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Acoustic Tradition and the Communicational Approach: Energy Transfer and Information Processing

If we wish to understand sound and its behavior generally, as implied by the term "acoustic communication," and we turn to the traditional disciplines that study it, we find that they are scattered institutionally throughout the arts and sciences, engineering, and medicine. Moreover, each discipline or specialization concerns itself with only a particular aspect of the entire subject, and often no attempt is made to bridge the arbitrary gaps between them. Each discipline has also developed its own terminology and concepts through which it expresses its knowledge, and like all specialized subjects, acoustics uses a great number of abstract ideas that often seem removed from the perceptual immediacy of the acoustic world that surrounds us.

Books on acoustics, following the general development of the discipline, have come to rely more and more heavily on visual representations of their subject matter. One almost comes to think that the two-dimensional wave diagrams that populate these books, showing undulating lines moving around a horizontal one, must actually correspond to what's happening in the air (or the "medium" as it is always generalized), instead of being simply a convenient representation of a three-dimensional phenomenon in only two. One only has to go back to the writings of the 19th-century acousticians with their ingenious demonstrations of acoustic principles through sounding experiments, or their examples drawn from such real-world experience as Tyndall's observation that "the day was acoustically clear; at a distance of 10 miles the horn yielded a plain sound,"[1] to understand how far the modern scientific approach has led us away from everyday perception.

A great deal can be learned, of course, from both the theoretical and experimental achievements of acoustics, but it can also leave us wondering whether such knowledge has been placed beyond the public's reach and comprehension. At the same time, environmental noise is an ever present

[1]John Tyndall, *Contemporary Review*, 1874, p. 826; note that the distance referred to is in nautical miles.

problem over which one feels one has little control. The essentials of scientific knowledge seem not to have filtered down to the level of general public awareness, and, too often, decisions are left to "experts" who speak only a technical language.

The scientific method has achieved its results through an experimental methodology that allows observable phenomena to be studied in isolation from the variables that normally complicate most situations. For results to be verifiable they must be able to be replicated at any time and place, and this constraint necessitates a type of study where each variable can be controlled. The environmental context in such a study is essentially idealized. Problems in the contemporary world seem increasingly to involve complex interactions at many levels simultaneously, and techniques designed for ideal situations often fail when applied in actuality. Although I am not claiming that scientific procedures cannot be devised or adapted to contemporary problems, I am suggesting that at least in the realm of sound, such methods have been slow to emerge, and the answers offered thus far are fragmentary at best and all too often, ineffectual. This book is an attempt to sketch out a new framework for understanding acoustic contexts in all of their subtlety and complexity. It presents a communicational model to show how sound, in all its forms and functions, defines the relationship of the individual, the community, and ultimately a culture, to the environment and those within it. However, in order to understand the potential of the communicational approach, it is necessary to examine it in the context of the traditional models, and therefore we will present first a brief survey of the basis of physical acoustics and the related model of signal processing.

The Energy Transfer Model

To go more deeply into the sources of the gap between traditional knowledge and contemporary problems, we can begin by examining the model on which most disciplines dealing with sound have been based, namely the energy transfer model. With the advent of electronic technology, the model has become that of signal transfer, but we can see that the same principles are embodied in it as well. The energy transfer model deals with acoustic behavior as a series of energy transfers from source to receiver. It examines how these transfers occur, how efficient they are, and what variables affect them. The energy originates with a vibrating object that radiates its energy to the air or through any object with which it is in contact. The most common example quoted is probably that of the tuning fork which sounds faint when struck, but becomes clearly audible when placed on a table or other object with a large surface area. Acoustics tells us that the energy transfer in the first case is inefficient (it's called an impedance mismatch). In the second case where a greater surface area is involved by "coupling" the fork to the table, the energy transfer is more efficient, and since less energy is lost in the transfer to the air, the sound is more clearly heard. Similarly, we discover that the outer parts of the ear (the auricle and pinna) are especially well suited for the transfer of energy from the air to the narrow auditory canal, because they act as a kind of funnel to direct the sound waves in the appropriate direction.

Once the energy has radiated from the source, it propagates through the "medium," normally air or water, with varying speeds and other characteristics. A denser medium where the molecules are closer together, such as water or metal, allows the energy to travel more quickly. In air, the speed of sound through a warmer air mass is greater than through a cooler one, and so on. Environmental acoustics also studies how different frequencies behave during propagation, a subject that will be dealt with as "response" characteristics later on. When the sound wave comes into contact with objects, its energy is transmitted through the object, absorbed within it, or reflected from it with varying degrees of efficiency depending on frequency.

On arrival at the ear, the sound becomes the subject of study for *psychoacoustics* which examines the chain of energy transfers as the sound wave is transmitted from the outer ear via the eardrum to the bones of the middle ear called the ossicles. This transmission involves the transfer of energy from the air to a solid, a process which the eardrum through the course of its long evolution from the equivalents found in fish and reptiles is remarkably adept at performing. The actual distance moved by the eardrum in response to the slightest vibration which can be heard is less than a wavelength of light, i.e., it can not be seen, even with a microscope! The bones of the middle ear are attached to the oval window of the spiral-shaped cochlea which is filled with a fluid that can transmit the energy from the mechanical vibration of the stirrup, the last of the bones of the middle ear. The sound energy in the cochlea creates a bulging of the basilar membrane located within the cochlea, and the shearing motion of this membrane against the thousands of tiny hair cells in the organ of Corti activates them to produce electrical impulses which travel via the auditory nerve to the brain. It is through the firing of the hair cells that the first level of analysis of the sound wave occurs in terms of frequency and intensity, or more generally, in terms of the energy distribution (or "spectrum") of the sound. Once analysis is involved, it seems appropriate for psychoacoustics to use a signal processing model to describe the operation of the auditory system.

Psychoacoustics documents the processing of incoming sound waves by the auditory system to extract usable information for the brain, in other words, the process called hearing. To do so, it has relied in the past quite heavily on a model drawn from 19th-century psychophysics, namely the stimulus-response model. The founder of modern psychophysics, Gustav

Fechner, attempted to understand how the brain formed subjective impressions based on the magnitude of external stimuli. For instance, how does our concept of "heftiness" relate to objective measures of weight? Fechner discovered that there was a systematic relationship between the magnitude of the stimulus and that of the subjective response. In fact, he suspected that there was a universal logarithmic relationship between the two for many, if not all, stimuli, i.e., that larger and larger stimuli were required to produce equal increments in the corresponding subjective sensation. Although modern work has refined the nature of this principle, we can see that Fechner's concept generated several new ideas. First, it allowed subjective reactions to be scaled and therefore made amenable to scientific study. And secondly, it allowed the concept of energy transfer to be extended into the realm of individual experience by treating it as a "stimulus" with dimensions called parameters which transfer to the corresponding dimensions of subjective "response."

Thus came about the modern scientific distinction between the "objective" acoustic parameters, such as intensity, frequency and waveform, and their psychoacoustic, "subjective" counterparts, namely loudness, pitch and timbre, respectively, which describe the brain's response to those parameters (Plomp, 1976; Roederer, 1975; Tobias, 1972; Moore, 1982). This distinction allows us, for instance, to ask what is the smallest change in the objective stimulus that produces a perceptual change, a measure called the "just noticeable difference" (jnd). Or, we can ask, as did Fechner, whether the relation between stimulus and response is linear (i.e., equal changes in stimulus produce equal changes in response), or whether it is logarithmic as described above.

More subtly, psychoacoustics determines what are the physical (i.e., acoustic) characteristics of a stimulus that result in a single sensation or a double one (e.g., one tone or two, based on frequency difference). Masking experiments, for instance, determine the conditions under which one sound, by virtue of its intensity or frequency content, makes it difficult or impossible to hear another sound. The time variable is also considered: how long must a sound last or be separated from another for a certain type of percept to occur? Such data, collected over many subjects, tends to show a statistical unity of response; that is, within certain, fairly narrow statistical limits, individuals perceive sound in generally the same way, according to the psychoacoustic parameters as defined. Just as with the concept of energy transfer, response to stimuli can be rationalized as essentially known, quantifiable behavior.

Although contemporary psychoacoustics is developing the concept of the "percept" as the end result of auditory processing (McAdams & Bregman, 1979), the enduring influence of the psychophysical stimulus-response model can be seen even in such a peripheral area as the noise study. The objective of such studies seems simple enough—to document subjective reac-

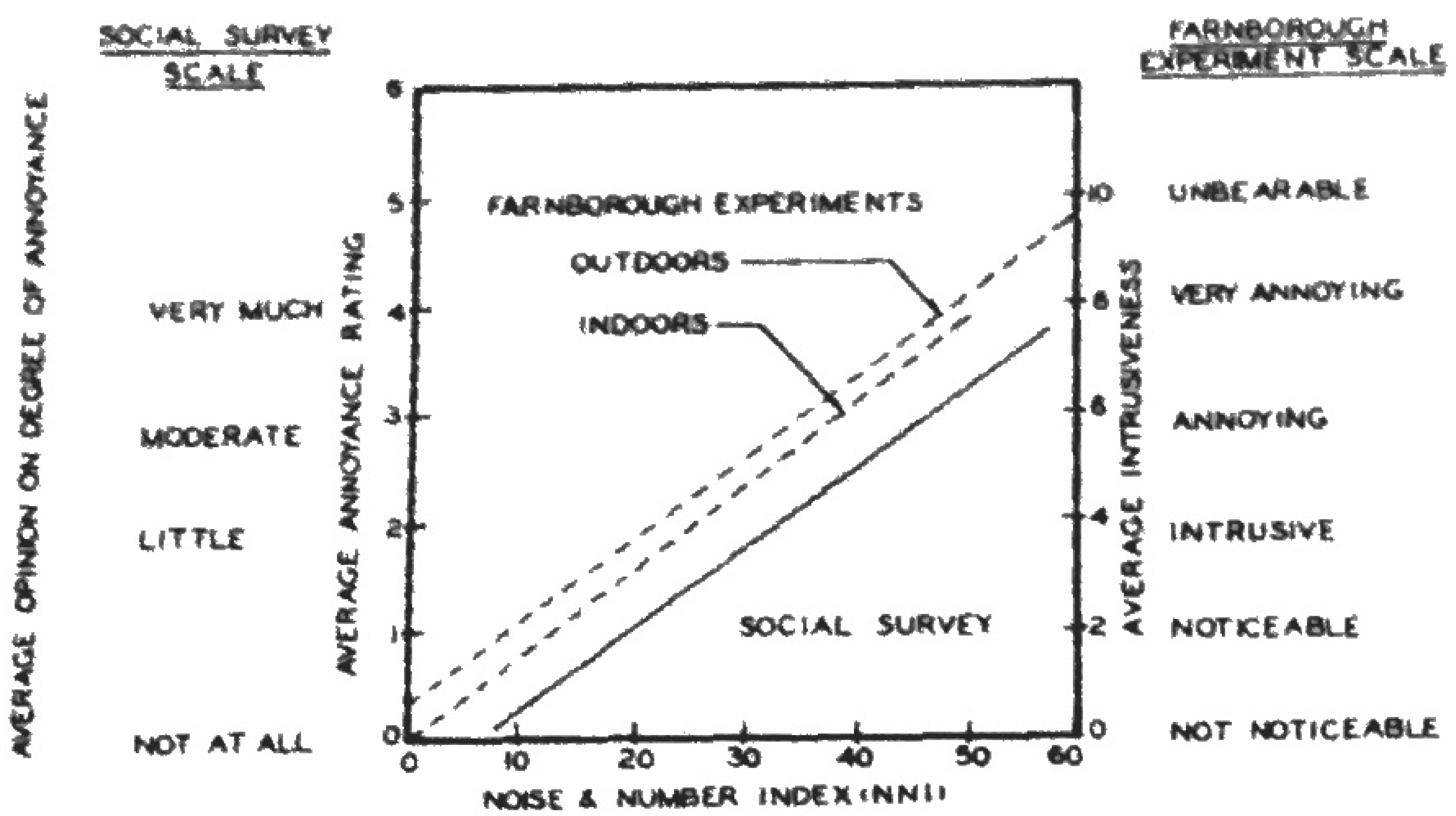

Fig. 1. Relations between annoyance rating and Noise and Number Index obtained from social survey and Farnborough experiments (from Wilson Committee on the Problem of Noise, *Noise: Final Report*, Cmnd 2056, London, HMSO, 1963, p. 208, used by permission).

tion to noise, in particular its magnitude. Not surprisingly, the result of such studies is often a plot of subjective reaction, usually related to a concept like "annoyance," against the magnitude of the "stimulus." This plot of the subjective on the vertical axis and the objective on the horizontal frequently yields, again not too surprisingly, a straight line, linear relationship! Equal increments of noise seem to produce equal increments of public response, such as in the 1960 Wilson study of Heathrow airport that proposed the Noise and Number Index.[2] The results, as in Fig. 1, show the degree of annoyance in a linear relationship to the scale for noise measurement which they have proposed. Instead of the usual approach of quantifying subjective response, the noise study devises a method for measuring noise levels that produce subjective reactions on a linear scale. In terms of the energy transfer model, the concept of annoyance is the final dissipation of "heat" in what has been a long series of energy transfers from source to listener!

By comparison, one of the many American systems, the Community Noise Equivalent Level, originating in California,[3] creates a vertical scale (Fig. 2) on a somewhat more pragmatic basis: the number and vociferousness of complaints, progressing to threats of legal or community action. Here

[2]Wilson Committee on the Problem of Noise, *Noise: Final Report*, Cmnd 2056, London: HMSO, 1963, p. 208.

[3]U.S. Environmental Protection Agency, *Community Noise*, document NTID300.3, 1971.

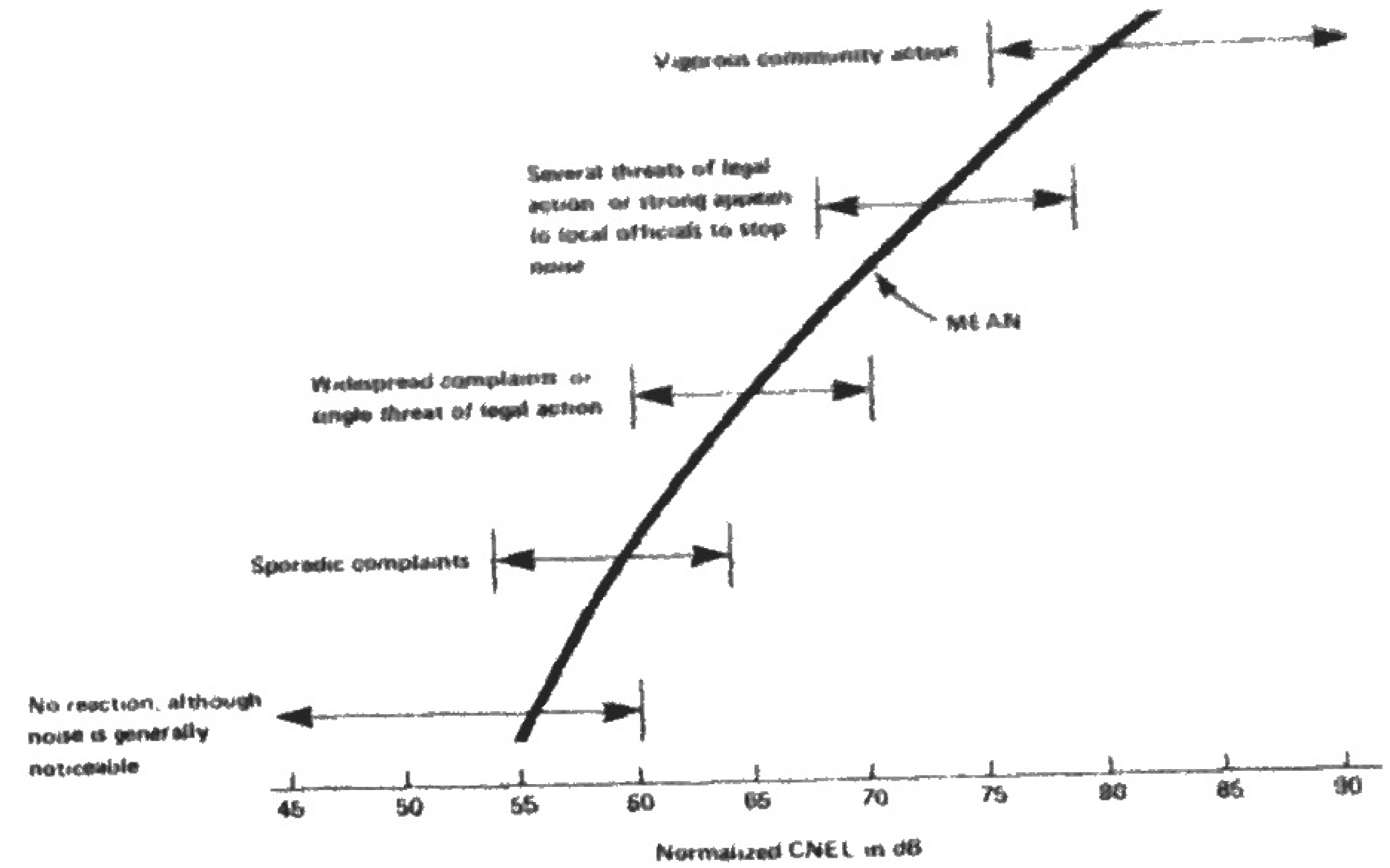

Fig. 2. Community reaction as a function of normalized CNEL values as calculated from case histories (after U.S. Environmental Protection Agency document NTID 300.3, "Community Noise," 1971).

the choice of vertical scale takes on political overtones, and the clear imperative of the system seems to be for those in authority to keep the noise level, or at least its rate of change, within limits that preserve community equilibrium and quiescent adaptation.

Signal Processing

Similarly, the entire field of electroacoustics, the result of the application of 20th-century technology to sound, constitutes a sub-discipline of electrical engineering, i.e., audio engineering. It is concerned with the energy transfer from acoustic to electrical forms, a process called transduction, as well as the subsequent processing and/or storage of the resultant audio signal. The related process of radio transmission codes an audio signal into an electromagnetic carrier wave which is transmitted to a distant receiver instantaneously—another energy and signal transfer process. It is generally assumed that the electroacoustic process ends with the conversion of the signal back into acoustic, audible form via a loudspeaker.

The term "electroacoustic," as used here, is the one which in my opinion best embodies the essential nature of audio engineering, that is, the application of electrical and electronic technology to the processing or synthesizing of sound, the latter being the electronic generation of sound without an original acoustic source. It is significant, however, that the current emphasis of audio technology is almost entirely on the signal processing aspects and not on the actual points of energy transfer, i.e., the transduction process via microphones and loudspeakers, the problems of which are generally thought to have been solved.

The emphasis on the "audio signal," from the present perspective, suggests an intentionality and sense of content that the more neutral term "energy" lacks. Signals travel in channels which of necessity include a certain level of background noise. The signal is intentional and desired, and should be distinguishable from the "noise" which is both inevitable and undesired. Signals are presumed to "have" content, and yet the way in which they are processed is usually independent of that content.

These and many other paradoxes one encounters in the audio field can be understood through what I call the "black box" model of electroacoustics, as shown in Fig. 3. The signal enters and exits from the box via the transduction processes which convert the energy from acoustic to electrical forms and back again. Inside the box, the signal is manipulated, stored, and/or transmitted. The aim of the system is to achieve "fidelity" between the input and output signals, that is, to make them indistinguishable, at least ideally. Interestingly enough, early advertisements for the gramophone, just as with certain brands of magnetic tape today ("is it live or is it. . . ?"), emphasized the "you won't be able to tell the difference" quality of their products. One advertisement showed the friends of a famous opera singer of the day seemingly baffled as to whether they were listening to their acquaintance live or on record. Judging by what we now hear in these original recordings, the imagined psychological sense of "realism" must be attributed to factors other than technical fidelity!

Perfect fidelity, of course, is technically impossible to achieve because every stage of the signal transfer process inevitably adds noise or distortion to

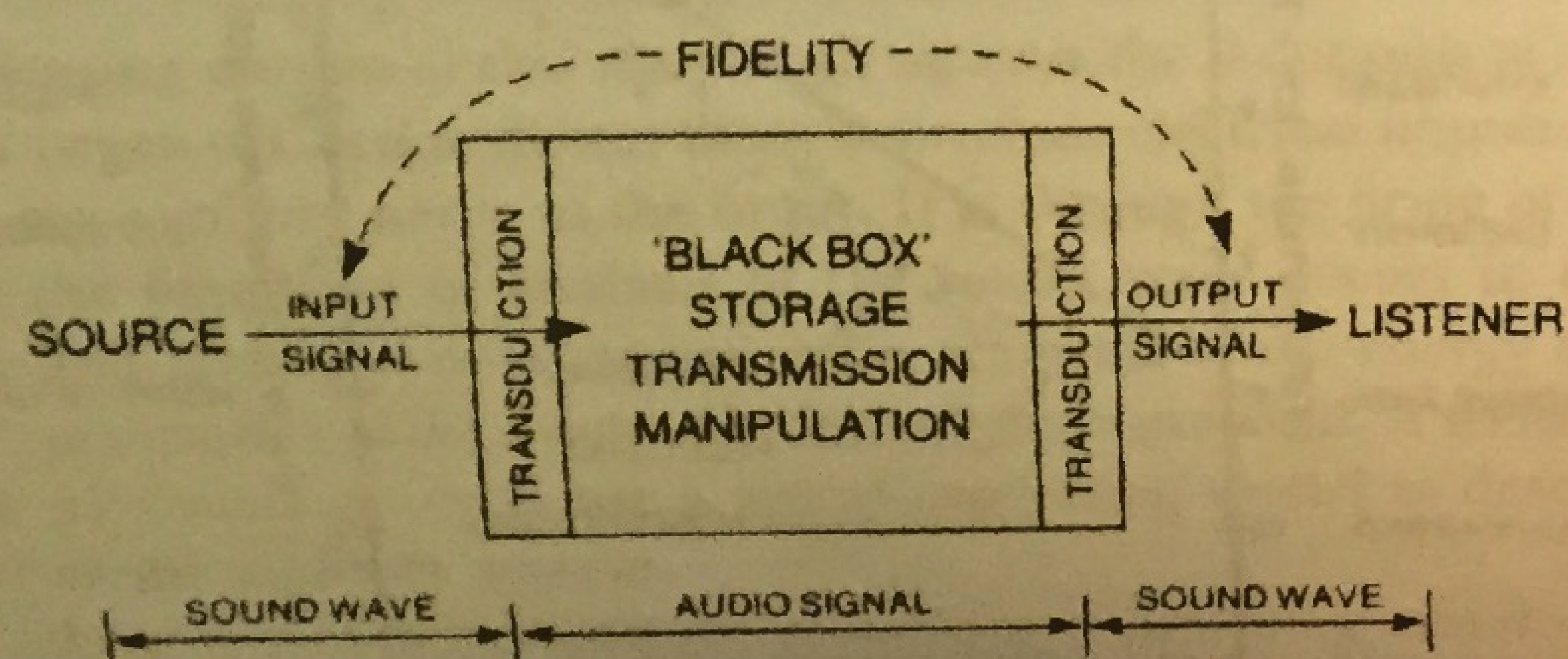

Fig. 3. The "black box" model of electroacoustics, showing the transduction of the sound wave into an audio signal, and back again into a sound wave with intermediate stages of storage, transmission, or manipulation.

the signal, however slight (or gross, judging by what is commonly heard over cheap loudspeakers daily). Thus, like the "true satisfaction" of the advertisements or the promises of other types of slogans, fidelity is unattainable, hence safe and unquestionable. What is significant, however, is that if true fidelity were attainable, the technology would become *transparent*. That is, if there were no difference between the original and reproduced signals, the result would be the same as if there had been no technological intervention at all. The technology would therefore be neutral, in the sense of being independent of, and therefore not responsible for, the content of the material it processes or the implications of its uses. Such "neutrality," as we shall see in part II, is far from the reality that has come about through the audio industry. We will examine the implications of technology on patterns of acoustic communication, and the new role into which the individual and the community are cast, in the second half of the book.

From this cursory overview of the traditional scientific approach to sound and hearing, it should be clear that it operates to a significant extent within a model of a linear chain of energy or signal transfers, much as the early models of communication processes posited a source-channel-receiver chain. Out critique of the tradition is not to deny the value of its knowledge or techniques (in fact we will constantly invoke them). Rather, it is intended to establish the limits of traditional thinking, and to clarify the concerns and goals of an interdisciplinary model of acoustic communication. Moreover, we are interested in creating a model which will provide new insight into problems which the traditional approach is incapable of solving, and design criteria which that approach cannot furnish.

A Communicational Approach

First of all, a communicational approach to acoustics deals with the exchange of *information,* rather than the transfer of energy. In other words, it does not deal with sound in isolation from the cognitive processes that understand it. In any of the cases of energy or signal transfer described earlier, the components of the system can be regarded individually—the tree falling in the forest creates a momentary series of energy transfers whether it is heard or not. Within a communicational framework we will be much more concerned about the information communicated by the sound of that tree.

Whereas hearing, in the end role of receiver in the linear model, is the processing of acoustic energy in the form of sound waves and vibration, *listening* is at the core of a communicational model. It can be defined simply as the processing of sonic information that is usable and potentially meaningful to the brain. Similarly, whereas the "sonic environment" can be regarded as the aggregate of all sound energy in any given context, we will use the term "soundscape" to put the emphasis on how that environment is understood by those living within it—the people who are in fact creating it. The individual listener within a soundscape is not engaged in a passive type of energy reception, but rather is part of a dynamic system of information exchange. Because of its importance, we will return to the concept of listening in the next chapter.

Secondly, a communicational approach includes the notion of *context*. The exchange of information is highly dependent on context, whereas the transfer of energy is not. For example, the acoustic study of sound propagation in an environment is normally carried out independent of social and cultural context. In such studies, noise behaves the same whether those it affects are poor or rich, used to it or not, capable of controlling it or dependent on it. The most attention such circumstances receive are as "correction factors" by which noise scales have to be adjusted so that the reported annoyance corresponds to the measured noise level and can be predicted from it. In a communicational approach, context is essential for understanding the meaning of any message, including sound.

Similarly, the "black box" model of electroacoustic communication, as in Fig. 3, completely ignores the fact that the context of the original source and the reproduced signal are entirely different. The concept of fidelity puts the emphasis on the quality of the signal, and therefore completely ignores the fact that there can be no "fidelity" in context between the original and the reproduced sound. Hence, a voice or music may be reproduced in any other space or time, whether appropriate or not, and often such reproduction seems paradoxical since it is "out of context." Take the example of hearing a hundred-piece orchestra in an elevator, or a hockey game on the beach! Our familiarity with such paradoxes may lessen their irony, but the arbitrariness of context remains fixed within the electroacoustic experience. On the other hand, when such devices as radio were first introduced, wonderment at the "magic" of hearing a disembodied voice over impossibly large distances was instilled in the first listeners. Before audio technology, no sound had ever been heard twice, exactly the same, nor had any sound ever been heard outside its original context.

The communicational significance of any sound can only be judged within its complete context in the broadest environmental, social and cultural sense. In fact it is through context that we understand how a sound functions. In the following sections we will examine how, within the traditional acoustic environment, the inseparability of every sound from its context makes it a valuable source of usable information about the current state of the environment. Moreover, in terms of a community, sounds not only reflect its complete social and geographical context, but also reinforce community identity and cohesion. Sometimes they are a frequent, almost subconscious reminder of context, and at other times they provide the uniqueness of occasion that reflects a community's individuality.

Thirdly, a communicational model will not deal with linear chains of energy or signal transfers, but with systems of related elements operating at different hierarchic levels. Instead of thinking of sound as coming from the environment to the listener and perhaps being generated back again, we will think of it as mediating, or creating relationships, between listener and environment. We can show this mediating function of sound as in Fig. 4, where it is placed at the top of the triangle to indicate this role.

Acoustic experience creates, influences and shapes the habitual relationships we have to any environment. The relationship may be highly interactive, even therapeutic, but it may also become alienating and both physically and mentally oppressive as in the case of noise. The relationship may be one that brings people together and binds the community, or one that isolates the individual and threatens the sense of shared experience that characterizes every community, no matter how it may be defined.

Through electroacoustic means, entirely new patterns of communication occur, bridging space and time, creating sources of power and control, and thus creating new relationships between people and their environments. In fact, one could say that technology creates new communicational environments that have few of the limitations of normal geographical ones. The listener is no longer a humble "receiver" at the end of a long and complex communicational channel, but becomes instead a member of a mass audience, a consumer market, or a target subgroup. Technology can create relationships that are repetitive, addictive, and a surrogate masquerading as a "real" relationship. When we come to an analysis of radio in part II, we will find that be being designed for the distracted listener engaged in other activity, radio attempts to fill the gaps left by jobs and environments that are not complete in themselves. It offers an alternative, seemingly more meaningful relationship, the consumption of which it in turn can use for its own commercial or other ends. However, technology also creates the possibility of innovative and artistic experiences through the artificial constructions of sound now possible, and it is these alternatives that we will return to in the last few chapters of the book.

Finally, through a communicational approach, we hope to establish useful criteria for *acoustic design*. The so-called "applied" fields of traditional disciplines, e.g., architectural acoustics, acoustical engineering, and audio engineering, have contributed extensive knowledge concerning the optimum

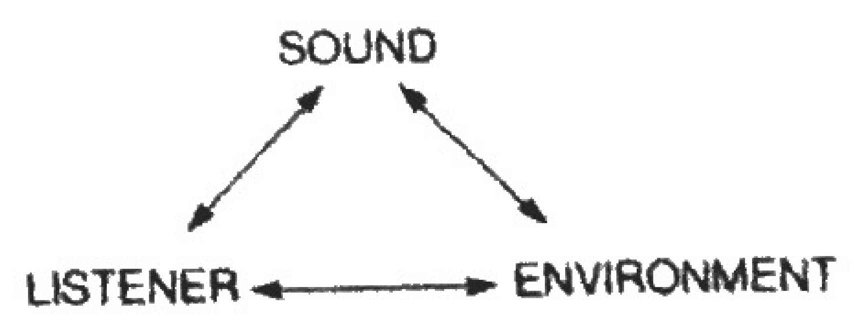

Fig. 4. The mediating relationship of listener to environment through sound.

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methods for controlling sound waves and audio signals. Their design goal is that the desired stimulus will arrive at the receiver and the undesired noise will not, or at least not in such quantities as to obscure the desired signal or create undue annoyance. The techniques used by traditional disciplines are obviously useful, but they do not lead to design criteria that go beyond the question of the appropriate control of signals to ask what kind of environment is desirable, meaningful, or beneficial—not just one that can be adapted to. Hence their failure to provide solutions to obviously malfunctioning situations where anything other than "objective" factors are involved, such as employee psychology, listening habits, government policy, zoning practice, economic and political forces, and so on.

We should keep in mind that the applied disciplines were never intended to offer solutions to these more complex problems. In fact, their most conscientious practitioners are quite aware of the limitations of traditional methods and constantly use personal knowledge to extend the benefits of their "objective" techniques. Our critique of the limitations of the traditional disciplines is intended to help us create a new model and theoretical framework for thinking about contemporary problems. We hope to build upon past knowledge by extending the conceptual basis on which it rests. For instance, a communicational model establishes acoustic design as what H. A. Simon calls a "science of the artificial," the knowledge about how artifacts function to fulfill certain goals, as distinct from the natural sciences which describe how things are (Simon, 1969). If we shift our focus from the sound wave and the audio signal as the artifact to the soundscape, where sound mediates relationships between the individual and the environment, we will be able to understand the intricacies of how sound *functions*, not simply how it behaves. Functionality, rather than simply aesthetic quality or the absence of annoyance, becomes the criterion for design.

Acoustic design, in the most general sense, seeks to modify the functional relationships within the listener-environment system. It may involve changing the sound environment itself, but because the listener is always included within the system, it may also mean modifying the listening or thinking habits of the listener as part of the design strategy. In this sense, design is less of a manipulative process than that in which the "expert" imposes predetermined criteria onto an environment. It may be as simple as the listener(s) choosing to modify the way in which sound is creating functional relationships within an environment. It may use new technology or invoke traditional models, not in any misguided attempt to turn back the clock, but in order to learn from the principles that have been successful in balancing a soundscape and promoting functionality in the past. Our analysis will reveal the vulnerability that acoustic environments have to degradation which no natural forces appear to be able to counteract. Therefore, conscious, thoughtful, and informed design becomes a necessity if we are to regain control of the soundscape and make it function to our benefit.