"In this volume, Théberge, Devine and Everrett have gathered together a fascinating body of writing on the technical, psychological and social construction of stereo. While the individual chapters provide some fine grained detail, the editors have situated them into the broader context of the burgeoning new discipline of sound studies."
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"This timely, rich and compelling book situates stereo sound so carefully in historical and contemporary cultures of science, commerce and listening that the book is itself a 'sweet spot' in studies of sound and music."
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"*Living Stereo* provides a site and a topic that serves as an exemplary model of recent scholarship on sound from the vantage point of outstanding scholars drawn from an array of disparate fields. The result is a multi-channel portrait—perhaps 'soundscape' would be a better term—of stereophonic sound from the 1880s to the present."
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Stereo is everywhere. For over half a century, the whole culture and industry of music and sound has been organized around the principle of stereophony. But nothing about this—not the invention, acceptance or ubiquity of stereo—was inevitable. This groundbreaking book uncovers the aesthetic conventions, technologies and listening practices that have made stereo seem natural and that have been necessary to maintain stereo's place as a dominant mode of sound reproduction.

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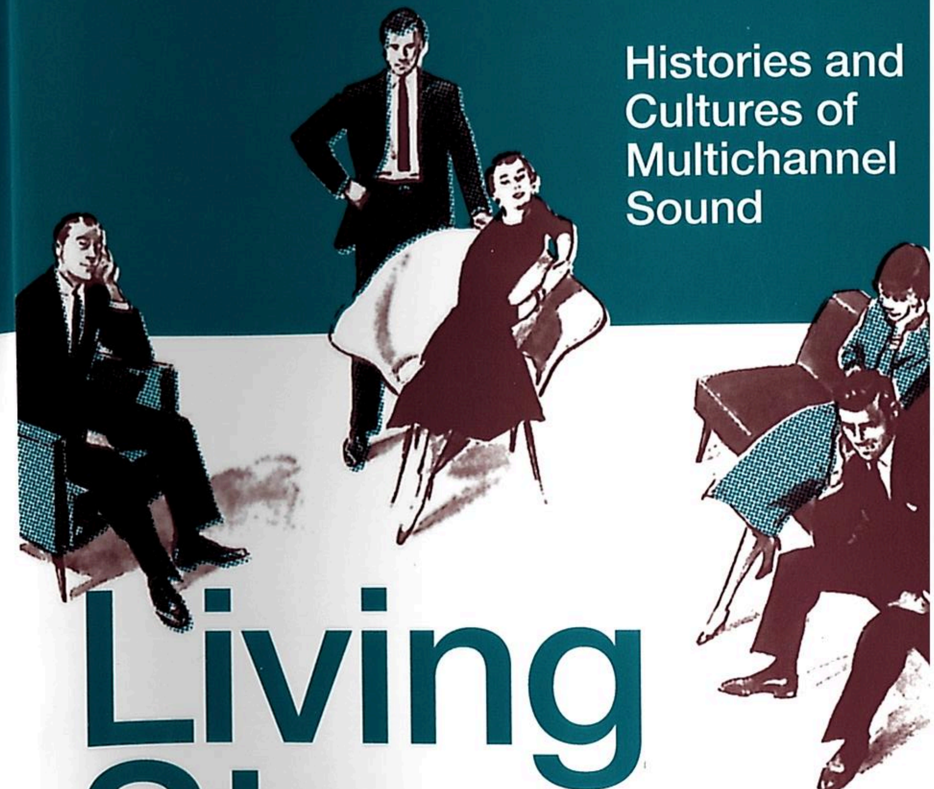

Histories and Cultures of Multichannel Sound

Living Stereo

Paul Théberge
Kyle Devine
Tom Everrett

BLOOMSBURY

CHAPTER THREE

Sonar and the Channelization of the Ocean

John Shiga

Histories of the film and music industries have explored the creative and commercial possibilities opened by multichannel sound from the early 1950s onwards. They have highlighted the manner in which stereo and other multichannel systems (such as surround sound) have been shaped by a long-standing tension between realism and spectacle as competing aesthetic models in the discourses of sound engineers, producers and critics (e.g. Chanan 1995). As Rick Altman (1992) points out, multichannel sound was marketed by the cultural industries under the banner of increasing realism; for audiences and critics, however, stereo's capacity to generate spectacular effects was at least as important as its claims to faithful reproduction of sonic events and spaces. This chapter suggests that, in the context of anti-submarine warfare, the principle driver of multichannel sound research and development was neither realism nor spectacle. Rather, it was the problem posed by the "blindness" of ships to underwater threats, and the potential of multichannel sound to extract locational information about those threats from the noise they unwittingly emitted. By the middle of the twentieth century, "natural" acoustic channels in the ocean became the basis for new command, control and communications systems in underwater warfare. From an impermeable, monolithic body of water, the ocean was redefined in sonar discourse as a vast multichannel sound system.

Although there were many competing figures available to sonar researchers for describing the acoustic space of the ocean (e.g. zones, layers, ducts), the predominant figure of ocean sound in sonar discourse was the channel. I argue that there were two main factors that help explain the prevalence of the channel in explanations of how ocean sound worked and how it could be exploited. First, the discovery and military use of underwater sound channels emerged out of a much longer history of the rationalization of space in modern systems of governance, including the development of canal networks and sea lanes as political technologies that anticipated naval models of ocean sound in the form of undersea channels. With the deployment of motor vehicles in twentieth-century warfare, the figure of the channel in land-based communication and transportation was extended to ocean-space in the form of "sea lines of communication." The "vast logistic tail" across the Atlantic that supplied motor vehicles and other machines of war with "fuel, spare parts, and maintenance and repair services" became a vital component of the Allied war effort (van Creveld 1989/1991: 161). Since sonar was developed to protect these logistic tails from submarines, the design and use of sonar during this period produced an acoustic pathway across the ocean, undergirding the rationalized, linear structures of naval convoys.

The second factor leading to the prevalence of the figure of the channel was its increasing prominence in mid-century sonar research funded by the United States Navy. Such research aimed to develop long-range acoustic detection systems in the Atlantic through the exploitation of a layer of ocean water called the "deep sound channel." I suggest that the figure of the channel became increasingly legible in sonar discourse during this period owing to broad shifts in understandings of "new" media in the first half of the twentieth century, which centered on the capacity to simultaneously send, receive and process signals independently of one another and across multiple channels. Initially developed in the wireless industry and subsequently extended to telephony through carrier multiplexing in the 1920s, and to sound recording in the 1950s, the capacity of electrical channels to enable the independent transfer and manipulation of multiple streams of signals had a profound impact on scientific understandings of underwater sound (Schwartz 2008). Additionally, I suggest that channel-oriented concepts of ocean sound in sonar discourse were shaped by new institutional alignments between scientists with expertise in underwater sound at US universities (particularly Harvard and MIT), who carried out basic scientific research for Cold War sonar systems and telecommunications firms (e.g. Bell Telephone Laboratories); in turn, engineers at these firms built a transoceanic infrastructure of acoustic surveillance. The concept of the ocean as a multichannel audio medium was thus a product, not only of the general trend toward multichannel media, but also of a particular institutional and ideological environment. In this environment, sonar researchers engaged with the problem of controlling undersea space while surrounded by the principles, techniques and infrastructures of multichannel sound.

From Canal to Channel: Archaeology of Liquid Media

"Channel" and "canal" both have liquid origins. They share the same Latin root, *canalis*, which translates as "pipe" or "reed." According to the *Oxford English Dictionary*, the terms "channel" and "canal" emerged in English during the fourteenth century and referred to a conduit for running water, such as a riverbed, or to a tubular structure conveying liquid. It was not until the seventeenth century that the meanings of "channel" and "canal" began to diverge and expand, encompassing the conveyance of ideas as well as water. By the nineteenth century, "canal" lost these associations, while the predominant meaning of "channel" became that of a circuit or band of frequencies for the "transmission of communications" in telecommunications and broadcasting.

We should understand the close connections between "canal" and "channel" not only as a matter of common cultural origins, but also as a consequence of the emergence of new modes of governance in which power came to be exercised through the directed flow of people, things and ideas—both within and across the borders of the modern state. In other words, the meanings of canal and channel have been shaped in similar ways by military and political efforts to control territory through the expansion of rationalized networks of waterways, roads and other lines of communication. Both sets of meanings were shaped by what Armand Mattelart calls the new "ideology of communication," which rested on the insight that the "means of decentralization that permit escape from confinement and from mental and physical barriers allow both the unleashing of movement and the consolidation of the center with the support of the periphery" (1996: xvi).

In eighteenth-century scientific discourse about electricity, the channel and other circulatory metaphors acted as conceptual relays between organic, technological and social systems, enabling those systems to be understood in terms of one another (Otis 2002). These figural links in turn supported new modes of governance, oriented toward the optimization of the "free flow" of capital, goods and ideas (though the latter tended to be downplayed in its importance). They achieved this both through the construction of new infrastructure and through the elimination of barriers to movement. From canals to highways to frequency bands, what might be described as the *channelization of space* became one of the hallmarks of rationalized governance that was based not so much on prohibition but on continuous and directed movement through closed systems. The canal networks in the eighteenth century, as documented by Mattelart, were centralized around the capital city and in this way supported dominant visions of modernity. "Canals," wrote the eighteenth-century historian

John Phillips, "may be considered as so many roads of a certain kind ... Bad roads, and a difficulty of communication between places remote from each other, occasion a kind of sterility in a country, and render most things much dearer and scarcer than they would otherwise be" (1795: xii). For Phillips, the canal provided "easy and secure communication of the different parts of the country one with another," which enhanced commerce and trade, created jobs and bound together disparate regions (viii). But the canal was also deployed as a means of social control, not only through its rationalized and centralized architecture, but also through the processes of canal construction, which involved the rationalization of labor, the standardization of tasks and the division of spaces for workers and supervisors.

In Allied anti-submarine campaigns during the First and Second World Wars, the free flow of people and things across the ocean surface came to depend on the subsurface flow of information along channels of sound and ultrasound. Rather than building networks of canals, warfare strategy in the twentieth century increasingly centered on the control of natural and artificial channels in ocean water. Owing to the poverty of light in the subsurface ocean, American and British scientists focused on the development of acoustic means for detecting undersea threats. In the context of sonar development, the channel was one of many "fluid media" metaphors, along with "current" and "flow." Such metaphors, as Jonathan Sterne and Tara Rodgers point out, enabled sound and electricity to be understood in terms of each other in the discourse of acoustics (2011: 45). But whereas channel, current and flow typically acted as metaphors when applied to electricity or sound in audio-technical discourse, in sonar discourse these figures were applied to structures in the ocean that were literally liquid. As a "symbol of maritime voyage," Sterne and Rodgers argue, the channel renders sound through "a masculinist and colonial rhetoric that promotes the bold traversal and technological mastery of turbulent waves and maritime frontiers" (47). Nowhere, perhaps, were such symbols more potent than in the context of sonar research, where the liquid properties of both the vehicle (the ocean) and the target (ocean sound) of the metaphor gave the channel the appearance of a natural and neutral description of the external world. But the channel was not a neutral description of the world: as I discuss below, the channel helped promote a view of the ocean and the human binaural sense as components of a vast audio surveillance machine that could be violently monopolized by military institutions.

Binauraling Ocean Sound

In his discussion of Freud's concept of memory-traces, Derrida fleshes out the many interconnections between writing and violence:

> We ought thus to examine closely ... all that Freud invites to think concerning writing as "breaching" ... opening up of its own space, effraction, breaking of a path against resistances, rupture and irruption becoming a route (*rupta, via rupta*), violent inscription of a form ... The route is opened in nature or matter, forest or wood (*hyle*), and in it acquires a reversibility of time and space. We should have to study together, genetically and structurally, the history of the road and the history of writing. (1978: 214)

Following Derrida's call, it is useful to examine how the relationship between violence and navigational practices of inscribing space became particularly clear, during the First World War, in the struggle for control of transatlantic shipping lanes called "sea lines of communication" (SLOCs) in naval discourse. For the Allies, SLOCs were a key part of the "logistic tail" along which fuel, parts and equipment flowed into the machine war raging in Europe. The German declaration of unrestricted submarine warfare aimed to disrupt merchant shipping and trade between Allied countries by severing these transatlantic SLOCs. To manage this threat, the American and British navies organized merchant ships into convoys protected by naval escorts equipped with underwater microphones, or hydrophones, to detect U-boats. According to Malcolm Llewellyn-Jones, transatlantic convoys consisted of

> a line of escorts, spaced a mile apart, across the front of the convoy at a distance of 600–800 yards. By zig-zagging, these escorts would provide a physical obstruction to U-boats about to fire at close range. Escorts would also be stationed on the flanks and, where sufficient forces were available, one or more were placed astern where they could respond to a torpedoing with a broadcast barrage of depth-charges. (2004: 9)

Convoys of up to ninety ships had the effect of compressing shipping into a relatively small geographic space, which reduced the U-boats' probability of finding targets in open water, facilitated the flow of information between ships, and reduced the need to communicate over long distances. As the British Royal Navy's Historical Section put it in a 1939 monograph on the First World War, the convoy system ensured that ships "kept in touch with the latest intelligence" and could thus avoid U-boats by altering routes on the basis of this intelligence (quoted in Llewellyn-Jones 2004: 10).

Early twentieth-century conceptualizations of the ocean's acoustic space were thus shaped to a considerable extent by nautical systems for circulating people and things—in particular, the sea lines of communication and the transoceanic convoy. Although U-boat sightings could be communicated between naval ships almost instantaneously by means of wireless telegraph, underwater acoustic detection was limited to the immediate area surrounding the convoys (Hackmann 1984: 69). Even during the Second World War, visual spotting and eavesdropping on wireless telegraphic communication between U-boats remained crucial to the anti-submarine campaign; at least half of U-boat detections were made by these visual and electric means, with underwater acoustic means accounting for the other half. The material and semiotic elements of early underwater listening systems were deployed along the SLOCs and were shaped by the nautical organizations that controlled these routes. In this way, the spatial distribution of underwater listening paralleled the arrangement of the SLOCs and helped reinforce the long, thin lines of rationalized and calculated space carved into the North Atlantic by navies and shipping organizations.

While the introduction of electrical media (telegraph, telephone, radio) in the decades prior to the First World War had inaugurated the separation of communication and transportation, and had in this sense "annihilated" space, many of the most promising early-warning techniques in the first half of the twentieth century—techniques that were deployed on both land and sea—relied on the integration of amplifying and focusing techniques with human directional hearing to "bring things closer" without electrical transducers or amplifiers. These nonelectrical, acoustical techniques, or channels, did not annihilate space (communication was not instantaneous and the distance across which communication occurred was still very limited in comparison with electrical channels); they did, however, extend the range of hearing as well as the period of time between the detection of a threat and the moment of attack or collision. Examples of such acoustic channels included Alfred Mayer's *topophone* (or "sound placer"), which worked like a binaural stethoscope for detecting the grumbling of icebergs at sea and later the engine sounds of approaching war planes, as well as the gigantic concrete "sound walls" built by the British military to amplify the distant engine sounds of incoming bombers (Case 2013). Motor power increased the speed of attack during the First World War and generated demand for "logistical media" which, as Judd Case writes, ordered and arranged "people and objects through feedback, remote control, and technological grids" (2013: 392). By making distant sounds audible, and by correlating those sounds with movement in quantified and calculable forms (e.g. coordinates, bearings, ranges, trajectories), nonelectrical acoustical channels "bought time" for decision-making in an era of terrifyingly accelerated warfare.

To enhance their control over the sea lines of communication, the American and British governments created new institutions to steer scientific research toward the general problem of the U-boat, and toward undersea acoustics in particular. In July 1915, the British government created the Board of Invention and Research (BIR) to promote and direct scientific research for the war effort. Of the BIR's six divisions, the "submarines and wireless telegraphy" division received the largest grant, with much of its funding going toward underwater acoustic research at universities, telecommunications and electronics firms, and naval research facilities (Hackmann 1984: 18–19). Following the sinking of the *Lusitania* by a U-boat in May 1915, the US government mobilized scientists with expertise in underwater sound into newly formed research and development organizations, such as the Naval Consulting Board (NCB) (under the direction of Thomas Edison) and the National Academy of Science's National Research Council (NRC), both of which attracted scientists from industry and the academy (Weir 2001: 6). New research facilities were created for work on U-boat countermeasures at a facility in Nahant, Massachusetts (financed by the Boston-based Submarine Signal Company) and in New London, Connecticut.

The production of acoustic channels in the ocean for anti-submarine warfare depended on the formation of transdisciplinary identities and discourses that would open channels of communication between naval and scientific cultures. While rival firms such as General Electric, Western Electric and the Submarine Signal Company initially showed great enthusiasm for working together on the U-boat problem, the NCB did not set out any specific arrangement for patent rights to underwater technologies developed through these collaborations (Frost 2001: 480). As Gary Frost argues: "Far from inducing Submarine Signal and General Electric to cooperate, the attempt to compel collaboration without resolving the patent issue forced competition between them" (ibid.). As a result, the larger firms involved in these collaborations (e.g. General Electric) tended to dominate government-funded, anti-submarine research, and systems developed by scientists associated with smaller firms tended to be neglected or actively suppressed.[1] In this way, institutional, political and personal factors (such as squabbles over patent rights) obstructed channels of expertise and knowledge between the Navy and the scientific community. It was not until the interwar period that such channels were opened by scientists who were comfortable in both naval and scientific cultures, whom Gary Weir describes as "translators."

[1]Such was the case with Canadian inventor, Reginald Fessenden, who was affiliated with the Submarine Signal Company but whose increasingly antagonistic relationship with other scientists at the Nahant facility ensured that his echo-ranging "oscillator" system—which offered an alternative to "listen-only" systems that were then dominant in antisubmarine warfare—remained obscure and unexplored as a means of undersea detection until the 1920s.

"[T]ranslators became a critical channel of communication," he writes. "In suggesting solutions from engineering practice or scientific research they promoted the flow of ideas across a distinct but ill-defined boundary between two communities of practitioners" (2001: 105).

Although collaboration between military, industrial and academic institutions was limited during the First World War,[2] military-supported acoustics research led to a growing appreciation of the complexity of acoustic channels that cut through water, metal and air to make underwater sound audible to listeners inside a ship. Research during this period also led to the development of novel ways of integrating the heterogeneous elements of these acoustic channels. In particular, many of the First World War developments in sonar technology defined human listening capacities in a way that facilitated optimal "splicing" of human hearing into mechano-acoustic and electro-acoustic channels. Mechano-acoustic channels were configured in pairs to exploit the human operator's capacity to discern differences in phase and amplitude between left and right ears so that locational information about U-boats could be extracted from incoming sounds. Among the best known of these devices was the Walser apparatus, developed by French Lieutenant Georges Walser in 1917. In this system, two blister-like "sound lenses" were installed on each side of a ship: made of metal and containing many diaphragms, each sound lens was three to four feet in diameter (Hackmann 1984: 55). Inside the ship, an air horn was placed at the focal point of each lens to capture incoming sound and a "trumpet-like arrangement" of metal tubes carried the sound to a stethoscope worn by the listener (ibid.). The length of the channel to each ear could be adjusted by moving the tubes and had a similar effect on the sound as electrical delay lines in a telephone system (Lasky 1977: 286). Using this system, the operator could determine the bearing of the target within a few degrees and could also determine when the target was directly below the search vessel (an ideal position for the use of depth charges). Moreover, the apparatus was relatively easy to use and was less plagued by noise than other listening systems, owing to its focusing capability.

Increasingly, American sonar research, too, shifted from the problem of detection and early warning to the problem of extracting directional or locational information from ocean water. The solution to this latter problem was by no means clear at the outset of war. While experiments with sound-ranging gear (which sends acoustic pulses or "pings" into the ocean at regular intervals and listens for echoes bouncing off objects in the water), in combination with adjustable listening channels, demonstrated the advantages of binaural techniques for locating targets as early as 1915, such equipment was expensive and required major modifications to ships.

[2]This was primarily due to weak channels of communication between institutions and the lack of influential "translators" between military and naval cultures.

Instead, "drifter set" hydrophones (portable, non-directional detection devices that could be easily lowered over the side of a ship) were produced en masse in 1916 and used on fishing boats enlisted in the anti-submarine campaign. British engineers modified the American drifter set by replacing the bidirectional hydrophone with a unidirectional hydrophone, which enabled the direction of the target to be roughly estimated (Lasky 1977: 287). Another widely used device, introduced in 1917 as the US entered the war, was the "SC tube." This consisted of a T-shaped piece of metal installed through the hull of a ship with a rubber bulb at either end of the upside-down "T" connected to a stethoscope.[3] The direction of a target could be judged by rotating the "T" until the sound had the same intensity and phase in both ears (Hackmann 1984: 56). However, range "could only be crudely estimated" by manually rotating the "T" and noting the point in the rotation at which the sound became loudest (Lasky 1977: 287). By 1917, a consensus began to form around binaural techniques at conferences organized by the NCB and NRC and attended by American, British and French scientists (Weir 2001: 8–9). From these discussions there emerged a number of proposals for systems that integrated binaural techniques to extract locational information from underwater sound (Lasky 1977: 287). The advantages of binaural listening led the US Navy to develop its own version of the Walser apparatus, called the MV-tube. The key component in this system was its "American binaural compensator," which "consisted of two metal plates with circular grooves" (Hackmann 1984: 57). By rotating the upper plate, an operator could adjust the length of pathways of the sounds picked up by each hydrophone. Once the sounds were binaurally centered, the bearing could then be simply read off a scale.

Two-channel sonar systems enacted powerful models of underwater sound as a rich source of locational information that could be tapped through "binauraling." However, these channels increased the flow of both wanted and unwanted sound into the ears of operators: while the channels were intended to increase the circulation of submarine sounds into the ship, binaural systems also increased noise, making it harder for the operators to listen. Based on discussions at the joint conferences of 1917, American scientists experimented with towed hydrophones in combination with either binaural listening or multiple hydrophone arrays. Towed

[3]To enhance the flow of sound from the water into anti-submarine ships, new acoustic channels were developed between ship and water, which involved cutting holes in the hulls of ships for sound lenses and other gear and thus had the potential to make those ships fragile at sea. Capturing and focusing distant sounds in non-electrical systems required large lenses, which hindered large-scaled deployment, since "Royal Navy ship architects had a great reluctance to cut holes in the hulls for any form of extraneous apparatus" (Hackmann 1984: 57). Taken too far, the punctuation of space through channels transecting the air–water boundary would optimize one form of circulation (the movement of information) and destabilize the other (the movement of ships).

hydrophones had two main advantages over the existing systems such as the drifter sets and the SC tube. First, they eliminated the need to cut holes in the hulls of ships and thus allayed fears among naval officials and ship architects that listening gear would make ships flimsy and vulnerable at sea. Second, by setting the hydrophone apart from the ship, "self noise" could be prevented from entering the listening channels. Based on suggestions from the international conference on undersea acoustic detection, American scientists developed a number of towed devices, including the "Rat" (consisting of non-directional hydrophones that were made directional by installing them in geometric configurations and by means of a compensator), the "Dinosaur" (three hydrophones spaced four feet apart, of which the operator would use two in combination with an electrical delay line to determine the bearing of the target), and the "Eel" (with each ear connected to six hydrophones towed 100 feet below the surface, the operator using an electrical compensator to focus and binaurally center the sound) (Lasky 1977: 287, Hackmann 1984: 58). The Royal Navy found that two Eels used in combination with an MV-tube (the American version of the Wasler "blister" apparatus) enabled the determination of relatively accurate bearings through the triangulation of the sound source.

The sounds produced through single-channel and multichannel hydrophone arrays may have seemed very similar to untrained ears: auditors would have heard a similar mixture of sea noise, self noise and the distant engine sounds of U-boats or other ships through both systems. But as N. Katherine Hayles argues in relation to a much more recent and general transformation of representational practices by information-based technologies, "the technological processes involved in this transformation are not neutral" (1999: 28). Beginning with binaural hydrophone systems, multichannel sonar was shaped by, and contributed to, military efforts to exploit underwater sound for information about the location and identity of objects in the water. There is thus a significant shift in the logic or rationality guiding the development of underwater listening channels during this period. Drifter sets and other devices based on pre-war, single-channel systems sought to increase the range of detection (by distributing them en masse to hydrophone flotillas) so that ships could take evasive action. With the introduction of binauraling and triangulation, the main concern of scientists and engineers began to shift to the recognition and localization of U-boats. As channels proliferated, the purpose of the underwater listening gradually moved from early warning to targeting.

The main driver of these changes was the transition from non-directional, single-channel techniques to binaural listening as the appropriate mode of sensing, signifying, recognizing and locating underwater objects. While non-directional and binaural hydrophone systems may have produced sounds that were very similar, the latter was linked with new lines of scientific inquiry into the sound spectrum of submarines and new

techniques of sound analysis to discern threats in the broad spectrum of underwater noise (Hackmann 1984: 50–1). In Lisa Gitelman's terms, the multichannel transition in underwater sound technology is suggestive of sonar's "material meanings" or the "nexus of cultural practices, economic structures, and perceptual and semiotic habits that make tangible things meaningful" (2004: 203). Mechano-acoustical channels—and in particular the expandable and collapsible air columns contained in adjustable tubes or grooved plates—embodied a new disposition toward underwater sound as a signal to be decoded (rather than listened to "directly") through human sensing, in conjunction with mechanical compression and decompression of space in the channel. The figure of the channel in the discourse and process of binauraling becomes more than just a delivery system linking two points in space. Channels become signal-processors: they split the sonic event into two transmissions and manipulate their arrival time and phase by compressing and decompressing the spaces across which these transmissions occur.

Nuclear Submarines and the Deep Sound Channel

In the 1950s, military officials and underwater sound researchers feared the Soviet Navy would soon develop long-range submarines that would undermine the SLOCs between the United States and its European allies. By the late 1950s, the Soviet Navy developed nuclear-powered submarines that could remain submerged indefinitely and which were much less prone to visual and acoustic detection; in the early 1960s, nuclear-powered submarines armed with nuclear ballistic missiles were added to the Soviet fleet. The rapid speed of nuclear attack, combined with long-standing anxieties among military and political officials about the vulnerability of the SLOCs, led to the development of techniques for exploiting the "tonals" that Soviet submarines unwittingly emitted into a layer of ocean water—called the "deep sound channel"—that can carry sound for thousands of kilometers (Weir 2006). Scientists at MIT, Columbia and Harvard carried out basic research on ambient ocean noise, sound propagation in the ocean, and sound signatures of vessels, while engineers at Bell Telephone Laboratories developed infrastructure based on this knowledge. The result of this intensification of sonar research and development was SOSUS (Sound Surveillance System). This was, by far, the largest underwater listening system that had ever been built. During the construction of hydrophone networks for the US Navy, the figure of the channel thickened and became increasingly complex, particularly with the emergence of a new conceptualization of the ocean as a channeled audio medium. Borrowing a variant of the term "channel" that was popular during the 1950s, this section traces the "channelization" of the ocean's acoustic field. I suggest that ocean channelization shaped, and was itself shaped by, ongoing efforts in naval bioacoustics to incorporate ocean sound into intelligence, reconnaissance, surveillance and targeting systems for the destruction of submarines.

In October 1941, the US Secretary of the Navy requested that the National Academy of Sciences form a committee—chaired by Edwin Colpitts, the former vice-president of Bell Laboratories—to investigate the German submarine threat and the degree to which the US Navy would be prepared to confront this threat in the event that the United States entered the war. In its report, the committee emphasized the need to study the "sound propagating properties of oceanic waters over the entire frequency range likely to be involved in the use of detecting devices" (quoted in Weir 2001: 112). Improved training would be necessary to avoid a condition of sonar "blindness" due to poor weather and water conditions. The key problem highlighted by the report was that operators required extensive training to identify the sound signatures of friendly and enemy vessels in different water conditions. Such training depended on oceanographic research and a massive sound inventorying program which did not yet exist; this was a troubling finding for Navy officials and one that helped bolster oceanography and its wartime model of oceanic water as an acoustic weapon. Other prominent scientists, such as Columbus Iselin, director of the recently formed Woods Hole Oceanographic Institute, noted that, unlike the military scientists with whom they frequently worked, fleet officers did not accept the idea that underwater sound could act as a weapon. In Gary Weir's terms, fleet officers did not share the scientists' view of "the potential of employing the characteristics of the ocean environment as a shield, or perhaps even as a lethal weapon" (2001: 114). The report prompted the US National Defense Research Council (NDRC) to create a five-branch anti-submarine research organization with laboratories on the East and West coasts, which were supported by researchers at universities and firms such as Western Electric, RCA and General Electric (117).

Conceptualized as a homogeneous and bounded space enabling directed flow of objects or information, scientific thought suggested that the figure of the undersea sound channel might enable acoustic positioning and targeting in the "third dimension" (depth). But a number of insights into the material structure of the ocean during the Second World War challenged this idea. One such complication was the "deep-scattering layer," first noted by American biologist Martin Johnson, who was contracted by the US Navy to search for possible sources of ambient noise hindering sonar operators in the Pacific. The noise, "not unlike the crackling sound of dry burning twigs," was sufficiently intense (around thirty decibels) to interfere with anti-submarine listening and seemed to move closer to the surface at night. Johnson determined that shrimp were producing this white noise and

subsequent studies identified numerous other organisms that contributed to the deep-scattering layer (Weir 2001: 166). Other zones of inaudibility (or "shadow zones") produced by layers of sharply declining water temperatures, called thermoclines, also blocked and distorted sonar transmissions (Llewellyn-Jones 2004: 31). Considerable military funding was directed toward geophysical research on thermoclines and on techniques for mapping temperature zones. This knowledge became critical to sonar design and operation, "since changing temperature zones deflect sound waves and can create sonar 'blind spots'" (Burnett 2012: 538).

During an experiment to test the utility of seismographs and explosives to explore the ocean floor, Maurice Ewing and his collaborator, J. Lamar Worzel, began to rethink the problem of the ocean's material heterogeneity. What if layers of water differentiated by pressure and temperature—which muted the sounds of submarines beneath them and which had therefore been long regarded as barriers to sound transmission or as sources of distortion—were in fact elements of larger structures that conducted sound over extremely long distances? With his ear to the railing of his ship, *Atlantis*, Ewing listened to TNT explosions reverberating between the seabed and the ship and hypothesized that a layer of water that minimized energy loss, by preventing contact between sound waves and the ocean surface and floor, would also permit sound to travel great distances (Weir 2001: 172). Ewing called this layer of water the "deep sound channel" and in a report to the Bureau of Ships, in 1943, proposed the use of this channel for long-distance communication using "time-coded explosive charges in the sound channel itself" (Whitman 2005: para. 7). In 1944, as proof of concept, Ewing detonated one pound of TNT underwater off the coast of the Bahamas and monitored the ocean with a hydrophone 2,000 miles away, near West Africa (Smith 2004: 54). Instead of hearing one explosion, the hydrophone picked up a multitude of explosion sounds traveling along different pathways in the sound channel, with different times of arrival. The explosion was nevertheless easily heard on the other side of the ocean with "judiciously located hydrophones" at the correct depth for tapping into the sound channel (Whitman 2005: para. 4).

New devices for measuring temperature and sound velocity developed at MIT and the Woods Hole Oceanographic Institute began to confirm Ewing's explanation for the incredible distances across which sound could be detected: water does not absorb or scatter low-frequency sound as much as it does high-frequency sound, which means that low-frequency sound can travel further without losing as much energy. This alone, however, did not explain the incredible distance traveled by the sound of the explosion. What Ewing had discovered (Soviet scientists made the same discovery independently of Ewing) was a layer of ocean water sandwiched between the warm, surface layer and the cold, high-pressure deep layer. Sound speeds up in both the warmer surface layer and in deep, high-pressure water. These two "high-speed" layers act as the floor and ceiling of the deep sound channel. Sound that enters this layer tends to stay there, bouncing off the warm water above and the high-pressure water below, thus avoiding "lossy encounters with the surface and bottom" (Whitman 2005: para. 2). This permits sound to travel with "minimal loss of signal over thousands of kilometers" (Smith 2004: 55).

To interest the Navy, which was at this time funding research with immediate applications in ending the Second World War, Ewing suggested that the deep sound channel could be used to locate downed pilots in the ocean. (The idea of using the channel for submarine detection and targeting did not emerge until after the war.) Based on Ewing's work, the US military was able to construct an air–sea rescue system—dubbed SOFAR (Sound Fixing and Ranging)—by the end of the War (Weir 2006). The key to this system was a network of hydrophones cabled to shore stations where incoming signals would be monitored. If a pilot crashed or ejected into the ocean, he would drop an explosive package set to detonate in the deep sound channel. The sound of the explosion would be picked up by several hydrophones and the time differential would enable operators at shore stations to triangulate the pilot's location.

The SOFAR channel was not easily monopolized by the US Navy: marine mammals, the Soviet Navy and, more recently, bioacoustics researchers and marine scientists have also made extensive use of it. However, it wasn't the layer of water that needed to be monopolized but rather the acoustical knowledge and techniques that enabled low-frequency sounds to be captured and analyzed as indices of the position of sound sources within it. As Hackmann notes, "It was no easy matter to unscramble the complex low-frequency sound signals repeatedly subject to multipath reflection and refraction which were found, for instance, in the SOSUS long-range sound channels" (1984: 342).

Although the channel itself was difficult to control, the US Navy attempted to monopolize knowledge about the channel and about how to interpret information flowing through it. At the request of the Chief of Naval Operators, the National Academy of Sciences investigated the threat posed by long-range Soviet submarines to the North Atlantic supply lines. MIT professor Jerrold Zacharias agreed to organize a summer study group, known as the Hartwell Project, to explore the problem posed by the "interruption of intercontinental supply of men, material, and civilian supplies between the US and its allies" by the Soviet Union (Project Hartwell 1950: 1). The circulatory imperative is clear in the basic assumptions of the Hartwell Project: "It will be imperative for the U.S. and allies to keep open the sea lanes to harbours in its areas of interest … and to protect shipping against submarines and mines" (ibid.). However, the group underscored the limitations of surface sonar for securing overseas transportation and noted that "sonar performance can be very greatly improved and underwater sound, in general, can be made much more useful to the Navy than it is now" (7). Low-frequency (under 500 Hz) sound detection systems, the group concluded, had enormous potential to detect and target submarines. However, since very little was known about such frequencies in the ocean, the system envisioned by the group would require a large-scale research and development program to investigate geophysical elements of the ocean affecting sound transmission, sound signatures of vessels and undersea weapons, and new data presentation techniques.

For the Hartwell group, the problem of Soviet disruptions of overseas transport seemed to require the production of scientific knowledge about the ocean as a system of low-frequency, acoustic communication. The main advantage of low-frequency arrays was that they could "furnish information accurate enough for closing and attack" on submarines (Project Hartwell 1950: B-4). Hydrophones and other equipment for tapping into low-frequency emissions trapped in the sound channel would need to be designed in tandem with "effective weapons [that] are necessary to successfully conclude an attack once the target has been brought into range," such as high-speed torpedoes and underwater rockets (ibid.). In the Hartwell group's vision of the Atlantic under US control, surface-level circulations of people and things would be secured by channels of low-frequency sound integrated into underwater weapons systems.

After the war, the US Navy commissioned classified sound channel research at university laboratories in what became known as Project Jezebel, aimed at developing infrastructure that could reliably exploit the deep sound channel as an instrument of anti-submarine warfare. The Office of Naval Research funded a contract with AT&T to construct a subsea surveillance network that would use low-frequency sound propagation to identify, locate and track Soviet submarines. AT&T modified its sound spectrograph technology for a new device called LOFAR (LOw Frequency Analysis and Recording), which consisted of a console that produced a visual representation of incoming sound using a stylus running across sensitized paper, the inscriptions of which darkened according to the strength of the signal (Whitman 2005: para. 12). Echoing the Hartwell group's recommendation to integrate the human operator into the system by "tailoring the output of the gear to the sensory capacities of the operators," new techniques of sound analysis and display were developed, including maps of the sound channel throughout the world's oceans (the channel's depth varies from region to region), ray-tracing techniques which plotted each ray or path of the multipath transmission through the sound channel, and low-frequency signal processing techniques designed specifically for this environment (Project Hartwell 1950: 9). It was a knowledge monopoly preserved through secrecy until 1991, when SOSUS was declassified by the US government.

After spending $51 million on research and $375 million on the development of the initial network, the SOSUS network began to take shape.

New hydrophone arrays were designed that activated in response to low-frequency sound waves, moving the hydrophone's diaphragm and generating current. Each hydrophone was connected to a cable that ran hundreds of miles to purpose-built shore stations called, simply, Navy Facilities or NAVFACs. Developed by Bell Telephone Laboratories and Western Electric, these facilities were where signals from the hydrophone arrays were collected and translated into "lofargrams" for visual analysis (Hackmann 1984: 342). NAVFACs identified and tracked objects picked up by hydrophones by generating smaller and more focused sound channels in the ocean. This was done using "beam-forming" techniques, that time-delayed signals coming from different hydrophones in order to "focus" the hydrophones in particular directions.

But since underwater sound typically radiates in multiple directions rather than moving in a narrow and directed way, deep sound *channel* may seem to be an odd name for this structure. Why, then, did the term "channel" seem so fitting for this particular structure or set of structures in the ocean?

The deep sound channel and the broader concept of the ocean as a channeled audio medium were shaped by cultural assumptions about new media in the 1950s. That is to say, they enabled transmission and recording on discrete channels, and that multiple flows of sound streaming from the same source implied not only direction but also location or position. This was particularly clear in the case of new audio media in the 1950s, with the laying of the first undersea coaxial cables, which drastically increased the number of voice channels that could be carried by a single cable, as well as the transition to stereo in the recording industry, the first stereo television broadcasts and the first commercially available four-track tape recorders (Chanan 1995: 8, 143). The ubiquity of channeled communication technologies during the post-war period shaped concepts of communication and social processes in terms of the channel: complex economic, political and cultural processes were commonly described in terms of flows or movement within and between multiple channels throughout the 1950s.[4] The same institutions that developed the multichannel techniques and infrastructures of the telephone and radio networks were contracted by the US Navy to build sonar networks that would tap into the deep sound channel. Bell

[4]Perhaps the most well-known instance of this turn in communications thought emerged in sociology, where Kurt Lewin's theory of gatekeeping proposed that any given idea, object or event can be traced back to the flow of its constituent parts through parallel channels, governed by individual or institutional "gatekeepers." Operating as a kind of master concept for theorizing social processes, the channel's appeal in this period derives in part from the apparent balance it strikes between the multiple structures that enable and guide movement from one place to another (the channels) and agency of those who occupy these channels whose collective action determines what moves forward through the channel and what does not.

Telephone Laboratories played a key role in this massive engineering undertaking and virtually all of the technical components of SOSUS were "off the shelf" technologies repurposed from the telephone networks (Weir 2006: para. 3). As Weir notes, "Even the LOFAR actuator, which recorded on paper the submarine detection data for SOSUS, emerged from a desire at Bell Laboratories to examine more closely human voice patterns with an eye toward enhancing basic customer services" (ibid.). The idea of the deep sound channel was in this sense overdetermined: researchers working to exploit this deep ocean structure were steeped in a scientific and engineering culture in which the "channel" was a foundational concept for thinking about flows within and across organisms and machines; the broader cultural associations between multichannel media and directivity and positioning meant that the figure of the channel could communicate across scientific and naval culture; and organizations, such as the Hartwell group, seeking to persuade political and military administrators that domination of the ocean and its soundscape was indeed feasible, could point to the telephone network and its constituent parts as ready-made models and material resources for the channelized ocean.

Conclusion

If the figure of the channel embodied by canal networks underscores the importance of rationalized movement in the domination of land-space by emerging nation-states, the concept of the channel developed in the 1950s articulates a growing concern on the part of Cold War military officials and scientists with the optimization of information flows between ocean water, human operators and machines. The domination of deep ocean space and the monitoring, measurement and reconfiguration of information across human and machine elements became intertwined in the discourses of military-funded scientists and engineers in the 1950s as they worked on the urgent problem of how to detect submarines carrying nuclear missiles in deep ocean environments, where it is difficult to hear and even more difficult to see. In this context, the channel was not only a description of sonic movement as directed flow but also a diagram for the reconstruction of the subsurface ocean as a striated space in which wars could be fought and political power could be projected. Perhaps more than any other development during this period, the deep sound channel demonstrates the critical role that the figure of the channel played in the mid-century rethinking of borders between human "operators" and machines as permeable and reconfigurable.

The discovery of the "deep sound channel" in the late 1930s, and its subsequent use in ocean surveillance, thus highlight the ongoing centrality of channel-oriented thinking about sound in the military and scientific communities during this period. The channel metaphor is not an after-the-fact translation or simplification of pre-existing knowledge about an acoustic phenomenon to non-experts. Rather, the channel metaphor is a crucial part of what might be called the "poetics" of underwater communication and navigation, or the "figural dimensions of the process itself as well as the modes through which the process is represented in audio-technical discourse" (Sterne and Rodgers 2011: 35). While other metaphors were conceivable for oceanic structures (zones, layers, ducts, etc.), the channel was quickly installed as the central metaphor in both the process of acoustic surveillance in the ocean and the audio-technical discourses surrounding that process. Such metaphors, as Paul Edwards argues, are "part of the flesh of thought and culture, not merely its communicative skin. Therefore the politics of culture is, very largely, a politics of metaphor, and an investigation of metaphor must play an integral role in the full understanding of any cultural object" (1996: 158).

Through SOSUS, the US Navy, university research laboratories and telecommunications firms enacted what was then a new model of the ocean as an audio medium suitable for real-time monitoring of subsea entities and events. By opening up the ocean's acoustic environment as the "hunting ground" for Navy-funded research—and by repurposing elements of commonplace, multichannel media such as the telephone to exploit this new understanding of long-distance information flows in ocean sound—the US Navy channelized the ocean. The ocean's soundscape was segmented and could now be treated as a set of discrete sound channels for the purpose of rendering the sources of sound more detectable, predictable and controllable. SOSUS split ocean sound into a series of frequencies with different propagation properties; it mapped the ocean in the form of a diagram resembling a multichannel audio medium; and the system was designed to enclose the ocean in its network of hydrophones, listening stations, satellite relays and surveillance aircraft. In these ways, SOSUS embodied a militarized concept of the ocean soundscape as a series of quantified, addressable and locatable points where no sound would go unheard, undetected or unidentified—and where no sound would escape the Navy's underwater ears or the conceptual categories of signal and noise that guided both the design and use of this infrastructure.

Since the declassification of SOSUS in 1991, the Navy has been providing data to civilian researchers working on Navy-approved projects, including acoustic studies of ocean warming, monitoring of undersea earthquakes and volcanic eruptions, and the communication and migration patterns of whales and other marine mammals. This changing of hands has opened up deep-sea listening techniques and infrastructure to groups and organizations that sometimes use the channels in ways that conflict with the military's interests. But new techniques of controlling ocean space by monopolizing particular sonic frequencies have emerged in the form of giant, towed sonar arrays, which are "portable" in the sense that they are not permanently fixed to the ocean floor like the SOSUS network and can be deployed on what is called a theater basis.

Sonar, and SOSUS in particular, constructs the ocean not only as rational—this, Burnett tells us, emerged in the mid-nineteenth century in the figuration of the chronometrical sea or the use of the ocean as kind of clock (2003: 12-13)—but rather as a part of the closed world in Paul Edwards' sense of a cybernetic space of perfect prediction. And yet, as one digs further into the SOSUS episode of sonar history, one encounters unexpected turns toward a conceptualization of the ocean as radically open—open, for example, to an assortment of "mystery sounds" that for decades both fascinated and frustrated sonar operators and SOSUS analysts. The ocean soundscape in SOSUS also became open to new sensings and intuitions about nonhuman intelligence, such as the long-distance communication of whales, which also use the deep sound channel to communicate from opposite sides of the Atlantic Ocean. This, in turn, inspired musicians along Canada's West Coast in the 1970s to use Navy-derived hydrophones to broadcast music to whales. Over time, the multiple uses of SOSUS highlight growing tensions between the ongoing preoccupation with the channel as a modality of prediction and control, and the exploratory, affective and often spiritual associations with the channel on the margins of mainstream military and scientific activity.

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