersection of developments in telegraphy, geology, weather monitoring and high explosives.

> Phased-array spatial audio applications — the central mechanism in pervasive diagnostic, surveying, monitoring and extraction techniques — are developed in overlapping contexts of hydrocarbon exploration and submersible warfare.

> Sound beaming synthesis techniques, that closely resemble Wave Field Synthesis (WFS), were patented more than 70 years before WFS was officially invented at TU Delft.

> Print media, transmission and recordings are central components in hatching the trans-national Soviet subject.

> Audio was first applied in Bolshevik propaganda (radio and recordings), predating by more than two decades audio propaganda in World War II.

> There is a formidable second-wave of underwater surveillance technology deployment currently underway, comparable to the first SOSUS (Cold War) initiative.

Operational Circuit Approach (OCA)

This study proposes that the ontology of a sound and cultural-historically situated understandings of sound are inextricably intertwined. Both being and appearance in sound — what sound 'is' and what it 'seems to be' — are deeply rooted in the sound's spatial-material *operations* that are themselves dependent upon circumstantial conditions. This applies to implicit and explicit epistemologies, such as understated sound theories embedded haphazardly in sonic practices or absentmindedly circulating in the sound studies literature, as well as explicit models of sound such as the axioms of acoustics in applied sciences. The operation circuit approach (OCA) presents a novel integrative, non-totalizing method for finding back the varied qualifications of sounds through their corresponding contextual circuit functions. The approach recognizes that sound's manifestations reflect divergent contextual configurations, calibrated within, and scaled to, corresponding operational circuits.

OCA allows for the recovery of seemingly contradictory ontologies of sound as equally significant *oscillatory behaviors* within a broader dynamics of the extant. Its ontological pluralism accounts for variations and paradoxes in qualitative appearances of sounds as essential *features* of the processual manifest. To comprehend the spatial-materiality of a sound, one must seek its corresponding *operational circuits*. Every sonic manifestation expresses material traits where qualitative specificity is a gateway to contextual operations to which OCA provides partial access. This thesis demonstrates the utility of retrieving sound's agencies from within its networked materials and meanings, dynamically patched through sites of attention.

The operational circuit approach exercises a contextual empiricism bound to the material realities of its subject sounds. In this approach, dimensions of the real remain tightly bound to circumstances of their materialization, the contexts of which only partially manifest in the subjects at hand. The approach places particular emphasis on sound's details, quirks, and relational nuances, while providing access to active currents, perpetually distributing elsewhere, in the making and unmaking of its features.

The thesis argues for a closer attention to the agency of *contextual dynamics* in sound and provides concrete examples for probing situated, relationally interlinked, sonic contexts and their role in determining the spatial-material qualities of sound. It also argues conversely, that spatial-material qualities of sound can provide partial maps for navigating the dynamic. OCA's encompassing approach diminishes binary distinctions such as natural/artificial, history/prehistory, technical/cultural, and organic/inorganic while at the same time factoring in dimensions of the observer and existential processes at large.

Sound is discerned in its emergent, transformative properties and contextual operations, providing a robustly differentiated alternative to prevalent universalizing models of sound. The sited, polyvalent ontologies and epistemologies of sound are understood to be shifting senses of materiality whose qualities reflect differing refractive-transductive circuits. OCA provides glimpses into the processes, providing a platform for analysis, strategies for change, or more generally a direct sense of the interconnectivities enmeshing the surrounds. Within my own artistic practice the latter aspect is crucial for sensing interlinks and taking heed of the processual splendor that abounds.

Although OCA has been fostered in sonic domains, the situated-observational approach towards identity could also be applied to other, complex, time-sensitive, contextually relational, categories of qualitative appearance.

It should be noted that OCA is considered an *approach* and not a methodology as it potentially fosters alternate tools and methods at each site. OCA does not aim to, and in fact cannot, provide comprehensive rules, techniques and procedures to be applied universally across *all* circuits. Each encounter potentially calls for its own calibrations and dedicated means of access, hatching innumerable situated tools and ad-hoc procedures in unforeseen, site-dependent methodologies.

Implications of Findings for Academia, Education and Practice

OCA as a Strategy of Inquiry

The operational circuit approach offers a comprehensive framework for grasping sound's contextuality and terrestrial agency. It encompasses a wide range of vibratory, undulatory, and oscillatory configurations associated with spatial-material impressions of sound. This approach views every appearance of sound as a continuously reconfiguring 'moment' in relational, contextually bound circulations. It challenges conventional, unproblematic definitions such as 'hearing', 'sound', 'acoustics' and 'communication' by confronting them with their situated conditions and milieus. It shuns analytic binaries such as object/subject, measured/perceived, music/noise, and natural/technical, observing instead the manners in which these binaries arise through haphazard developments and practical constraints. The approach is particularly effective for unpacking biased agencies in sound's multifarious audio and noise abatement careers.[8]

8 For a comprehensive account of the various careers noise as assumed across the ages see Schwartz, Hillel. *Making*

OCA cannot be discipline bound as it purposefully surpasses disciplinary borders, knowledge distinctions and temporal frames, beckoning further navigations though intertwining relations and dynamic processes at large. The leveling-out of the (sonic) field is applied in order to examine sound's conductive infrastructures across social, historical and geo/physical domains, observed instead in terms of their continual movements, interlinking the expanse. Extending sounds over their vocational horizons and beyond their epistemic constraints aims at drawing sounds back into more pervasive dynamics of the extant. Assuming a position where sound's discrete, distinctive qualities are simultaneously discerned in their situated configurations as well as their role in larger, undulating energetic tangles. Admittedly this vantage seems tedious at first, though it is a necessary step towards the reassessment of sounds in their integral, complex, *terrestrial agency*. The resolutely non-disciplinary stance sustained throughout the research has proven paramount for the unpacking sonic operations across incongruent domains.

There is a broad range of implications to approaching sound through its operational circuitry, first and foremost as a means of qualifying its manifestations from within its emplaced realities and not by way of extraneous schematic abstractions. It also calls for careful *contextual analysis* of *operational dynamics* in disciplines and practices confronted with questions pertaining to sound.[9]

Sound's active circuitry, with its operationally networked and dynamic-based infrastructures, can serve as a useful model for other fields attending to context-dependent and time-sensitive qualities and identities over a broad range of fields and practices. Furthermore, sound's marked situatedness, ontological diversity and multi-temporality offer a powerful framework for rethinking context-bound materiality in general, revisited in terms of its *relationally-active* constraints and interleaved subject *distributions.* The conditional operations and shape-shifting in sound can serve as a guide for nuanced observations in transience of other context-bound qualities and identities.

Getting a grip on the extents of a subject remains a challenge in this approach. Unlike conventional 'things', circulating things-in-the-making — oscillating between things and flows — continually evade comprehensive grasp. Observing their constructs requires perpetual dialogue, not more room on the shelf. The emphasis on entities considered simultaneously as *things* and *processes*, in perpetual exchanges with dynamics of the expanse, could be applied to specific questions in a broad range of disciplines. For example mapping threshold dynamics in the definitions of borders, zones and territories or rethinking the limits of organisms, gauged in terms of interlocking processes.[10] More generally, OCA provides a tool for revisiting the status of subjects and substances circulating in the applied and natural sciences.[11]

Most urgently though, the operational circuit approach offers inexhaustible connectivity, a feature that can assist in *unmaking* detached, self-contained, universalizing impressions of matter. Predominant impressions linked to detrimental attentions facilitating the human-induced ecological crisis. It may even provide some leeway into grasping the complex dynamic of attention circuits involved in identity polarizations at zones of political conflict.

Noise: From Babel to the Big Bang & Beyond. Zone Books, 2011.

9 Tools for raising contextual awareness could include but are not limited to sound mappings, sound modeling, operation circuit diagrams, context circuit surveys, field recordings analysis and experimental in audio montage. AI techniques could also prove productive for navigating particular aspects of context.

10 The architect and scholar Marc Schoonderbeek points out the inadequacy of conventional architectural and urban planning analysis tools when confronting the 'increased level of complexity, fragmentation and multiplicity' characteristic of contemporary spaces, stressing the importance of inventive, situated mapping strategies capable not only of grasping the intricacies of spatial thresholds, but also strategies where mapping knowingly and actively participates in preparing future actions (Schoonderbeek, 2021). Process biology similarly revisits definitions of biological entities, grappling with their temporal dimensions and entanglements with environments, proposing a view of living systems as *processes* (See for example Dupré et al., 2018)

11 Material properties underlying categorical distinctions in the natural sciences over-emphasize properties and structures of physical substrates, asserting a primacy of their 'object' status. Even with the 19th century turn away from objects and into the interest in energies there remains a bias of energy categories and classifications, enforced through epistemic as well as institutional departmental distinctions. In order to access *reciprocities* of the expanse, instead of discerning categories, observations should be trained on *continuities* of energetic dynamics, passing between heterogeneous physical domains with multitude appearances.

OCA's Timely Validity

Civilization is a set of practices calling for closer scrutiny. Human existential techniques interleave oscillatory fluxes, facilitating vast reconfigurations of the expanse. Techniques of advanced civilization, rife with myths of progress and littered with detached universalized material presumptions, participate in complex epistemic and ontological frameworks informing quotidian social ways of being. Accumulations of tools and techniques usher in a flood of absentminded perceptions that partially transpose into to actual accumulations of flash floods and landslides in the current epoch. What practices enforce detached/extracted impressions of materiality and subjectivity linked to the currant impasse? It is generally accepted that media formats sustain spatial and temporal biases but what are the infrastructures and dynamics through which those biases circulate and anchor in conscious perceptions? How do ubiquitous techniques calibrate shared social attentions?

The urgency of complex *operational accounts of attention* (sonic or otherwise) becomes increasingly evident through the vast array of transient forces infiltrating and influencing seemingly intimate quotidian space. Locality is continually bisected with global currents and interspersed with territorial fluxes of climate and politics, unfolding on multiple spaces and scales. Recent research draws links between periods of intense environmental change and corresponding political upheavals, how do globally networked audio and digital imagery contribute to the dynamic?[12] Individuals are patched into expansive electronic networks (that are also terrestrial circuits) in perpetual reconfiguration. Personal subjective attention, and by extension subjectivity itself, is distributed across media infrastructures to such an extent that attention itself has become a viable commodity, harvested in online activities, algorithmically mined for profit. Network access also means that diffuse identities are susceptible to external forces and redistributions such as divisive polarizations. Recent conflicts in the Ukraine and the Middle East demonstrates collective identity as a key battle tactic including the weaponization of subjective emotions for political gain. Today, the networked, non-locality of the self is a material fact. From the vantage of terrestrial operational circuits, there is nothing 'new' in such a paradigm besides, possibly, the fact that the patchworks are more electronically ducted, extensively interlinked and expansively distributed geographically in comparison with periods prior to the domestication of electricity.

Consequently, effects of distributed-locality are more perceptually apparent. At times even distractingly apparent, especially during periods of rapid reconfigurations in networked behaviors such as during the spread of pandemics or the outbreaks of political conflict. Novelties of algorithmically networked attentions and distributed subjectivity invite more investigations, however there is currently, to the best of the author's knowledge, a lack of *models* and *approaches* for examining dynamic relational repercussions of circuit operations. Observing sound's terrestrial participations provides some hints. Seeking the cardinal contextual operations relating to attention circulations can provide an approach.

Taken as a model, the sonic circuit considers perceptual attentions as contextually-invested, malleable, functional configurations that are as much in processes of corroborating towards an integrated sensory whole (sense-making coherent sensory-worlds) as much as they may be in competition with one another towards revealing the full gamut of possible sense impressions (contradictory presences). Not everything that can be perceived is *simultaneously* in reach for any given perceiver. Recognition consists of expansive circuit-movements involving context assemblages of human-non-human, organic-inorganic binds, clustering diverse domains of the extant through interlinked energetic movements in perpetual reconfigurations. In short, every perception, by its very nature, is a manifestation of certain biases that are discernable in the features of attentive specificity. Considered more broadly, differing attentions patch together alternate context assemblages, potentially drawing out concurrent manifestations from the expanse. One consequence is that shifts in attention circuits may offer differing impressions of situatedness. The operational circuit approach accounts for these complex *operations of attention* by following their itineraries and movements in terrestrial

12 For a compelling discussion of dynamic links between volcanic induced climate impacts and Chinese dynastic collapse, across two millennia of Chinese history see (Gao et al., 2021).

milieus. At the same time keeping track of aspects in the Umwelten-realities such movements and interactions tend to sustain.

The operational circuit approach is a preliminary step towards the development of complex accounts for terrestrial reciprocity, nested in a practical model of attention and sonic operations. The thesis provides fragmentary glimpses into a vast universe of relational interactions through situated accounts of sounds qualified in their distributed, operational splendor.

OCA and Spatial Discourses

Sites of hearing have been investigated in the thesis as milieus within which observer-observed emerge simultaneously through ongoing temporal interactions. The term 'site' is reassessed through OCA in terms of its status as a *critical node* (rather than inert backdrops) of intersecting motions in expansive circuit operations. In OCA terms, every 'site' already sustains preexisting orders that require examination and qualification. Emplacing mechanisms observed in sound circuits — sound's overt situatedness — could be taken as a guide for rethinking place-making attributes in architecture's diverse *conditions*. More directly, the operational circuit approaches remedies seemingly immutable geometric-tectonic biases by reacquainting 'forms' with their inextricable temporality. Recognizing the structures in vibrancy, asserts the primacy of atmospheres that subsume their tectonics.[13] At the very least, thinking through sonic circuitry has the potential of amending distinctions between primary and secondary materiality in architectural thinking and practice (materializing the so-called 'immaterial' and temporalizing seemingly static), highlighting the agency of ambiences and relegating tectonic form to a status of surface effects in more fundamental relational processes and interactions.

Contributions to the spatial discourse include providing an approach for rethinking spatiotemporal properties in terms of their broader existential constraints, beyond the touted social production of space and into complex palaeo-bio-geophysical horizons. In this broadened vantage, space and place are understood as *outcomes* of sited dynamics where spatial orientations and the materialities of places are considered transitory formations of movement-actions. Sound's essential participation in the production of space is a preliminary step towards a robust theory of events that is attentive to relational interactions, poly-temporal fray, and situated agencies of context. Both space *and* place become absorbed in processes. Their sites and locales deemed habitats of sustained interlocking circuits where immediate surrounds are capable of reflecting the distant and arcane. Place becomes multiple, radically heterogeneous, poly-temporal, transitory and fundamentally open to inextricable change.

OCA resolves the hackneyed opposition between 'qualitative space' and 'absolute space', where embodied, lived, intensive qualities of 'place' are pitted against the bygone abstractions of homogeneous, absolute (Euclidean-Newtonian) 'space'. Deeming both equally *real* to the extent that both — lived qualitative space as well as Euclidean-Newtonian spatial abstractions — relay functional circuits, enacting alternate social attentions and practices. Differing senses of the locale decisively impact manners in which quotidian surroundings are experienced, lived and inscribed with those lives. Furthermore, every milieu inevitably contains coextend and intermixed impressions sharing the same locale. Dynamics of the extant is interleaved through and through with patchworks of poly-temporal, discontinuous, contrasting sensory-worlds.

With sound as a guide, the approach rethinks frameworks of space in terms of circulatory processes, where material operations sustain diverse ways of being. Places, spaces, times and actions are subsumed in complex territorial shimmers, patterned and thickened through interlocking circuits. Beyond space and place is the dynamics of perpetual recombination, of ad-hock clustering and radically heterogeneous spatio-material potentialities.

Although by definition these contexts are distributive, expansive and non-localized, their dynamics

13 From the OCA vantage, tectonics itself is redefined as an intensive dynamic knotting of countless intermingling processes and effects. Different only in degree but not in kind from the multitude of other experiential, atmospheric, social-political, mineral-geological, site-specific qualitative properties stratifying locality that are often relegated to secondary circumstantial 'effects'.

none the less produce situated tendencies. On the register of discrete sonic entities, their subjects/matters are emergent properties of contexts in action. To a certain extent, events *perform* both the observer and observed, where subjects and qualities emerge from mutual contextual interactions. The proposal here is to think of 'locales' as culminations of circuit actions rather than indifferent backdrops, territories where properties and orientations continually unfold through ongoing movement-actions.

OCA in Borders and Territories

This thesis posits the site of sound as a model through which to examine shifting borders, zones of interaction, territorial dynamics and processes of differentiation and distinguishability. By tracing operational circuitries of attention through their eclectic, distributed, contexts, sonic sites reveal the comings and goings of their spatial and temporal ontologies. Attending to situated conditions and tracing corresponding fields of agency accesses infrastructures of appearance and importantly map out what is at stake in particular modes of presence.

Mapping sound's circuitry is a scale-less procedure that moves through radically heterogeneous components linked to a given context. For similar reasons this mapping procedure cannot provide complete inventory or clearly defined territorial delineations. Edges of the circuit remain fuzzy as constituent circulating components are inevitably bound to other, adjacent circuits. Nevertheless, following the eclectic, haphazard refractions as events transduce through a site reveal unexpected interrelations that cannot be discerned otherwise. The procedure also attempts to engage speculation and intuition, by attending to transformations and tendencies incurred through subjective observation.

Sound's circulatory operations could potentially be taken as a measure for reading territorial reconfigurations. Distinguishing threshold conditions dynamically shaping borders, zones and territories. Observing behaviours of sonic operations can assist in reimagining the notion of milieu, locale and site in terms of their on-going relational transformations. By extension, sonic ontologies of differentiation, call for more *temporally* informed tectonics and contextually responsive architectural thinking.

From the operational circuit vantage, experiential encounters are always importantly situated. Attentions together with the actions they entail, and territories they entangle, *perform* the site and their extended temporal interlinks. Dynamics of the expanse is in a continual process of differentiation through separations and recombination. Throughout these processes, that are agglomerations of organic-inorganic attentions, shifting borders and zones of action are everywhere articulated through qualitative specificities. Their zones are territorially bound, defined by the spaces that are actualized in their contextual operations. Attending to the dynamics reveals the sublime manners in which subjects aggregate, form, conform, fracture, fray, displace and sediment in combination with the pulsating expanse.

OCA as a Means of Critical Transformation

OCA has proven an effective analysis tool for grasping contextual dynamics. It could also be applied as a manner of transforming or manipulating contextual relations towards anticipated outcomes. However the circuit's inherent *emergent behaviors* complicate predictions of circuited eventualities. Nevertheless the approach could also be applied as a roadmap or means for diverting existing circuits as well as experimenting with novel repatching and reconfigurations.

Reflection on Inquiry Method

Navigating Context

A notable aspect of contextual dynamics in general, and circuits in particular, is that any point along the pathway could present a viable point of entry. The looped nature of circulating interactions means that any point along a current provides access. Entering the dynamics of the extant entails decreasing the distance between the observations and subject matters at hand. The process involves a double action on the part of the observer: an openness to recognize connective links as well as bifurcations in context. It involves the relaxation of preconceptions regarding determinate boundaries of its subjects. As such the process entails a kind of blur where the observer gradually becomes aware of the fusion with their field of observation. If tuned properly, the process and scopes of comprehension become immense. In navigating perceptual sites, an observer's attentions spread out over ever-greater spheres of eventfulness. The sheer weight of facts, details and accumulated qualities culled en-rout bears down on the observation process. Diverging yet overlapping temporal scales and subject matters, at times seem incommensurable, confounding common sense. That combined with the unbounded meandering navigations in overlapping zones and contexts can be adventurous but also daunting, tedious and considerably time consuming.

Contextual circuitry can only ever be vaguely apparent in advance. Being lost in contexts is of essence to the process but one must remain vigilant in recognizing changes of course or the breaching of central operational mechanisms. Once the observer is fully engaged in the flows, unexpected discoveries occur and the circuits begin to manifest in all their eclectic diversity and poly-temporality.

Snowballing contexts can quickly become an impasse through an overabundance of pathways they present. As site opens into the myriad entanglements of its specificities, its milieus radically expand. However the expansions also thwart possibilities of making distinctions and taking decisions. In other words the radical openness provides a wealth of signification that can also potentially lead to observational paralysis.

Unless the researcher is predisposed to this kind of approach, with its perpetual uncertainties, ongoing recalibrations, continual transformations and excessive effort involved, I would *not* recommend adopting OCA as a general inquiry tool. In addition, for those accustomed to empirical research, these aforementioned aspects may prove more a source of anxiety than a strategy for analytic resolve. However, for those seeking nuanced, differentiated and paradoxical interplays of spatial-material attentions, open for adventurous travails, OCA holds great potential.

The Limits of Context

The notion that contextual dynamics facilitate modes of appearance raises some challenging questions regarding the dynamic extents of context. Attempting to broach the intricacies of context by streaming along its tributaries reveals itineraries whose limits are never clearly defined. At every threshold, the next is revealed such that context potentially grows exponentially, eventually encompassing an entire universe of interactions. So either the limits of context are arbitrarily set to the convenience of an observer, or contexts themselves are illusory phantoms in a much larger fluctuant totality. If either of those conclusions were indeed the case, observations of contextual processes would be ineffective at best, or worst, dangerously reductive illusions of what is essentially a monolithic clump of interconnections - a monism. In practice, contexts prove themselves to be otherwise, manifesting in peculiar attractors, with clumpy heterogeneity, capable of diverting currents and altering manners of interaction that bring forth alternate contexts, reclusively reorienting the circuit flows.

In order to avoid monist pitfalls, it is important to keep hold of the central characteristics of particular qualities as a guide and maintain course with the flow. Spatial-temporal-material particularities keep the contextual boundaries in check. Fuzzy edges occur in locales where the clustering draw of quality ceases to effect adjacencies of a sound. A change in force is not unlike the sensation of moving from the central current in river to its periphery. If a quality changes, so do the circulated attentions, redistributing the contextual contingencies and flows. Qualities such as space, materiality and temporality are emergent agencies of contextual dynamics, facilitating tendencies and orientation of the motions — attracting, repelling, combining and dispersing — their presence exerts a force. Context is its circulatory milieu. OCA makes the movements palpable.

Limits of Embodied Attention

As attention spreads out over increasingly larger territories and more interconnections materialize, the sheer enormity of contextual expanse rapidly reaches the limits of comprehension. This is not so much a weakness as much as it is a feature of the operational circuit approach. The practice seems to be at odds with the faculties of embodied comprehension, as the unraveling of sensations counteracts reflexive orientations maintained by the perceiving body that is geared towards immediate actions in its surrounds. Put simply: the underlying relational configurations of sound, continually shifting meanings and spatial-material appearances, are not readily accessible behind the apparent artifacts of reflexive perception. They need to be retrieved, with some effort, drawn out of their operational contexts. Sound's infrastructures must be traced out by way of their operational configurations, followed over the various courses of oscillatory perturbation through discontinuous locales and over multiple scales and times. The resultant *tectonics of hearing* produces a partial map of those sounds, traced back through their dedicated spaces of action, where each sound occupies a particular cycle in much larger dynamic tangles. The practice of redirecting attentions back towards their objects, refracted-transduced over their formative contexts, is an exhilarating, as well as exhausting process that has the potential of uncovering vast interlinking *attention circuits* in all their peculiar quirks and dazzling details.

Two central challenges encountered in refracting attentions through the sites of hearing:

1) Spreading observation, over larger and larger portions of the extant, produces a multifocal attention, testing the limits of observation and challenging the abilities of comprehending. Loosening the stranglehold of predetermined meanings cast *over* a site, in order to open *into* its agencies has proven crucial for such contextual navigations. However maintaining a course and bearing remains difficult while traversing the dissolve over myriad, bifurcating, pathways.

2) From the OCA vantage, existence appears more statistically interleaved than causally bound. However, the more one focuses on the *relationships* between eventfulness and its spatial, material, and temporal characteristics, the more these events resemble a puzzle. Or even a conspiracy. This intensified sense of causality — one event leading to another — requires further research into how meaning constructs persist and disperse while refracting through the sites of attention. Language and narration play a crucial role here, as they selectively frame events based on certain perceptual filters.[14] However, this selective framing can lead to a fragmentary understanding of events, glossing over other circumstantial relations in the milieu, potentially obscuring more fundamental aspects of the dynamics.

For example, the 'evidence' paradigm, central to the forensic approach, operates within *predetermined*, unproblematic event limitations. Foreclosed in presupposed meanings, projected retroactively over a site, seeking qualifications in sequences of causal effects. In that sense, forensic approaches, by definition, can *never* capture the full complexity of events due to their rigidly calibrated preconceived, often anthropocentric, orientations. This suggests that cause-and-effect chains themselves may be linked to observational biases — and narrative reflexes — calling for more research into relations between narration and sense-making.

What distinguishes the circuit model is that its features are also its operations. They arise and sustain through relational tensions *not* chained to causal effects. Contrary to the forensic approach that attempts to recover a singular 'truthful narrative', the operational circuit approach multiples narration potentials as more and more details come into play. The narrative-polyphony of OCA presents practical limitations for empirical observation, but also creative potentials in terms of the range of possible forms and formats OCA can take on.

Addressing both challenges, it is imperative, at least in initial encounters with a site, to consciously

14 Grammar may exaggerate impressions of causality, especially when narrated in languages that are past-present-future tensed. Descriptions of actions, potentially over-narrate their events, producing forced impressions of sequential causation. Overemphasized outcome conditions that potentially, retroactively, adjust orientations and limit constraints of a more complex unfolding.

resist verifications of predetermined meanings projected over the site, and instead open up to the multiple associations arising in-situ. Attending to the various strands, seeking their relational encapsulations, unveils multiple transductive and refractive forces structuring the site.[15] Eventually, more complex, multi-scalar, poly-temporal and concurrent, impressions emerge, superimposed on, and interleaving with, the initial sensations. At the same time, certain recognitions and movements tend to appear more vividly than others. This culling of context is an unavoidable outcome of observer participation that is a crucial component in contextual navigations. It also underscores the importance of observer-dependent calibrations, the recognition and acknowledgment of subjective biases, and careful assessment of the responsibilities entailed in any given site navigation.

OCA Shortcoming

Although OCA provides a portal into dynamics of the expanse, as of yet, it does not account for mechanisms of circuit dynamics. Neither has it provided a good definition of what constitutes the components of a context. For example why do circuits mobilize certain portions of a context and not other adjacencies? Why does one assembly takes precedence over another? How do circuits perpetuate or evade dissipation? When/how do circuits transform? What determines a circuit's movement structure? When do circuit components form productive/destructive relations (e.g. processes of coevolution/dissolution)? Although these questions were not directly addressed in the current research, they have often popped up as nagging reminders of unattended mechanisms while navigating itineraries of the extant. It is not clear to me, at this point, how (or if) its possible to gain a better grasp of such mechanisms, though needless to say a better understanding of behavioral patterns could influence future itineraries and produce more informed navigations of the extant.

The unending nature of the approach is challenging in many respects: in terms of the effort of maintaining focus, determining points of closure, not to mention finding appropriate formats for sharing the circuit navigations. In that sense OCA is more closely related to unfinished projects such as Benjamin's Arcades (Passagen-Werk) and Warburg's Bilderatlas Mnemosyne (networked assemblages) than it is to common historiography or 'studies' paradigms.

Reflection on Structure

Sound Writing

The writing builds on observations — culled from over two decades of the author's sonic practice and research — into the situated dynamics and spatial-material operations of sound. The approach outlined in this thesis has been fostered through ongoing participation with the substances, techniques, sites and milieus pertaining to sound. Within the social praxis, speech and words play formative roles in shaping shared experiences of sound. Language sedimentation in written documents and treatises on sound are vital material traces for unpacking qualitative aspects of sonic manifestations where predominant historical, material and technological tropes inevitably turn up as integral components of sonic theories and epistemic models.

Materially speaking, written sounds are *transductions* of embodied events. Scripted sound transduce multiple times en rout to their writing: from air to ear and on through neural pathways, into speech formations and eventually through pens and keyboards into graphically formatted symbols. Books are delay-lines, conduits for rehearing sounds. Sounds already heard, yet waiting for future listeners. Sonic commentary, recorded, printed or digitally stored, alters the propagation pathways and recalibrates sound's spaces of action.

Awareness of writing's *participation* in the production of sounds means neutrality of commentary is implausible. Moreover, this realization is an open invitation to experiment with manners of expression that

15 Another strategy explored in-situ, when confronting contextual overabundance, was overloading on meanings, to the point where narration itself, along with related observational mappings, break down. What remains is some sense of the flux and glimpses into vectors of the possible.

bypass hackneyed dichotomies of objective/subjective prose, addressing instead the dimension of *terrestrial operations* common to all speech and writing. Structural openings, gaps and juxtapositions in the text take their cue from sound's incessant meandering that confounds the tidy conclusiveness of narration.

Understated ethical responsibilities are also linked to observational writing, not least in the manners in which texts remains relationally, materially, entangled with the environments it claims to represent. Those delayed attributes of a site also sustain for extended periods on bookshelves and repositories. Digitized books increasingly provide fodder for AI learning, meaning diffuse trails are currently spreading wider and linger longer. What's at stake with reiterating sonic attentions and to what ends? What are the contextual extents and circuit dynamics of predominant modes of hearing? What sounds remain unheard or intentionally suppressed? What does 'hearing otherwise' entail? Critical dimensions in the writing take heed of such eventualities. For example highlighting paths not taken (e.g. Mach's vibrant materiality) or uncovering controversial histories (e.g. links between tactical obsessions with sound localization and the development of globalized atmospheric hearing). In such cases OCA serves a remedial purpose and not only an analytic tool, pointing out oppressive flows or branches towards alternate circuit pathways.

Latent onomatopoetic dimensions of text, explicit and implicit, common to transcription that recounts phonetic dimensions of speech should also be mentioned in connection with language considerations. Attending to the sonority of sound writing, inevitably influences choice of descriptive words, sentence flow and punctuation. Traces of both the transductive (text as action) and mimetic (language as sound) are reflected throughout the thesis in articulations of cadence and structure. Although these two medial aspects of text are not the same, overlaps inevitably occur.

In summary, the thesis, understood as a textual substance — of sedimentary oscillations — is not extrinsic to the materials it claims to engage and is taken to be a transduced and refracted portion of sound's processual expanse. Sounds delayed in lettered type, patiently waiting on storage media for interactions with future listeners. Accumulated sentences, combining with your reading bring them back up to speed, giving rise to alternate circuits in ongoing, open-ended transformations of sonic sense.

Functions of Format

Aspects of material transduction are also traceable in image-text relationships throughout the thesis. Images serve as important anchors, waymarks and counterpoints for the words and ideas. Forming networked pathways, resonances and visual continuities traversing and interlinking the pages and thoughts. They are not merely deployed referentially, but in some cases serve extensions of the processual nature of the analysis. Further processual extensions are also picked up in the footnotes. For example they can perform as relays to larger implied territories or contexts or provide additional resolution to commentary that otherwise would divert the central meandering flux (see for instance the use of footnotes in the chapters *Baku Sirens* and *Earth-bound Sound* chapters).

The challenge throughout the operational circuit approach has been sustaining attention to continuities, and by extension directing the reader's attention, to corresponding yet dispersed details, while traversing vast swaths of data, history and locales. Meandering tributaries in the text at times intersect and recurring themes or familiar configurations emerge. This is especially the case while crisscrossing predominant auditory sites (such as radio) via alternate trajectories, revealing networked interconnections, with differing tendencies, streaming in and out of the sites.

Infrastructural clarity of the interleaving circuitries inevitably comes at the expense of the comprehensiveness (and conclusiveness) of subjects encountered on-site. If ever subject would be addressed comprehensively the continuities would be lost. Instead, open ends in the text serve a functional purpose. Inviting further investigations on the part of the reader, through your own idiosyncratic attentive calibrations, ensuing further processual operations and alternate manners of traverse.

Future Research Suggestions

Gaps Between the Historicity and Natural History of the Senses

OCA's staunch functional approach demonstrates that divisions between technical and cultural are superficial and that calibrations in techniques of being have crucial ramifications for the range of possible futures. The ways in which humans (and other organisms) arrange and stratify their material surroundings and thoughts inevitably orient their future ways of being. The implications of this simple fact are immense. Responsibilities of engineered landscapes, housing, artistic practices and design fields are paramount in hatching future selves and senses of sociality. Art and design are not merely cultural commentaries or social backdrop, but rather active agents in the making of tangible worlds. In terms of the current state of knowledge, the gap between the historicity and natural history of the senses requires urgent clarifications in order to better address operative dimensions in diverse fields of social production.

Situated Monitoring Techniques

Uncovering the biases of universalized and anthropocentric audio techniques provide fresh incentive to develop non-standard monitoring methods and techniques towards other sensory horizons. In other words, explore differentiated, context-sensitive, approach to observation. Including novel techniques for non-anthropocentric ways of listening. The author is currently experimenting with poly-temporal monitoring techniques and site transduction methods. The research project *Hearing Geoelectric* is another example exploring non-anthropocentric monitoring techniques.[16]

OCA and AI

Throughout the research, OCA was applied as an embodied practice, patched through my own idiosyncratic attentions and perceptions. Part of the experiment involved an attention to shifts in my own subjective experience, as contexts were uncovered. Though at times the processes proved daunting. Especially when trying to sustain snowballing contextual accumulations in conscious attention. Over the course of the project, AI never played a role in contextual navigations. However rapid advances in AI over the past 2 years (2022-2023) and some notable achievements in handling large datasets in the natural sciences (e.g. analysis of vast quantities of data generated by telescopes and satellites) have left me wondering about the possible utilities of AI in future OCA navigations. The primary challenge would be training datasets towards recognition of *linkages* rather than *identity* patterns. Training recognition of *processes* could be a formidable task, especially considering that data sets relevant for an OCA approach are spread *across* multiple heterogeneous domains.

Limitations of current generic implementations of AI are more than evident. A brief test, applying a robust GPT-4 model, linked to the Internet at large, failed to uncover a rudimentary OCA discovery regarding the agency of audio as a Bolshevik propaganda tool. In the test, the AI's response to the question 'When were audio techniques first applied in propaganda?' reiterated the widespread misconception that practices of audio propaganda originate in WWII.[17]

Contextual Movement Analysis

As previously mentioned, one shortcoming of OCA is the fact that, so far, it fails to provide adequate qualification of the precise nature of contextual motions. In other words the circuit components and linkages are made apparent but not the underlying logic of clustering (what clusters and what doesn't), as well as

16 https://www.researchcatalogue.net/view/545729/557132

17 The following question was posed on Jan 14, 2024, to the online search engine Phind, applying the V9 Model, linked to the internet. "When were audio techniques first applied in propaganda?" to which Phind answered "[T]he earliest application of audio techniques in propaganda dates back to World War II, with radio being a significant medium for disseminating propaganda messages." Phind Programming Expert. (2024). Excerpt from answer to query on "When were audio techniques first applied in propaganda?". Retrieved from Phind website https://www.phind.com/.

streaming and motion behaviors. More research into the movement specificities and other dynamic mechanisms is required. Devising a series of experimental setups that could test clustering behaviors and tendencies could be instructive.

Future OCA Navigations

The current research engaged a wide range of sites linked with modern (acoustic) hearing. There are many more sound circuits worthy of OCA navigations. Pervasive zoological and geological sounds provide some clues. In addition it could be productive to test OCA in other domains in order to gauge its broader utility and applicability.

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Glossary

Actuality
Actuality is the quality or state of being actual or real, denoting the many ways of existing without distinction between the ways in which things are and the ways things seem to be. In operational circuit terms, actuality includes all processual manifestations being, stratifying intermingling movements the extant at any given instant.

Circuit Operations
Circuit operations are paramount *mechanisms* of qualitative specificity in sound, structuring its agencies of material dynamics. Circuit operations exemplify *tendencies* and *interchanges* in physical surrounds, collectively informing one another. Circuits lend agency to the contexts they involve while exerting force through circumstantial adjacencies.

Dynamics
Throughout the text, the plural 'dynamics' is used to highlight the diverse relational interactions that give rise to a variety of dynamic categories associated with qualities of the extant. The singular 'dynamic' implies a single overriding principle, which is not the case in mechanisms of the manifest. Instead, the text argues that the diverse formations of sounds occur in the draw of contextual constraints, exhibiting a variety of arrangements with differing dynamic traits.

Extant
The term 'extant' aims to provide a synonym for existence that emphasizes the dynamics *in* presence, hence the noun-ing of the adjective. The term encompasses the sum total of qualitative materializations at any given moment, inclusive of intersecting, participant, experiential worlds. The extant is closely related to the term expanse, the latter emphasizes an expanded dynamic state of ongoing interactions. The former underscores materializations of processes.

Expanse
The term 'expanse' denotes the full extent of intermixed movements in processual actuality, with emphasis on an expanded dynamic state that incorporates emergent spatiotemporal properties of the extant. Expanse and extant are closely related terms, the former emphasizes an expanded dynamic state of ongoing interactions. The latter underscores materializations of processes.

Hearing
Hearing denotes an observer's encounters with oscillations, where material understandings of sound of have already taken shape and meaning taken hold. It includes a range of attentive conditions entailing degrees of knowledge arising from endured fluctuations. Hearing is an *outcome* condition of listening, indicating an attentive state of qualities recognized, towards which wh-questions such as *what*, *where* and *how* can be applied. In the operational circuit approach, hearing denotes examples where contextual dynamics form quasi-stable flows with correspondingly apparent recurrently confirmed meanings. In operational terms, hearing enforces and assists in delineating subjects and subjectivity.

Listening
Listening is an attentive category of reaching towards unknown fluctuant domains. It entails openness towards possible emergent materializations and underscores a creative dimension in recognition. In contrast with hearing's identity affirming state, listening, instead involves open-ended processes of meaning-in-the-making. Listening is a condition of nascent recognitions coming into being, of presences without distinctive outlined meanings. Although everyday use of the term 'listening' includes meaning-intensive practices such

as diagnostic listening (in medicine) or tonal listening (in melodic music), this thesis argues for a more fundamental distinction between destination-bound hearing (an arrival at materiality/meanings) and the reaching-out inclusivity of listening (meandering anticipations). In operational terms listening diffuses boundaries, provides interpenetration and introduces slippage in subject/object relations and senses of subjectivity.

Operational Circuit Approach (OCA)
Sounds observed in terms of terrestrially networked and territorially active circuit operations. The operational circuits approach constitutes a means of analysis and engagement with qualitative energetic manifestations. The approach uncovers contextual dynamics pertaining to sound's spatial-material manifestations, providing accounts of the *operational* mechanisms involved in its *specificities* of appearance. The circuit approach reveals flow patterns, across heterogeneous domains, linked to sounds materialities. OCA's situated-observational approach to sonic identities can also apply to other complex, time-sensitive, contextually relational, categories of qualitative appearance.

Refraction-transduction
A term combining characteristic behaviors of wave propagations, observable in a wide range of energetic dynamics conditions. Refraction-transduction behaviors typically arise when fluctuant energy traverses a heterogeneous medium or passing from one medium to another. The term emphasizes the *transformational* dynamics of travelling oscillatory waves, incurring shifts in direction, speed, spread as well as transformations in energy type along propagation pathways. Refraction-transduction is paramount to operational circuit activities and can also be applied as an analytical tool (circuit-sounding) for accessing sound's operative contexts.

Sound
Sound denotes a wide variety of qualitative materializations of oscillatory processes, especially those linked to mechanical fluctuations in land, water and air. Sounds involve situated qualitative appearances that are contextually dependent and expansively invested. Sounds are endowed with material specificity, possessing any number of observable attributes such as space, texture and time, linked to characteristic behavioral dynamics. Sounds denote expansive circuit operations and related attentions.

Sound Circuit
A sound circuit describes sonic manifestation as a dynamic, expansive, *system of movements* and relational interactions. The term sound circuit does not favor any particular component in the system, underscoring the *entirety of interconnections* involved in a particular qualitative manifestation. Sound circuits operate in the milieu, occupy portions of the expanse, involve contexts and activate agencies.

Transduction
Transduction is a particularly prevalent behavior enforcing continuities in operational circuit pathways across heterogeneous domains of the extant. It denotes expansive oscillation's shape-shifting properties, converting energy from one form to another (e.g. mechanical to electrical), while traversing the expanse. Electro-mechanical transduction mechanisms can be found in technical devices (e.g. microphones and loudspeakers) as well as sensory physiology (e.g. hearing and sight). In operational circuit terms, transductions is used in a broadened sense to include all physical-material conversions and transformations oscillations may incur and endure along expansive circuit pathways, including categories such as recordings, writing, gestures and speech.

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The cumulative endeavor embraces sound's inexhaustible earth-bound splendor.

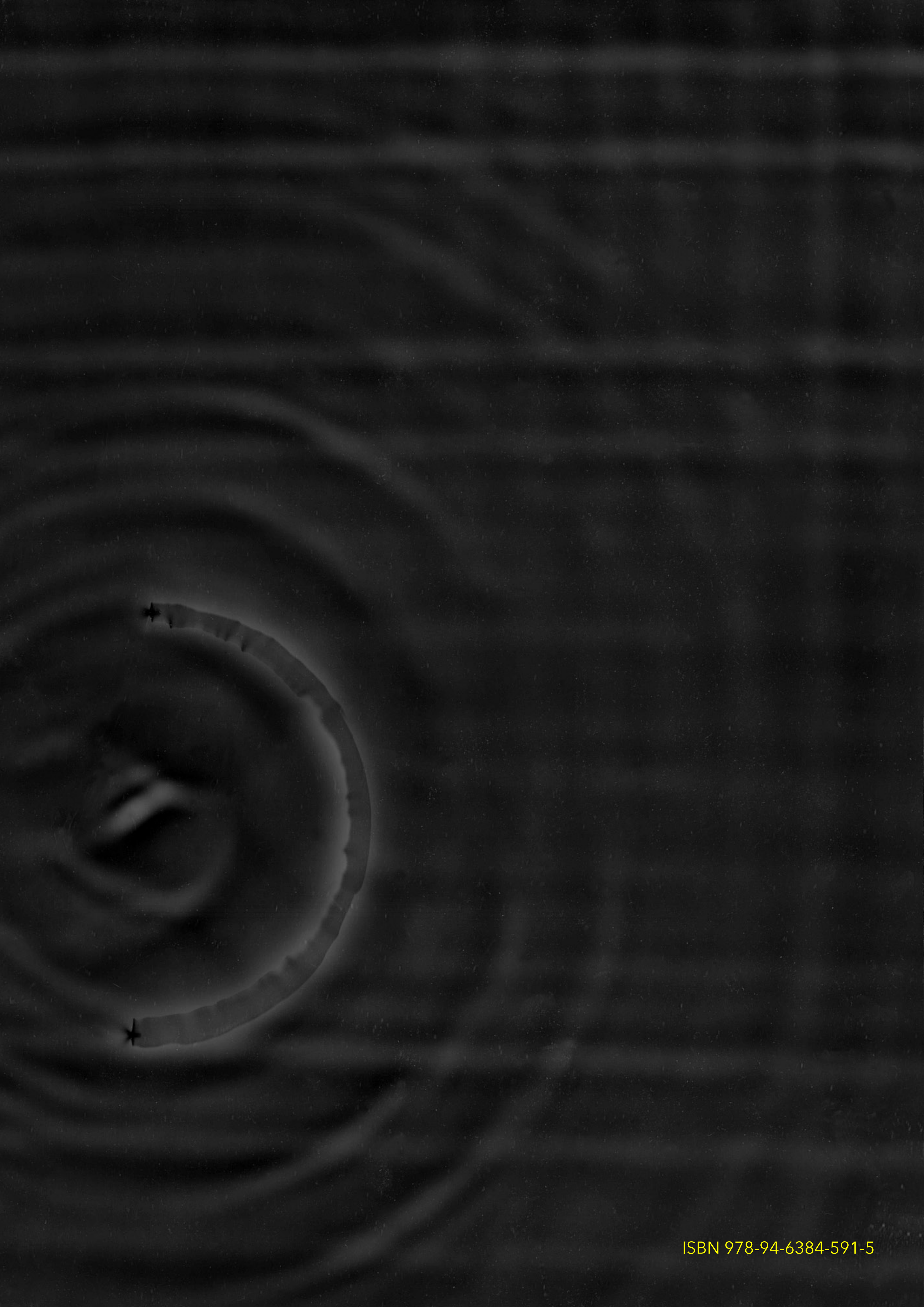
Curriculum Vitae

Raviv Ganchrow (1972) born in Madison (USA) and raised in Jerusalem (IL) is an artist and sound researcher based in Amsterdam, Netherlands. He completed his architectural studies at the Cooper Union, New York in 2000, and graduate studies the Institute of Sonology at The Royal Conservatory, The Hague in 2004.

Ganchrow researches the interdependencies between sound, place, and listening through installations, writing, and the development of pressure-forming and vibration-sensing technologies.

His sound installations and radio broadcasts examine spatial-material operations of sound, in situated conditions such as environmental infrasound, telluric currents, radio transmissions, ocean acoustics, and anechoic chambers. Recent installations employ in-situ circuits patched directly into locations activating contextual dynamics.

Ganchrow's works have been exhibited internationally. He publishes, workshops, and lectures broadly on auditory contexts and sonic agency at various international institutes and universities. He has taught architectural design in the graduate program at Delft University of Technology and is currently a faculty member at the Institute of Sonology, University of the Arts, The Hague, Netherlands.



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