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The Fine-Tuning of a Golden Ear: High-End Audio and the Evolutionary Model of Technology

JOSEPH O'CONNELL

Some scientific claims are accepted as scientific facts while others are forgotten. Likewise, some artifacts and ideas leave recognizable descendents in the history of technology while others are short-lived. The development of science and technology, according to this weeding-out process, suggests an evolutionary model in which theories and artifacts survive if they meet certain constraints of their immediate environments. Real history, of course, has more complexities than a simple model can capture. Still, the evolutionary model has attractive resources for historians because it permits the complicated social, cultural, and political factors influencing scientific and technological change to be considered components of an environment within which theories or devices compete for survival: "[The natural selection method] guides the careful survey of central environments for the generation and selection of ideas—that is, those environments constituted by the specific problems of the individual scientist and his community; but it also directs the exploration of intersecting and neighboring niches formed by other kinds of cultural concerns. That is, the model encourages the historian to attend not only to the logic and particular content of scientific theory development but also to its psychology, sociology, economics, and politics."[1]

In this article, an evolutionary model for technological change is suggested and is then used to describe several developments in

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[1]Robert J. Richards, "Natural Selection and Other Models in the Historiography of Science," in *Scientific Inquiry and the Social Sciences: A Volume in Honor of Donald T. Campbell,* ed. M. Brewer and B. Collins (San Francisco, 1981), p. 71.

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high-end audio technology over the last twenty-five years. This area of technology was chosen for its intrinsic fascination quite apart from any historiographic model and because it has many features that display technological evolution in a pure form, very much like the drosophila (fruit fly), whose ten-day life cycle and large chromosomes illustrate biological evolution so elegantly in the laboratory.

The evolutionary model of technological change is an extended analogy to biological evolution by natural selection.[2] The knowledge, artifacts, and classes of artifacts that evolve in technological history are roughly analogous to the genotypes, phenotypes, and species of biological evolution. Human agency (as an inventor, designer, or corporation) bears the relationship to technological evolution that a plant or animal breeder bears to biological evolution. Like a breeder who hopes to produce successful phenotypes by mating existing genotypes, the technologist constructs artifacts from existing, modified, or recombined strands of technological knowledge. These artifacts then pass from the technologist's control to an environment that either accepts or rejects them in a process like natural selection. Successful artifacts are themselves sterile but accomplish the equivalent of replication when the technological knowledge associated with them is used to produce similar artifacts.

Many of the constraints that would affect artifacts in the natural selection of the marketplace are vicariously duplicated in the selection from technological knowledge performed by the technologist. Technological evolution is half artificial and half natural—it resembles animal breeding because important parts of it are performed under the local control of one human will, but on a macroscopic scale it resembles natural selection because the ultimate fate of technological artifacts lies outside the control of any one will.

Biological and technological evolution both share variation, selection, and replication, but the analogy extends to some less obvious parallels that are the consequence of these central concepts. Some of the most influential factors in the environment of an evolving biological organism are other evolving organisms. Likewise, classes of technological artifacts form a significant part of the environment in which other classes evolve. For example, the sonic characteristics of audio amplifiers may gradually evolve to accommodate long-term changes in the typical characteristics of phono cartridges and speakers—the two components most closely associated with the amplifier in an audio system. This can occur (and indeed has occurred)

[2]The account given here shares many features with one developed less explicitly by George Basalla in *The Evolution of Technology* (Cambridge, 1988).

without audio designers consciously recognizing the large-scale long-term implications of each individual selection they perform.

As with biological evolution, the history of technological artifacts is not an evolution toward a single goal or according to a single evaluative criterion such as technical efficacy but is simply the product of whatever have been the temporally and spatially local standards by which the environments of technology have allowed its artifacts to live or die. The absence of teleology permits considerable drift of the selection criteria over time. Other important parallels follow from the absence of teleology in both forms of evolution. Because the human planning involved in technological evolution extends over just a short range, technological artifacts may fill needs and be put to uses for which they were not originally designed, finding niches in the environment that were not anticipated by their designers. Finally, the absence of an overall plan means that vestigial parts and functions persist in technological artifacts as well as in biological organisms.

The analogy between biological and technological evolution can be carried to considerable length, but it eventually breaks down as a consequence of human involvement with technological evolution. Unlike biological lineages, which are limited to sexual or asexual reproduction within the same species, technological lineages can split and recombine in many different ways. And unlike biological genotypes, technological knowledge can persist without being required to produce artifacts continuously, meaning that some lines of technological descent are not clearly visible and that the disappearance of technological artifacts of a particular class does not mean that technological extinction has occurred.

The role of human control in biological evolution is limited to breeding and experiments in which selection occurs artificially. In technological evolution, we acknowledge the analogous role of human control over the variability of artifacts sent to the environment, but we must also recognize that the environment within which selection occurs also can be controlled by the technologist to a degree, such as with advertising that is powerful enough to shape how consumers will react to a product. In addition, the artificial selection of technological knowledge may be governed more by planned innovation and monopolies than by a purely vicarious modeling of the natural environment. These divergences from biological evolution exist to a greater or lesser extent in different technological fields.

In addition to providing an analytic device for explaining technological change, the evolutionary model has some general consequences for how the history of technology is conceived. First of all, it emphasizes the continuity of technological knowledge, encouraging

the historian to look for antecedent knowledge and artifacts rather than novelty and to suspect that incremental changes rather than radical innovations lie hidden in the historical record. The ateleological character of evolution encourages attention to diverse, local, and perhaps unanticipated selection criteria that account for the success of variants in their local environments rather than for how well they meet the abstract standards of present-day philosophers of technology. Finally, by the general emphasis the evolutionary model places on the editing rather than the authorship of technological artifacts by human society, it will accord symmetric attention to the failure and success of technological devices.

While the evolutionary model could be adapted to explain cultural change in general, it is particularly suited to technologies that evolve by competition in a market of products or ideas with little conscious manipulation of the environment.[3] High-end audio fits this criterion and has some features analogous to the ten-day life cycle and large chromosomes that gave the drosophila such an important role in genetics research.

High-End Audio: The Drosophila of Technology

In America, high-end audio (hereafter HEA) began in the 1950s. Young men who had acquired electronics training and been exposed to sophisticated equipment in World War II returned with European audio equipment, which was more advanced than American at the time, or built their own with the skills they had learned. The increasing sophistication of sound in the film industry, the ascendancy of FM broadcasting, and better-quality records also contributed to a public interest in high-quality music playback.[4] The few dedicated audiophiles who wanted a higher level of performance than was available from commercial equipment were the first high-enders. They found they could obtain the level of performance they desired only by appropriating professional and studio equipment, modifying commercial equipment, or building their own. Most consumer equipment was designed with various economic or technical compromises, and usually lagged behind the state of the art. The same is true today, and modern audiophiles continue to eschew most mass-market equipment. Nowadays, however, there are enough price-no-object designers that they do not have to scrounge around adapting equipment

[3]See ibid. for a persuasive application of the evolutionary argument to the entire history of technology.

[4]See Norman Eisenberg, "30 Years of Audio," *Audio* 61 (May 1977): 48–52.

designed for another purpose. Home assembly has declined somewhat, but the ethos of uncompromising standards and personal involvement with equipment persists. High-end audio began as, and continues to be, a consuming passion for many men, and, on average, they now have more money to support their hobby; well-educated professional men with considerable disposable income currently make up the largest market for HEA equipment.

As with the evolution of drosophila in a laboratory, the development of the HEA industry has occurred in relative isolation from political influence—unencumbered by government regulations, not tied to cycles of military procurement, and lacking the structured international network of laboratories, journals, and reviewers that frustrates attempts to apply a simple evolutionary model to science. Thus, the effects of simple competition in a relatively homogeneous environment stand out clearly.

Compared to other technological industries, HEA is characterized by flexible manufacturing, low start-up costs, short product life, rapid advances, and little resistance to innovation—all of which give it the short generation time sought in the biological realm by genetics researchers. It is a young industry in which hundreds of small entrepreneurial companies, each producing from one to twenty products, compete fiercely for market share. Because many of the innovations that constitute improvement are not patentable, successful design strategies soon appear in other products. Large companies exist, but none has achieved a monopoly to the extent that it can govern the evolution of the entire field by strategically introducing "innovations" or by manipulating the market. The field is in a constant state of ferment and the artifacts and design philosophies considered state of the art have changed considerably in its thirty-five years. Audiophiles can typically afford to change the components in their systems frequently, so that new variations that fit their constraints can diffuse with less resistance than in other technological fields.

Another consideration, somewhat analogous to the visibility of the drosophila's chromosomes, is that the development of HEA can be chronicled by the sequence of objects deemed "state of the art." Stable and well-bounded objects present a clearer organism-environment distinction to the historian than an evolutionary history of ideas would, for example.[5] It is also relatively easy to estimate the success of a particular class of

[5]See William C. Wimsatt, "Picturing Weismannism: A Case Study of Conceptual Evolution," in *What the Philosophy of Biology Is*, ed. M. Ruse (Boston, 1989), for a similar argument about applying an evolutionary analysis to conceptual diagrams.

objects by the numbers that are bought, whereas measuring the success of ideas, texts, and other less-bounded organisms is more problematic.

Not only are the artifacts of HEA a series of objects, but they are consumer products as well, and, as such, bear a unique relationship to the cultural values that accompany their creation because of the use to which they are sometimes put by those values. The design of consumer technology is almost always underdetermined by the explanations commonly given for it, yet attention is often diverted away from the particular form it eventually assumes. For example, the rhetoric of equipment advertisements tacitly assigns responsibility for particular designs either to their scientific function or to the artistic idiosyncrasies of their designers, whereas, in truth, little more can be said than that these objects are the evolved result of the past history of the field and what the market, with all its complex and undifferentiated constraints, has wanted and has been willing to pay for. From what exist as complex and undifferentiated constraints from the point of view of the market, the historian (and to some extent the participants in HEA) can single out certain constraints and call them cultural values. The competition and evolution of products in an environment in which these cultural values are present can turn those values into physical objects that play a unique role in the culture. Adrian Forty argues: "Every product, to be successful, must incorporate the ideas that will make it marketable, and the particular task of design is to bring about the conjunction between such ideas and the available means of production. The result of this process is that manufactured goods embody innumerable myths about the world, myths which in time come to seem as real as the products in which they are embedded."[6]

In contrast to the sometimes short-lived messages of the media, the design of everyday objects has the capacity to cast ideas about who consumers are and what they value into permanent and tangible forms, so that these ideas seem to be part of reality itself. In tangible form, the ideas can then be fed back into society as if they were part of "nature" and used in a fundamentally different way than if they remained disembodied values. It is this function of objects, not shared in the same way by the conceptual products of culture, that makes them such useful, though problematic, resources for historical analysis.

The Cultural Environment in Which High-End Audio Products Compete

As the name suggests, audiophiles are individuals who have a strong emotional investment in their stereo systems. The typical

[6]Adrian Forty, *Objects of Desire: Design and Society from Wedgwood to IBM* (New York, 1986), p. 9.

audiophile is a well-educated young or middle-aged male professional with considerable disposable income. He learns about developments in HEA and about new equipment through equipment dealers and audiophile clubs but mostly by reading the magazines devoted to audiophiles—magazines with such names as *Stereophile, The Absolute Sound,* and *High Performance Review.* These magazines exert considerable influence through their equipment reviews. A recent survey of those who read *Stereophile,* the leading high-end magazine, indicated that 92.8 percent of the readers relied on reports in audio magazines to reach their purchasing decisions. This was followed by in-store demonstrations (63.4 percent) and previous experience with the same brand (43.6 percent).[7]

This survey reveals some of the characteristics of audiophiles.[8] Taking the average reader of *Stereophile* as our representative audiophile, we see in table 1 and figures 1 and 2 that he is a well-educated professional with an income considerably above the national average.[9] The distribution of ages (not shown) indicates two clusters: baby boomers and young professionals in their late twenties and early thirties. While not all audiophiles fit the same stereotype, striking regularities exist within the diverse population of audiophiles that allow us to identify groups whose numbers and reported purchases of HEA products indicate that they are likely to exert a significant influence on the evolution of those products' characteristics. From the demographic pattern of its readership and the fact that 92.8 percent

[7]*Stereophile* 11, no. 10 (October 1988): 73.

[8]The survey was conducted by a magazine with a circulation of approximately 45,000. About 9,000 forms were returned, which is quite good for this type of survey. The answers to the question "How much did you spend on hi-fi equipment in the last 12 months?" are the chief indication of the survey's value:

Amount Spent ($)	Percentage of Respondents
Nothing	9.6
1–499	21.1
500–999	19.9
1,000–1,999	20.1
2,000–2,999	12.1
3,000–4,999	8.6
5,000–9,999	6.4
10,000 or more	2.2

The average spent was $1,960. This figure multiplied by the 45,000 readers of *Stereophile* suggests a yearly total of $88 million. This represents a significant fraction of the U.S. high-end market and an indication that the survey represents a fair number of the people whose combined purchasing power strongly influences selection.

[9]Of the respondents, 99 percent are male.

TABLE 1
ANNUAL HOUSEHOLD INCOME OF STEREOPHILE READERS

Income ($)	Percentage of Respondents
Less than 20,000	8.7
20,000–29,999	13.7
30,000–39,999	16.3
40,000–49,999	13.9
50,000–74,999	24.2
75,000–99,999	11.7
100,000 or more	11.5

SOURCE.—*Stereophile* 11, no. 10 (October 1988): 70.

of readers base their purchasing decisions on reviews in magazines such as *Stereophile,* we can surmise that *Stereophile* is the yuppie equivalent of *Consumer Reports,* at least for HEA equipment.

But *Stereophile* is more than a guide to technical equipment; it is a guide to an attitude that might be called "educated consumption." Equipment reviews, industry show summaries, and other descriptive reports are commonly served up with discriminating references to food and eating. Sometimes food and technology are described with the same words. Descriptions of electronics trade shows are invariably accompanied by at least two paragraphs ruthlessly rating the local cuisine; then, the consumption of food blends imperceptibly into the consumption of technological and musical offerings, often with no shift in the reviewers' language to signify the shift in domain. The reader receives the message that he is justified in consuming the expensive goods to which others do not have access, provided only that he is discriminating enough to appreciate their quality.

"Quality" is the yuppie watchword and something *Stereophile* serves up to its readers with relish. Here is how the editors view their mandate: "The public has never demanded better sound, because the public is not CONSCIOUS of the quality of sound. Most people, in fact, don't seem to be conscious of the quality of anything. Scratch J. Q. Public, ask him what 'quality' is, and he'll tell you it's something that won't fall apart before the warranty runs out, or is something rich people buy. Your average person is uncomfortable with the whole idea of a difference in degree. He finds it much easier to cope with differences of KIND. . . . High fidelity? Who cares? We may, but the world at large just doesn't give a damn."[10]

[10]*Stereophile* 5, no. 4 (June 1982): 3. This stance was formulated at what turned out to be a historic moment for *Stereophile.* Although the magazine had been publishing continuously since 1962, it was plagued by financial troubles that resulted in small

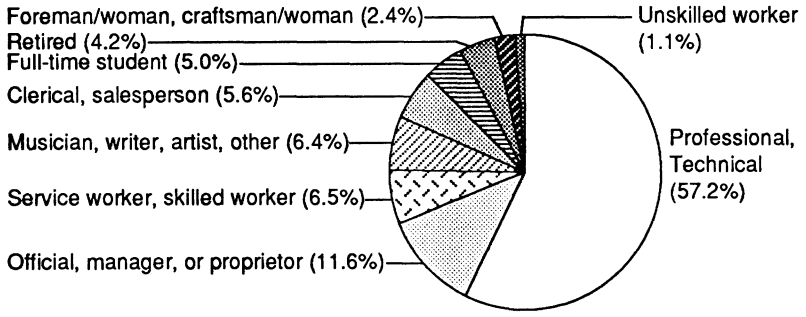

FIG. 1.—Occupation of audiophiles. (*Stereophile* 11, no. 12 [December 1988]: 70.)

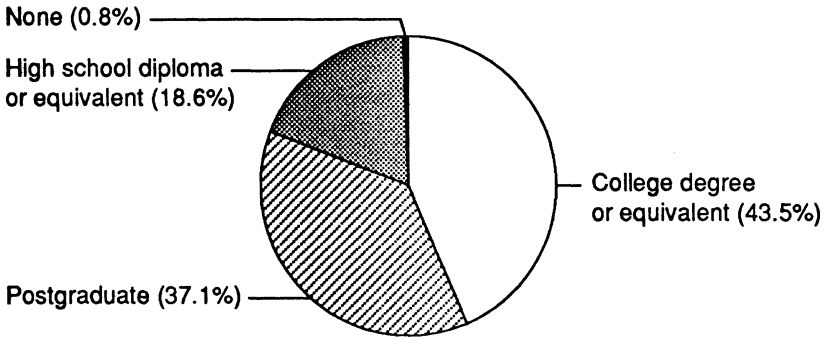

FIG. 2.—Education attained by audiophiles. (*Stereophile* 11, no. 12 [December 1988]: 70.)

The most conspicuous cultural message borne by many of the products purchased by audiophiles is that other people cannot afford them. A $6,000 amplifier, with its exotic materials and esoteric construction, is such a concentration of the universal medium of exchange in a particular location and in the hands of one owner, that its existence alone proclaims economic inequality. But before purchas-

issues and sporadic publication until the 1980s when HEA left its lean years behind and the circulation of *Stereophile* increased dramatically. Circulation went from 12,000 to 15,000 in the year this quote was written. Then, throughout the 1980s, as interest in high-quality consumer equipment soared, *Stereophile* enjoyed a tripling of its paid subscribers, many of them renewing for two and three years at a time. A more substantial format gave evidence of the influx of subscribers' and advertising dollars; starting with an average of forty black-and-white stapled pages per sporadic issue in 1980, *Stereophile* has grown to the point at which, in 1989, each of its 45,000 readers received a whopping 242 high-quality color pages per month. The 1980s were very good to *Stereophile* and, in general, to many American publications and organizations that adopted a similar stance.

ing such products, the audiophile typically feels obliged to demonstrate that its cost and the special pains taken in its construction are the rational means by which to pursue the interest of accurate sound reproduction. By arguing that the technology that puts a $6,000 price tag on an amplifier is the necessary means for achieving a relatively defensible end, the audiophile justifies the economic inequality that his purchase proclaims.

High-end audio equipment is not only a set of exclusive possessions, but the ticket to a world of experience that not everyone can share. Harry Partch, modern composer and inventor of musical instruments, quips, "In the right room acoustically, the Eroica [a six-foot bass marimba] is felt through the feet, against the belly, and, if one sits on the floor, it ripples through his bottom. It is very difficult to put on tape, and especially on records with any fidelity. Adequate playback equipment is absolutely essential, which means that the poorer generally are not privileged to experience a rippling through their backsides by an art form."[11]

The editors of *Stereophile* are very aware of the exclusivity implied by the products they recommend but defend it as the legitimate and unavoidable consequence of the quest for good sound:

> A number of recent letters have accused us of snobbishness and elitism because we devote so much space to reports about components that "common folk" can't afford. . . . Far from being chastened by these letters, I am proud to declare that they are right on target. . . . We Americans don't in fact *like* excellence, because it is so undemocratic. We prefer to believe that all people are created equal, and the person who excels—who rises above the common herd of average, undistinguished nobodies—is a discomfiting reminder that some people *are* born with more success points than others. That's why elitism—admiration of superior persons, or things—is so unpopular. It keeps reminding us of just how undistinguished the rest of us are.[12]

A polemic such as this seems out of place in the pages of a technical journal unless we recognize that technology is whatever knowledge, processes, and artifacts happen to be developed by people to achieve a goal they value at the time. In addition to the goal of good sound, HEA technology also serves to justify cultural values such as social stratification. *Stereophile* helps defend luxury spending by arguing that genuine benefits result, and that those benefits are desirable. It does

[11]*Stereophile* 12, no. 10 (October 1989): 137.
[12]*Stereophile* 8, no. 1 (February 1985): 5.

not have to lie to do this. For the most part, the distinctions that *Stereophile* reviewers claim to hear between a $500 and $6,000 amplifier can be demonstrated, both by double-blind listening tests and by reviewers' concurrence in simultaneous and independent subjective reviews.

Not everyone can hear these distinctions because humans differ markedly in listening ability—because of differences in natural acuity and its differential extension through the coaching and practice undertaken by some. The effort to resolve finer and finer differences with the human ear might be traceable to a premium placed on discrimination that has its source in the audiophile's cultural environment. The American audiophile is a man who has worked hard for material gain in a society that does not explicitly recognize status distinctions. It is to be expected that another economy will operate by means of which some of that money can be exchanged for the social stratification that is otherwise denied to him. In the realm of consumption, this sometimes involves simply outspending everyone else, but, in the case of HEA, such a crude approach is eschewed in favor of trying to demonstrate a greater *worthiness* to consume expensive objects. For this purpose, the ability to resolve differences in performance becomes, for the audiophile, a license to spend more than the "herd" on his audio system and to use exotic equipment built in different ways than everyone else's. The external differences between systems owned by an audiophile and a nonaudiophile pay tribute to innate differences in their owners' respective abilities to hear and appreciate music; the latter is the real source of status. One audiophile argues, "As I see it, there is no more reason to expect that everyone can discriminate the sound of one good amplifier from another than there is to think that everyone can tell the difference between a masterpiece and a merely competent artwork. The ability to make subtle sonic distinctions may be a reflection not only of training and experience, but also of constitutional differences in perceptual acuity and musical talent."[13]

Exotic equipment functions as the link by which quantitative differences between modern individuals can be converted into the one thing these individuals desire most—innate, qualitative differences that set them apart. But the exchange of money for qualitative differences is a transaction that cannot be made available to everyone, as this audiophile realizes: "Ideally, prospective consumers who are considering investing substantial sums in equipment should have an opportunity to put *themselves* in the test in a blind listening situation.

[13]*Stereophile* 12, no. 10 (October 1989): 25.

They should determine beforehand if the gold in their ears is commensurate with the gold in their wallets."[14]

The cultural motivation discussed above has a very general effect on HEA technology; it makes it possible for manufacturers to produce technology that is expensive and employs rare materials, exotic construction methods, unique circuit topology, and other features that the consumer can use to demonstrate that he is innately different. More specific events in the development of HEA technology can be understood with another type of cultural explanation. The examples discussed later in this article suggest that when he chooses one particular piece of equipment over another, the audiophile makes an implicit argument, either to himself or to others—following a structure that has been studied by radical scholars:[15] (1) the audiophile associates a certain cultural value with a piece of equipment; (2) without reference to whatever cultural value it has for him, the audiophile argues that the equipment is justified on technically rational grounds—as the necessary means to a generally accepted goal; (3) the audiophile then implicitly concludes to himself and suggests to others that the cultural value he associated with the component is necessary and rationally justified. In (3), the supposed neutrality of technology and art gives them a powerful role in legitimating social, cultural, and psychological goals.

The acceptable grounds for choice can be roughly divided into two groups: (1) the choice is the dictate of technical rationality (i.e., it is objective—corresponding to something "out there"); (2) the choice is the result of an inscrutable and innate aesthetic preference (i.e., it is individually subjective—legitimated by something so deeply "in here" that it is equally valid). Different as they are, both of these can play similar roles as legitimators of cultural values. In either case, an element from a natural category (i.e., physical nature or individual human nature) is used to legitimate something cultural. When a cultural value is surreptitiously attached to a choice that is rationally justified, it seems that nature and rationality themselves compel assent—which is what actually happens, to an extent, since the technical justification is no less valid because of the use to which it is put. Art also "has a reputation for being above things vulgar and mercenary, a form eternal rather than social, whose appreciation

[14]Ibid., pp. 25–27.

[15]This structure is adapted very loosely from suggestions in Forty (n. 6 above); and Judith Williamson, *Consuming Passions: The Dynamics of Popular Culture* (London, 1986).

springs from the discerning heart, not the cultural background."[16] But although they stand in no need of legitimation themselves, appeals to art are not strong enough in HEA to support other values. By contrast, technical arguments that refer implicitly to what is "out there" not only stand on their own but are strong enough to legitimate whatever cultural values can associate themselves.

Double-Blind Listening Comparisons: The Test of a Golden Ear

Since the professed goal of HEA is sound quality, the audiophile must justify his equipment choices by claiming to hear a difference between the components he prefers and those he rejects. If he cannot hear any difference, then he is forced to admit to himself and his peers that his choices are based on other, less acceptable factors. Given a single goal or hierarchy of goals, it might seem that technical measurements alone could be used to determine what are desirable pieces of equipment. But at the farthest reaches of performance, objective measurements at present cannot completely predict how a component will sound, and the final evaluation must rely on listening tests. The underdetermination of sound quality by measurements has left the door open for subjective evaluations of components and has generated tremendous debate between engineers and subjective equipment reviewers. Since the rise of subjective equipment reviews in the last twenty-five years, engineers have often claimed that audiophiles are lying or are deceived when they claim to hear differences between components that measure identically and that the preferences of audiophiles are rooted in elitism, nationalism, and other cultural factors.[17]

High-end audio is a self-policing field for one of the same reasons that science is: some of its members realize that, if they allow too many unfounded claims to circulate, the credibility of the whole field will suffer and even well-founded claims will lose their legitimacy. If responsible audiophiles allow too many cultural preferences to ride on the coattails of poorly constructed justifications, they lose the foundation on which they justify their preferences. In response to criticism from the objective-measurement crowd, the editors of *Stereophile* argued for limited double-blind listening tests:

> The question must be resolved if the perfectionist-audio field is to advance much farther than its present semi-stagnant state of stasis. We all know that there are indeed audible differences between

[16]Williamson, p. 67.

[17]Many of the cultural explanations offered in this article are developed from the more or less articulate suggestions of audio engineers and audiophiles who criticize what "the other guys" are up to.

> components which appear to measure identically. . . . The time has come when we self-styled golden ears must put up or shut up. What is needed, right now, is a listening test that will prove (or disprove, if it works out that way) to the scientific community at large that trained ears *can* hear things we cannot as yet measure, or are not as yet correctly interpreting our measurements of . . . —at the dire risk of my credibility—I'll be happy to serve as a listening panelist. . . . Gentlemen (and ladies), the gauntlet is flung. Do I see someone coming forward to pick it up?[18]

The gauntlet was picked up by *Stereo Review,* a measurement-oriented magazine, and the Audio Engineering Society, which counts a number of mass-market hi-fi manufacturers among its members. A series of double-blind listening tests were run at audio trade shows and seminars to compare CD players, amplifiers, and speaker cables—components most engineers believe should sound the same. *Stereophile* also ran some double-blind tests of its own design.

Double-blind tests for audible difference typically follow the *A/B/X* format. The group of listeners under test are first presented with the sound of two components identified as *A* and *B*. Then a component called *X* is played, and each listener must decide whether it is *A* or *B*. In some tests, each listener can switch between *A, B,* and *X* until they are sure of their decision; in other tests, a computer automatically switches back and forth several times. Each unknown *X* determination is called a trial. A number of listeners typically perform a series of these trials to obtain a statistically significant amount of data. Because the true identity of *X* is determined randomly for each trial and all the switching is done by computer, not even the test administrators know the correct answers until the end of the test. Ten years of tests under these conditions have demonstrated that, while genuine differences exist, most people who claim to hear them cannot prove this when asked to do so under double-blind conditions; they are only slightly more successful than if they guessed randomly. However, a few "golden-eared" audiophiles typically do very well, discerning with nearly perfect accuracy between components that critics claim should sound alike. These otherwise ordinary individuals also perform above average on clinical audiometry tests. That such a disparity has lain undiscovered in the human population is not surprising, given that exceptional hearing is unlikely to be uncovered except in artificial tests.

Perhaps the most important thing demonstrated by the double-blind tests (which are expensive, time consuming, and have relatively little

[18]*Stereophile* 4, no. 9 (November 1981): 6.

commercial payoff) is that they involve something very important to these people. The suggestion that a small population of audiophiles may be innately sensitive to factors others cannot hear probably explains the strong but mixed feelings audiophiles have about the tests. On the one hand, a small amount of double-blind testing is accepted, even actively sought out, because the success of a few golden ears demonstrates that the differences are genuine and therefore detectable in principle by everyone. But whereas a small amount of double-blind testing lends legitimacy to HEA as a field, a large amount would challenge that legitimacy by disqualifying too many of its members. Before double-blind testing became common, an audiophile could gain entrance to the high end simply by claiming to hear a difference; he was taken at his word. Now, however, the "club" is starting to limit its membership. Double-blind tests have suggested ominously that quite a few members of the club have gotten a free ride on the coattails of the golden ears. The strong feelings aroused by double-blind tests suggest that legitimacy is highly valued by audiophiles.

The fact that measurable specifications do not fully determine the sonic attributes of audio components permits an audiophile to justify choosing one component over another, provided, of course, that his ears are good enough to discriminate what the objective measurements typically do not. It should be noted that the double-blind tests address only the existence of difference, rather than the separate question of whether that difference is one of quality and whether it justifies the expense of high-end equipment. It is curious, however, that even the critics of HEA will leave this question of quality entirely in the hands of the audiophile once he has demonstrated an ability to hear difference of any sort.

As improved measurement techniques narrow the gap between measured specifications and sound quality, there is a powerful incentive for an audiophile to preserve his right to choose by training his ears to hear ever finer distinctions. Subjective reviewers acknowledge that their job is becoming more difficult: "Differences among the best high-end components are becoming so small that it is increasingly hard for a self-professed golden ear, let alone a professional reviewer, to hear describable differences. . . . We are working these days at the very limits of human perception."[19]

But what if two components sounded so alike that the best golden ears could not tell them apart? Could audiophiles still find legitimate grounds to choose the one with the greatest appeal to their cultural values? The problem with such questions in the social sciences is that

[19]*Stereophile* 9, no. 1 (February 1986): 9.

they seldom meet face-to-face with experiments on sufficiently large groups. But in the case of separating the cultural and technical contributions to the evolution of amplifier design, the closest thing to a real "experiment" was performed in 1985 by a man who is now much richer because of the outcome. He is Bob Carver, an accomplished engineer whose Carver Corporation is easily the largest domestic manufacturer of audio electronics. Because of what has been called the "Carver challenge," he now deserves credit as an empirical psychologist, with much of the audio community acting as his test subjects.

The Carver Challenge to Golden Ears

Carver claimed to the editors of *Stereophile* that he could modify an inexpensive solid-state amplifier to the point where it would be sonically indistinguishable from any amplifier they chose. He knew they would choose an expensive amplifier well loved by audiophiles. The editors accepted his challenge, and the event was reported in the high-end press: "When Bob claimed, some time ago, in conversation with Publisher Larry Archibald, that he could make his $700 Model 1.0 amplifier sound 'indistinguishable from' any amplifier of our choice, we were confident that he was finally out of his depth. Carver Corporation is, after all, a 'mainstream' manufacturer, not a 'high-ender.' Bob's designs are unabashedly aimed at the mass market, notorious for its lack of aural perspicacity. . . . Bob's claim was something we just couldn't pass up unchallenged."[20] After some discussion, they agreed on a simple test criterion: Carver had to make the two amplifiers sound absolutely identical, or at least similar enough in sound that none of the editors could tell one from the other with better than 50 percent (pure chance) consistency.

Carver started out with a stock $700 amplifier that everyone agreed sounded worse than the $6,000 reference amplifier whose sound he would try to duplicate.[21] Carver began his sophisticated tinkering in a semicontrolled environment: "The hotel room was a shambles! Across one end was a long table buried in oscilloscopes, distortion

[20]*Stereophile* 8, no. 6 (October 1985): 33.

[21]The editors did not make it easy for Carver: "Is it possible to make a $700 'mainstream-audio' power amplifier sound exactly like a high-priced perfectionist amplifier? Bob Carver, of Carver Corporation, seemed to think he could, so we challenged him to prove it. . . . We knew that Carver couldn't possibly pull this off, at least not to the point where none of us would be able to distinguish between his modified 1.0 and our reference amp. After all, some of the most highly trained audio ears in the world would be listening for the differences. . . . We decided . . . not to

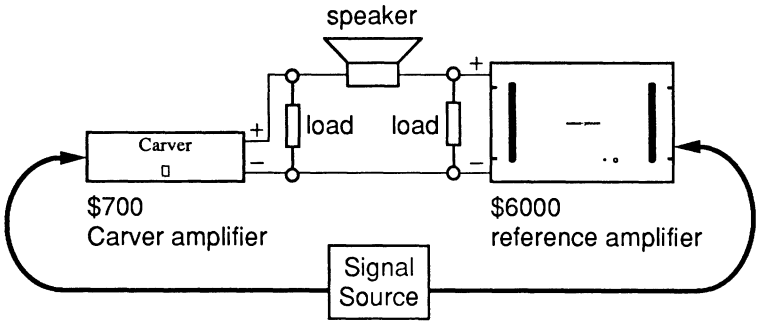

FIG. 3.—In this schematic representation of the Carver difference-nulling strategy, the speaker plays only the difference between the two amplifiers, making it easy for Carver to match their sonic characteristics.

analyzers, voltmeters, the two amplifiers, a soldering iron, a white noise generator, two unidentifiable chassis full of inductors, resistors, and capacitors, a large table fan (there was no air conditioning), a half-dozen partially drained Diet Coke cans, and perhaps 50 feet of audio cables, test leads, and clip-lead interconnects. The adjacent sofa and table were covered with countless little plastic bags of resistors and capacitors, several schematic diagrams, and sheets of paper crammed with arcane numbers and calculations."[22]

The approach Carver used to compare the sound of the two amplifiers is called a nulling test and is shown in figure 3. Both amplifiers are fed the same input signal, either music or noise. A speaker is connected between the positive output terminals of the two amplifiers, meaning that any signal that appears at the output of both amplifiers will cancel out and not be heard. Only the difference will be audible to Carver.

Carver used the nulling strategy to guide him as he made adjustments to the circuitry of his amplifier, subtly changing its frequency response, phase shift, distortion characteristics, and damping factor until no sound emerged from the difference speaker. The virtue of the difference nulling approach is that it quickly demonstrates

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reveal the 'reference' amp's identity, saying only that the reference unit is a high-powered, very expensive stereo unit with a strong and unique sonic 'personality,' and a penchant for being very finnicky about the loudspeakers it works with. It was, we were gleefully confident, likely to be *very* dissimilar in sound from Carver's own designs, and probably much more unpredictable in terms of its behavior with a given loudspeaker. . . . We were confident that we had effectively stacked the deck against Carver's success." Ibid.

[22]Ibid., p. 34.

real-world audible differences in electronics that are almost impossible to ascertain by conventional measuring techniques. Carver did not need to fully understand or measure all the possible sources of sonic imperfection; all he had to do was eliminate them.

The editors chose various program sources to highlight specific sonic attributes:

> "The Portrait" and "Peter the Hermit," from *Growing Up in Hollywood Town* (Sheffield CD-13 and Lab 13) for depth and perspective, HF naturalness, bass heft and tightness; Respighi's *Church Windows* (Reference Recordings RR-15) for breadth, depth, bass range and control, and massed-string tone; Beethoven & Enesco *Violin & Piano Sonatas* (Wilson Audio Specialties W-8315) for tonal accuracy, depth, and imaging specificity and stability; "Improvisations" by Jim Keltner, from *The Drum Record* (Sheffield CD-14/20) for high-end openness & timbre and low-end attack, control and range; and McBride's "Mexican Rhapsody," from a badly worn copy of *Fiesta in Hi-Fi* (Mercury Living Presence SR90134) for treatment of HF stridency and mistracking.[23]

The outcome astounded and exhausted the editors. On the fourth day of listening tests,

> the listening went on through the whole afternoon and much of the evening, until all of us were listened out. More leisurely listening, refreshed by a good night's sleep, failed to turn up anything. As far as we could determine, through careful comparisons and nit-picking criticisms, the two amplifiers were, in fact, sonically identical. It is a gross understatement to say that we were flabbergasted! . . . On the face of it, what Bob Carver pulled off should be impossible. You can't make a silk purse from a sow's ear. . . . The implications of all this are disquieting, to say the least . . . the field of high-end audio amplifier manufacture will never be quite the same again. High price and high status will continue to be handmaidens in audio, but the knowledge that high performance and high price need no longer be inseparable cannot help but impair the glamor of cost-no-object power amps.[24]

Reflecting on the incident a year-and-a-half later, they said: "We're glad there was no wager involved. After a mere four days of work, Carver presented us with a solid-state amplifier that, after two days of

[23]Ibid., pp. 38–40.
[24]Ibid., pp. 42–44.

listening comparisons, we could not distinguish from the reference amplifier."[25]

Within a short while, Carver capitalized on his success and the tremendous publicity it received. He took the modified Model 1.0 back to his factory and incorporated the changes he had made into production versions. Many audiophiles and manufacturers criticized Carver for stopping once he had copied another amplifier, saying that instead of merely equaling the reference, Carver should have gone on to produce his idea of the world's best-sounding amplifier. But Carver knew that, if an amplifier were built to his own sonic standards, it would necessarily sound different from other high-end amplifiers; and regardless of whether that difference represented an improvement to his or anybody's ears, it would give the high-end reviewers some criteria on which to claim they honestly disliked his products. Making a culturally unappealing amplifier sound identical to a culturally attractive amplifier was a far subtler point, and it made many audiophiles squirm.

Both the reference amp and Carver's copy are offered for sale to the same market, producing an experimental setup that would be nearly ideal if audiophiles believed the two amplifiers sounded alike. Would audiophiles continue to buy the expensive reference amp, even though its technical justification was cast somewhat in doubt by the challenge? Or would they grit their teeth, put out a measly $499 for Carver's Model 1.0t, and find some other use for the remaining $5,500?[26]

What actually happened is less dramatic: both the original and the copy found ready markets, although with two very different groups of people. The Carver Model 1.0t amplifier sells (in great quantities) to those people who appreciate Carver's Yankee ingenuity and the image of an engineer-hero he has earned and cultivated. Another high-end manufacturer wrote: "The ego-secure among us will admit that Bob Carver is an innovative designer, a red-blooded American hero, a paradoxical showman, and deserving of every bit of the great success he has achieved in the mid-fi market."[27] Carver's customers get a lot of amplifier for their money and they appreciate buying from an American manufacturer who gives away nothing to the Japanese in the cost-efficiency of his products or his manufacturing.

It is ironic but perhaps not surprising that sales of the reference amplifier and others like it have not been hurt by the Carver challenge. There remains a strong and growing market for amplifiers

[25]*Stereophile* 10, no. 3 (April/May 1987): 117.
[26]Carver lowered the price from $700.
[27]*Stereophile* 9, no. 1 (February 1986): 60.

built according to the " 'heroic' design philosophy, extreme in its disregard for efficiency, size, and weight."[28] When a consumer chooses a piece of American or European equipment and defends that choice on technically rational grounds, he supports not only where the product was made but how it was made. Because the merits of an audio product depend, in some irreducible way, on the subjective evaluation of the audiophile community, members of that community have the power to legitimate the "heroic" approach to design every time they choose such products under the pretext of sonic quality. Although he probably drove to work in a Japanese car and acquired many other inhumanly compact and efficient electronic devices, the audiophile would like to believe that the reproduction of music—the part of life most dear to him—follows a set of rules that have not yet fallen prey to the logic of efficiency, miniaturization, and automation.

Because of the implicit rules of the game, however, purchasers of the reference amplifier must be able to claim that they hear differences between it and other amplifiers that justify the additional expense. Although the amplifier that Bob Carver personally nulled in the Carver challenge was a match for the reference amplifier, *Stereophile* ran a follow-up article in which several days of listening revealed sonic differences between the reference amplifier and Carver's production versions. The difference may lie in Carver's inability to duplicate in mass production the feat that he performed personally, or they may be explained by the fact that the follow-up took place one-and-a-half years later and the reference amplifier uses tubes—electronic components that change their characteristics over time. Whatever the explanation, the reestablishment of difference now gives the audiophile a defensible argument for choosing the reference amplifier and those similar to it.

Small differences in sound quality that cost the audiophile $5,500 might not withstand a cost-benefit analysis by anyone willing to put a price on sonic pleasure—but that is precisely what the audiophile who purchases the reference is trying to say cannot be done. As long as some difference is present (no matter how slight), and as long as there is a reluctance to equate money with quality, the reference amp remains a defensible choice according to the rules of the audiophile game. (See fig. 4.)

The Tube Renaissance

A surprising development in HEA, at least to those persuaded that technology proceeds unidirectionally according to an internal logic, is

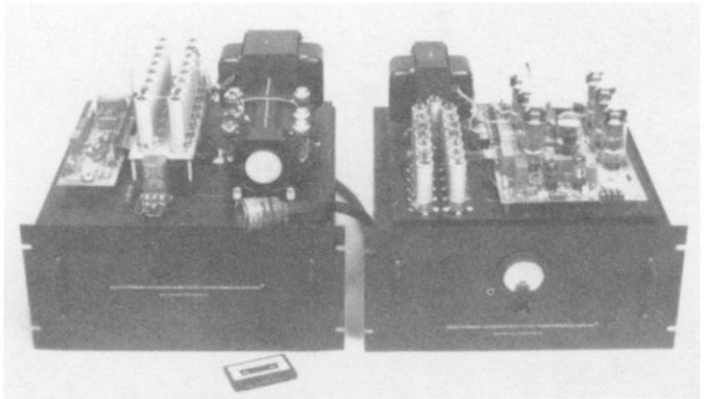
FIG. 4.—Bob Carver has run another experiment on the HEA community. The tube amplifier on the left sells for $17,500 a pair but includes all the subtle touches that tube fanciers love, while the solid-state copy sells simultaneously for $800. Carver claims these amplifiers sound very similar, though admitting that "$17,500 does buy you something extra!" One might almost conclude that Carver is running an experiment for his own satisfaction (and material gain), comparing the success of two products with similar technical justification but different appeals to cultural values. (Courtesy of Carver Corporation.)

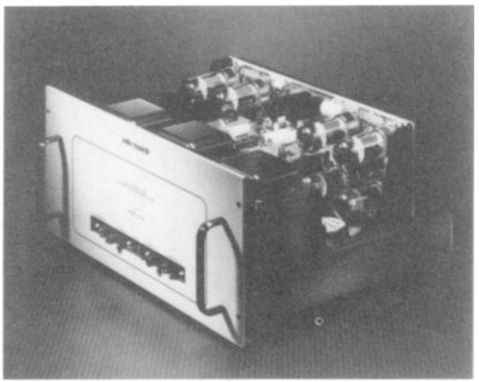
the renewed interest in vacuum tube equipment among American audiophiles.[29] The revival of tube electronics began gathering much of its momentum in America at a moment when Japan bashing became the popular reaction to the domination of many consumer markets by Japanese manufacturers. In a short period of time, audio components that were bulky, inefficient, and typically handcrafted in small quantities in America or Europe became preferred over equipment that was compact, efficient, automated, and mass-produced in the Far East. While a "discernable xenophobia"[30] spurred a return to English- and American-crafted products, there was also a bit of romantic longing for the past involved. Tube equipment is often fitted with the same type of bakelite knobs and round-faced meters that adorned World War II military gear and that evoke the postwar era when America and Western Europe enjoyed technological supremacy. Advertisements and reviews manage to imply that tube technology, which once reigned supreme, now deserves another look, not for a return to the past but for genuine merits that have been overlooked as the world rushed prematurely into the transistor age. Tube circuitry is called "timeless" or "classic"—designations commonly used to evade explicit reference to a work's production by a particular society and era (see fig. 5).

The appeal of tubes lies not only in the nostalgia they inspire, but also in the similarity of their physical properties to those of a living organism: tubes are warm, they change their characteristics subtly over time, and they age both sonically and visually—their envelopes slowly darkening until they eventually die. Their nature seems less contrary to that of the muse who is entrusted to them. Compared to solid-state electronics, tubes are the building blocks of a more friendly technology because their operating principles can be grasped intu-

[29]As most readers are probably aware, vacuum tubes all but disappeared from consumer, commercial, and military electronic equipment when semiconductors became practical alternatives in the 1950s and early 1960s. Audiophile equipment has been something of an exception, however, with an interest in tube equipment persisting in Europe, America, and especially Japan. Recently, however, the popularity of tube equipment has increased dramatically. In 1988, e.g., a new journal was founded solely for tube enthusiasts, and in that year, there were more tube amplifiers to choose among than in any period prior to 1965 (*Glass Audio* 1 [1988]: 3). Although tube equipment is manufactured and enjoyed in Japan, most American audiophiles associate the Japanese with the much greater quantity of solid-state equipment exported by that country. The tube equipment preferred by Americans is manufactured in their own country, with very few exceptions.

[30]From D. R. G. Self, "Science v. Subjectivism in Audio Engineering," *Electronics and Wireless World* 94 (July 1988): 692–98, in which a prominent engineer laments the influence of nationalism on the audio engineering field.





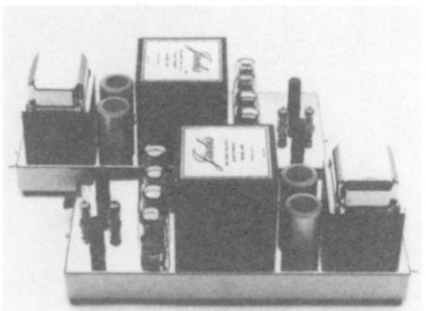


FIG. 5.—Tube equipment. (Courtesy of New York Audio Labs, Jadis, and Carver Corporation.)

itively, their working parts are visible to the eye, and they are not so dreadfully miniaturized. Edward Dell suggests that these reasons (in addition to, or perhaps instead of, the cultural explanations offered above) underlie the primary appeal of tube electronics to those audiophiles who received their electronics training with tubes in World War II or shortly afterward and are, consequently, more comfortable with these than with the solid-state technology they never learned.[31]

The fact that tube equipment fits certain cultural features of the current HEA environment does not mean that tube equipment cannot also satisfy an interest in better sound that is unconnected to those cultural interests and also present in that environment. On the contrary, it was precisely because tube technology also fits this more acceptable interest that it became so appealing to audiophiles. There are many devices that could meet the cultural constraints alone (including a cardboard box with certain sentences written onto it), but only a few devices that can successfully meet all constraints of the environment.

Recently, the tube renaissance has taken a new turn; equipment that combines tubes with transistors or tubes with digital electronics has been introduced by manufacturers and gained popularity among audiophiles. These hybrids offer a harmonious blend of the virtues of the old and the new technologies. The hybrid approach might not immediately seem to fill any cultural need, but it certainly suggests comparison with the commercial application of the fragmentation and recombination of cultural elements to everything from popular art to consumer products to architecture—combining the best of modern developments with a whimsical respect for, and return to, traditional values.

An analogy between cultural phenomena and the technological development of hybrid electronics is suggested in part by an editorial in the first issue of *Glass Audio,* a new journal for tube enthusiasts:

> Here we are reading or writing about vacuum tubes. Thermionic valves, almost a century old, were written off as dead a good two decades ago. Are we Luddites, some weird form of audio recidivist? Not quite. A simple analogy will suffice, from another field also riddled with technology for the sake of it: horology. Ask yourself, what are the two biggest recent success stories in the watch-making industry? Japanese digits and Japanese digits? Wrong. It's Swatch and Rolex at opposite ends of the price scale. Okay, so the Swatch is electronic, but it shares something with the

[31]Edward T. Dell, editor of *Glass Audio,* letter to author, June 23, 1989.

> Rolex in that both have good old hands on dials instead of big, bold numbers. True, the millions buying Swatches and the thousands buying Rolexes may be buying them for fashion or status, and it's unlikely that many of these purchasers are "watchophiles," but they know what they like, and what they like happens to be old technology, regardless of the new dressing. More and more, this is happening in hi-fi, and it's tubes to which people are turning—however small the flood.[32]

The analogy made in *Glass Audio* between watch fashion and audio fashion can be extended to include hybrid audio equipment and the new hybrid watches:

Watches	Audio	Cultural Reference
original analog (before 1970s)	original tubes	traditional values
digital watches (1970s, early 1980s)	solid-state	modernism
return to analog (1980s)	return to tubes	reactionary nostalgia
analog/digital hybrids (late 1980s)	tube/solid-state hybrids	postmodern juxtaposition of modernist and nostalgic themes

Analog watches have returned for a number of reasons, some of which are explicitly sanctioned by the culture; they are more readable to some people, often last longer, and clash less with formal apparel than digital watches. But the association of analog watches with an age when technology was less threatening has probably contributed to their acceptance as well. The analogy suggests that tube equipment was revived for a variety of similar reasons. Eventually, the reactionary stance embodied in analog watches and tube electronics lost its initial novelty. Or perhaps the explicit arguments used to justify the complete throwback could no longer be sustained after a point. So a cultural premium was awarded to those products that could successfully merge the old with the new—using technology to represent and resolve tensions between old and new forces in society. This cultural premium may account for the success of hybrid watches and hybrid electronic equipment (see fig. 6).

[32]Ken Kessler, "The Tube Revival," *Glass Audio* 1 (1988): 1–3.

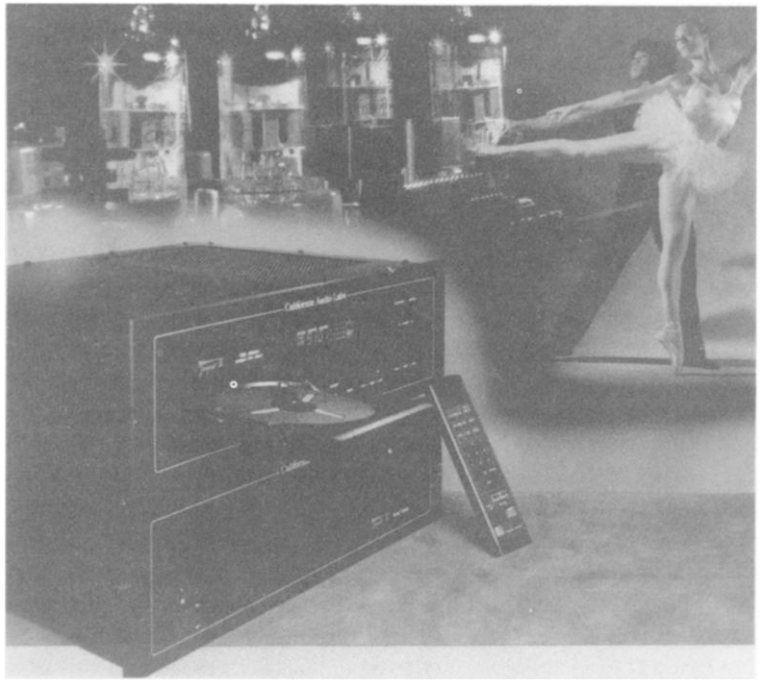


FIG. 6.—This advertisement for the California Audio Labs Tempest is a masterpiece of the advertiser's art of representing technical and cultural tensions and suggesting that these are resolved by the advertised product. The most obvious resolution occurs between the tubes and IC chips, which represent the tension between the friendly tube technology of the past and the frightening new computer technology sometimes associated with the Far East. Despite the opportunity for conflict, the advertisement suggests that the CAL Tempest manages to get them to work together in harmony. Meanwhile, in the back right, a white dancer moves in harmony with a male dancer who manages to look simultaneously African, Eskimo, Indian, and Asian. The message here is also a reassuring one but on a cultural level: the white woman need not be protected from contact with the Other any more than tubes need fear contact with new technology. One could go further with this sort of analysis; he (representing solid-state electronics) is flat-footed while she (representing the more musical tube technology) is lighter on her feet. They are not exactly dancing together, but he appears to be supporting her solo effort—a relationship that parallels the electronic division of labor that occurs between the solid-state and tube sections of a hybrid component. (Courtesy of California Audio Labs.)

Initial Reaction to Digital Audio

In its electrical form (at the output of a microphone, for example), music is a voltage that varies with time. Whereas analog equipment treats this changing voltage as a continuous quantity, digital recording splits the amplitude into 65,536 levels, and time into 44,100 slices per second. Digitization can be compared to putting a very fine grid over

the graph of a musical waveform and recording the waveform as a sequence of coordinates. The signal can then be recorded and processed numerically, which means that virtually no new distortion will be introduced by the storage medium, at least until the sound is converted back to analog. Digital compact discs (CDs) were the first recognizably digital medium to acquaint many people with this recording technique.[33]

These technical aspects of digital audio suggest why audiophiles reacted violently to the new medium, even before hearing it. For the most part, they reacted to two aspects of digital recording: (1) what digital audio does to music—cutting it up "unnaturally" and "defiling" it; (2) what digital audio might do to high-end audio—democratizing quality to the point where anyone could obtain for $200 what formerly cost audiophiles thousands of dollars.

In anticipation of digital CDs becoming widely available to consumers in 1983, a number of tirades were launched against it by audiophiles who denounced it on principle, months before hearing it. They objected to the fact that digital audio is inherently distorting—the only reason it might sound so good in practice is that it chops up the music too finely for human ears to detect. Audiophiles are painfully aware that the technical standards for digital audio were not set with the goal of flawless reproduction but with an intimate knowledge of the human sensory apparatus and its limitations. The whole idea of digital—the chopping up of music into little pieces, and reconstituting it like powdered orange juice—simply offends some people because it treats music as something to be processed and treats themselves as imperfect machines to be fooled.

The plea of many audiophiles to save music from digitization may also have a nationalistic and racist connection. Although CD technology was developed mostly by Philips engineers in the Netherlands, the Japanese quickly dominated the American market and became associated with digital audio in people's minds. The music that some audiophiles want to save from digitization is mostly American and European classical music. Some of their protestations evoke the racial stereotypes of the popular Fu Manchu films and other Hollywood movies of the 1920s and 1930s, in which a sinister Japanese villain abducts a pure and innocent Western heroine. Some of the early protest against digital audio took it as a mission to protect "the virgin sound." What many audiophiles did not realize was that the virgin had already been deflowered. In fact, recording studios had used

[33]The CD was preceded by the Sony PCM-1 (1977) and PCM-F1 (1981) digital sound processors for professional recording, but these machines did not find widespread use.

digital technology for years to master the recordings that eventually became the analog discs that audiophiles loved. Many records that some audiophiles believed were analog had actually passed through a digital stage without anyone knowing or complaining.

A less extreme (and more typical) reaction by most audiophiles to equipment that is digital and Japanese is probably connected with the perceived poor quality of early Japanese units and cultural prejudices. The following reviewer thinks back on his long-standing prejudice against Japanese equipment and offers some explanations: " 'This won't take long,' I thought, as I opened the box containing the new Denon DAP-5500 'digital preamp.' Like many audiophiles, I guess I'm prejudiced against Japanese components. Whether this stems from long (and unhappy) associations with Pioneer and Panasonic equipment in my moneyless youth, or is a holdover from postwar 'Japanese-Crap' thinking, I don't know. . . . This was my attitude as I replaced my trusty reference preamplifier (a tube unit) with the DAP-5500."[34]

Opposed on principle to any kind of processing that the popular press suggests might be "perfect," audiophiles are likely to resent digital audio and look for scientific arguments to discredit it. One attempt to establish some antidigital claims was launched in 1985 by Judith Reilly of Quinsigamond Community College in Worcester, Massachusetts, who claimed to have discovered that digitally mastered analog discs damage the turntables on which they are played. Her initial research purported to reveal a statistical correlation between the number of hours a phono turntable had been used to play digitally mastered discs and the constancy of its speed. She proposed a causal mechanism in which ultrasonic spuriae, produced by digitization and recorded in the grooves, would propagate from the stylus to the turntable bearing, causing microcracks. She also believed that ultrasonic spikes on digitally mastered analog records "rotted the innards" of the electronic equipment through which they were played. What made her different from other "digiphobes," at least temporarily, was the scientific support with which she bolstered her claims, claims made in a variety of audiophile journals and accompanied by references to the literature of metallurgical theory and ultrasonic propagation, photographs of oscilloscope traces purporting to show ultrasonic spikes, graphs of turntable speed versus time,

[34]*Stereophile* 11, no. 1 (January 1988): 129. The reviewer, George Graves, is subsequently won over by the Denon DAP-5500 and concludes his review by highly recommending it.

electron micrographs of turntable bearings, and reports of corroboration by independent testing laboratories.

Her claims attracted much notice, including the attention of several high-end turntable manufacturers who tried to duplicate her results, but without success. Ultimately, Reilly's findings were dismissed when neither she nor anyone else could duplicate them. It was a noble try, remarkable for how well it used the rhetoric of science. Other attempts have been made, including one purporting to demonstrate a correlation between digitized sound and listener stress. All have attracted attention and impassioned devotees, but none could withstand scrutiny.

The primary motivation of such people as Judith Reilly does not seem to be swindling people. How could acceptance of her claims conceivably earn Reilly any material gain? If not money, she and similar audiophiles must be dealing in some other form of invisible currency—perhaps the priceless "currency" of legitimation, a form of payment audiophiles receive when their personal ideas are granted universal acknowledgment if the devices or theoretical formulations that embody them are accepted by the community on technical grounds.

A different type of antidigital bias is traceable to the leveling of social and economic differences that digital audio seems to portend. An analog turntable, tonearm, and cartridge is a joy to own and play with. The mechanical components that make up an analog playback system and the system's extreme sensitivity to fine adjustment provide an almost unlimited palette of modifications that will slightly change the sound obtainable from any record. But since the information stored on a CD is just a string of numbers, a ceiling is put on how much of it can be extracted and enjoyed. In the words of one reviewer, "CD players lack sport. You plug them in and have nothing to do!"[35] The popular press initially suggested that all CD players would sound alike. If this were true, then anyone could plunk down a few hundred bucks at Sam Goody and gain entrance to the once-exclusive club of audiophiles who extracted superb sound from their systems only at great expense and with personal involvement and skill. If all players were equal, reviewers would lose their jobs, and audiophiles would lose the argument of difference among components by which they had justified their culturally motivated choices in the past.

Obtaining good sound from an analog system demands formidable effort, expense, knowledge, and personal involvement—typically

[35]*Stereophile* 9, no. 4 (June 1986): 114.

requiring years of experience and thousands of dollars worth of equipment. Digital audio initially offered the opposite relationship between an audiophile and his music; the equipment required absolutely no input of skill, it gave no intuitive clues as to its operating principles, and was consequently offensive and frightening to people accustomed to understanding and working very closely with their equipment. In a letter recalling how digital equipment changed the high end, a typical audiophile bares his soul:

> There is clearly a symbiosis that exists between man, his music, and his equipment. We expend considerable effort in trying to make our systems yield maximum musicality, and through this effort, we develop definite relationships with our systems. The fruition of our efforts leads to an emotional response much like that of witnessing your child walk for the first time. Isn't that what it is like when, after those countless hours of adjusting VTA's and speaker placement, your favorite piece of music fairly brings you to weeping? We love our systems, the product of so much contemplation. The relationship is much like what the airmen of WWII experienced with their B-17s. These men developed relationships with their machines because their lives depended on them. And so it is with our systems—our musical lives depend on them, and for many of us, music is a deeply personal vehicle for emotional catharsis.[36]

An audiophile with this kind of relationship to his hobby will certainly oppose the democratization of sound, not simply on elitist grounds, but because it will render years of emotional and financial investment utterly superfluous.

Audiophiles were not the only high-enders worried about the democratization of quality sound. An audiophile record company called Mobile Fidelity Sound Labs (MFSL) had built its entire reputation and market share on a two-tiered record catalog that offered higher-quality LPs that were pressed on premium vinyl. The extra cost of these records was justified because the special pains taken in their manufacture resulted in truly superior sound. But since CDs store only a string of numbers, it is difficult for a manufacturer or consumer to justify an elite CD.

As an answer to this problem, MFSL tried marketing a line of 24-carat gold CDs. (Standard CDs are made of an aluminum foil sandwiched between two layers of polycarbonate.) Research done by

[36]*Stereophile* 12, no. 9 (September 1989): 15. "VTA" stands for vertical tracking angle—one of the many tedious and continuously variable adjustments that can be made to a phono cartridge in an analog playback system.

MFSL indicated that, in accelerated aging tests, some discs with certain types of foil, polycarbonate, and processing might eventually deteriorate. Regardless of the fact that no CD manufacturers currently employed the types of processing implicated, the test made newspaper headlines in Britain during the summer of 1988. Mobile Fidelity Sound Labs proclaimed its 24-carat gold CDs the answer to "CD rot."

Gold discs with a premium price were also the answer to the lack of stratification that initially existed in the digital audio world, and they achieved some success. However, because the technical justification of the CD rot theory has been severely lambasted by the press and other record manufacturers, it is unlikely that the gold CDs will have much effect on future technology. Nor do they represent significantly new technology, beyond the fact that MFSL had to solve the rather trivial problem of making CDs out of a different metal. The gold CD is not a satisfactory answer to the cultural problems raised for audiophiles by the digital revolution, but it represents a first stab at a problem that subsequent attempts have more successfully addressed.

Subsequent Reaction to Digital Audio

The hostile reaction of modern audiophiles to digital recording recalls the reaction in 1925 to the introduction of electrically produced phonograph records. At that time, the new electrical recordings were widely accepted by the general public but were scorned by audiophiles, who called the new technology "unnatural." In their history of the phonograph, Oliver Read and Walter Welch explain the opposition to electrical recordings of the 1920s by a combination of causes that could apply equally to the recent opposition to digital: strong cultural biases against the new technology accompanied by perceived sonic deficiencies in the first machines and recordings.[37] The audiophiles' negative reaction to electrical recording in the late 1920s seems to have had little effect on the history of technology. Within a few years, electrical recording technology had won the battle, which essentially means that subsequent technological developments have been applied to it rather than its competitors. In evolutionary terms, the species of acoustical recording became extinct shortly afterward.

It appears that history will repeat itself. Digital audio seems to be winning its fight with analog, initially in the popular market, and lately among audiophiles despite some persistent cultural biases. The tech-

[37]See Oliver Read and Walter L. Welch, *From Tin Foil to Stereo: Evolution of the Phonograph* (Indianapolis, 1976), p. 373.

nical potential of the CD and the declining production of analog records are together so overwhelming that even *Stereophile* was recently forced to conclude, "The position of CD is firmly established. CD *will*, eventually, replace vinyl as the primary program source for audiophiles . . . not necessarily because audiophiles embrace it openly, but because they will have little choice. The only question remaining is how long it will take."[38] Given a superficial glance, the victory of the CD over cultural opposition might suggest technological determinism, but the closer examination that follows reveals a more complex relationship between technology and culture.[39]

We may think of the introduction of a CD player into a typical HEA system composed of other components as the introduction of a new organism into an environment composed of other evolving organisms. Many audiophiles who had spent years tweaking their analog record-playing systems were initially dissatisfied with the sound of CD players that, in some respects, should have been near-perfect reproducers of sound. One reason for this dissatisfaction that was initially overlooked by observers is that in the thirty-five years before digital playback devices became available, the standards for other HEA components had evolved incrementally by a process in which thousands of experimenters and manufacturers made slight modifications to different components and evaluated the effects of the changes by listening to entire systems. Over time, the different "species" such as cartridges, preamplifiers, amplifiers, and speakers evolved to fit the types of distortion and sonic coloration typically produced by the others. The technological coevolution that occurred between different components in HEA systems can be understood with reference to a phenomenon studied by evolutionary biology. Biological coevolution "refers to the joint evolution of two (or more) taxa that have close ecological relationships but do not exchange genes, and in which reciprocal selective pressures operate to make the evolution of either taxon partially dependent upon the evolution of the other."[40] The

[38]*Stereophile* 11, no. 3 (March 1988): 110.

[39]There are at least two theses that might be called technological determinism: (1) technology uniquely determines itself—proceeding independent of human control—and (2) technology determines other things, such as cultural values or social structure. Neither of these emerges from a close examination of digital audio's victory.

[40]This is taken from Erich R. Pianka, *Evolutionary Ecology* (New York, 1973), p. 175, quoted by Edward W. Constant II, *The Origins of the Turbojet Revolution* (Baltimore, 1980), p. 14. The existence of biological coevolution invites us to recognize that, in many cases, much of what the naturalist calls the "environment" of a particular organism is, to a large extent, an aggregate of different organisms that are themselves evolving and that strongly affect the chances for survival of the organism in question. Making an organism-environment distinction is the somewhat arbitrary choice of the

coevolution of complementary types of distortion is especially likely to occur in HEA, which, as an environment for audio components, is somewhat isolated from the constraints that prevail in the mid-fi realm, and which relies on listening tests of entire systems rather than on objective measurements of single components.

Compact disc players burst on this scene as the first new species in years that had not coevolved along with the other species. Initially, most audiophiles said CD players sounded terrible, despite measuring very well. The CD players were not intrinsically flawed but did not sound good in combination with the HEA systems in which they were evaluated by the audiophiles. Part of the negative reaction was due to cultural factors, but much of it was legitimate. Referring to this situation, one reviewer wrote, "Thus, we have a rather odd situation where CD players which I would conjecture as being more accurate (the top Japanese ones) are seen by perfectionists as being inferior to those apparently less so."[41]

Recent trends suggest that the introduction of CD players is slowly changing the characteristics of the other coevolving components. But it is even more common to see CD players changing to fit the ecology of most HEA systems. Many newer models alter their mostly neutral sound to achieve a better fit in the niche left by the turntables which they replace.

The California Audio Labs (CAL) Tempest is one of the first of the new breed of CD players. To be successful it had to fit both the technological environment (the audio components in a typical HEA system) and the cultural one (the community of audiophiles). It

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naturalist who singles out just one part from the web of biological causes and effects. The arbitrariness of the organism-environment distinction was a central theme in Wiebe Bijker, Trevor Pinch, and Thomas Hughes, eds., *The Social Construction of Technological Systems* (Cambridge, Mass., 1989), in which the development of technology is understood by the metaphor of a seamless web, woven of thickly interpenetrating causes and effects among artifacts, actors, politics, economics, culture, and social organizations. One virtue of the evolutionary model is that it recognizes the seamless character of the web yet provides analytic resources, such as the organism-environment distinction, which permit particular elements in the web to be singled out for description in relation to the others. After all, the historian typically approaches the web with the intent to write the "history of" a particular class of artifacts or to explore certain classes of causal relationships between technology and its cultural or social environment. This article concentrates on the evolution of a field of technology in its cultural environment, calling artifacts the "organism" and designating everything that affects their evolution the "environment." But it would be equally possible to produce an account in which the culture of the same period is the organism evolving in an environment of many elements, one of which might be the technological knowledge and devices of HEA and similar fields.

[41] *Stereophile* 10, no. 6 (September 1987): 139.

succeeded in both areas by using tubes in part of its circuitry. Electrically, the tubes colored the sound to make it similar to that produced by a good turntable-cartridge combination. Culturally, they paid tribute to all the virtues of tube electronics, particularly in their hybrid marriage with digital electronics (see fig. 6). Here is an excerpt from a preview of the CAL Tempest:

> [Audiophiles attracted to CD despite a cultural bias] have the perennial problem of forever having to cast paranoid glances over their shoulders in case a "real" audiophile should see them toying with their little silver bijoux. But now at least, it should be possible to enjoy CD without guilt: the Summer CES saw the launch of a compact disc player that such undecided audiophiles can own. Will the inherent tonal brightness—if it exists—of the CD medium be tamed by the inherent warmth—if it exists—of thermionic circuitry [tubes]? Can the audiophile bask in the reassurance that the player has been conceived by a designer aware of the subjective subtleties accompanying high-end electronic technology, and not by a faceless committee of corporate test-bench engineers? The California Audio Labs Tempest CD player should supply the answers to both questions, but most of all, its owner can enjoy the pleasure of owning a piece of hi-fi guaranteed to turn heads—"you mean it uses *tubes?*"[42]

The real question to be answered by the CAL Tempest was whether lab and listening tests would establish it as a rational choice irrespective of its cultural appeal. Audiophiles could then choose it, for whatever their reasons, without guilt or accusation.

Another successful attempt to fit a CD player into the cultural environment is one player's use of complex digital processing governed by a user-replaceable ROM cartridge. When a new program is developed for the player, the audiophile can upgrade to a new ROM or perhaps develop his own to guarantee himself subtle differences attainable by no one else. ("Tweakers will love it," rejoiced one review.[43])

As with so many examples in HEA, the technology necessary to build these and other new CD players is not a piece of standard engineering knowledge pulled off the shelf of science by some savvy marketer, nor does it represent a complete departure from previous technology. Rather, it is new knowledge evolved from old knowledge in the direction particularly favored by the cultural and technical

[42]*Stereophile* 9, no. 6 (September 1986): 120.
[43]*Stereophile* 12, no. 3 (March 1989): 105.

environment of HEA. Now that it has been developed by technologists and accepted by the environment, it will become incorporated into future generations of equipment, perhaps finding applications outside of HEA. Although cultural factors could not prevent the introduction of CD players to the HEA market, they slowed its domination and only permitted its recent success after it had evolved to fit a unique set of technical and cultural standards.

An Intimate Connection to Culture

It should be obvious from the examples presented in this article that the twists, turns, and reversals of HEA technology can only be explained by a complex account of the cultural and technical constraints that prevailed in its environment. The importance of culture in technological evolution is illustrated particularly well by HEA because it has evolved in the presence of a highly marked culture that exerted a powerful effect in a few clear ways, and in the absence of many of the economic, political, and structural complications that are often present in other evolving technological fields.

In addition to the general importance of cultural constraints in technological evolution, this partial and episodic history reveals a particular connection between culture and technology that may play an important role in the evolution of other technologies. In HEA, and perhaps much of modern consumer technology, a powerful legitimacy flows from science and technology to whatever elements of culture can attach themselves to it. If culturally suspect preferences can be supported by technically rational arguments, they obtain a legitimacy that has gone almost unchallenged in the time period in which HEA evolved. Looking at the relation of culture to technology over a longer period of time, however, would reveal that the legitimacy technology currently parcels out to elements of culture was obtained wholesale from society in a separate transaction at a different time.

An exclusive concentration on this separate transaction suggests a theory of technology that accords primacy to elements of culture, treating technology as no more than the medium of exchange in a cultural economy. Indeed, a persuasive argument of this sort can be made by observing that, although the activities of audiophiles are almost exclusively confined to the production, evaluation, comparison, buying, selling, loaning, testing, assembly, and disassembly of objects, these activities can be plausibly explained as the testing, manipulation, and recombination of the cultural meanings that repose in the objects.

But what this (admittedly caricatured) position frequently overlooks is that, when technological arguments are used to give legitimacy to cultural values, they gain a power over culture that occasionally backfires. It is usually a different group of historians who take notice when cultural values groan under the strain of technology and call it technological determinism.[44] The second of these relations is the consequence of the first, however. The reception of digital audio presents an excellent example of both relations occurring within a short time of each other. Before digital audio, audiophiles had sought technical arguments to justify choices that were often culturally based, giving technical arguments a certain power over culture by the support they drew from it. Then, when technical arguments began to support digital audio, audiophiles who would have liked to dismiss it out of hand could not do so because their previous reliance on such arguments had given the arguments strength. Gradually, audiophiles were able to find solutions that fit both cultural and technical constraints, but some audiophiles remain shaken by the digital experience and still resent it.

The vigor with which audiophiles police their field shows they find it hard to resist technically rational arguments. But to characterize audiophiles as predominantly rational, as men who follow the dictates of reason wherever it leads them, is to look no deeper than the surface. For some of these men, it might be more accurate to say that they try to get technical rationality to follow them around, lending their choices legitimacy in the eyes of the wider culture that respects technically rational arguments.

In their careers and in the technical devices they construct, they exhibit a tremendous capacity for rational detachment, yet in other ways they are deeply and sensuously immersed in an economy that traffics in cultural symbols and analogical connections. Although audiophiles produce equipment whose technical virtues are recognized outside their immediate environment, much of this equipment evolved in ways that are inseparable from how audiophiles have implicitly connected it to their particular cultural situation.

Generalizing from the Drosophila to Other Cases

The chief reason HEA lends itself so readily to cultural explanations is that its development has occurred in the absence of many constraints except those imposed by the fairly homogeneous culture

[44]For a critical review of technological determinist positions, see Thomas J. Misa, "How Machines Make History, and How Historians (and Others) Help Them to Do So," in *Science, Technology and Human Values* 13, nos. 3 and 4 (Summer and Autumn 1988): 308–31.

that uses audio technology to pursue good sound and to lend legitimacy to some of its peculiar cultural values. I doubt that this type of analysis could be applied to science to the same extent—not because scientists are special individuals who are less immersed in culture than audiophiles (in fact many of them are audiophiles!), but because the cultural heterogeneity of the environment for scientific theories tends either to cancel out or else is so general that it is hidden from the historian because of his or her own participation in that culture. By contrast, HEA is the activity of a small part of the population characterized by a unique, homogeneous, and strongly marked culture that has an observable effect on selection. Other evolutionary constraints that are present in science and other areas of technology are noticeably absent in HEA, isolating the effect of the cultural environment.

The ways in which HEA differs from the rest of science and technology do not diminish but, rather, enhance its heuristic value in the same way that differences between the drosophila and other animals enhanced the value of the former to genetics researchers. During the relatively short period on which this article has concentrated, the evolution of HEA has exhibited a relatively pure and simple form of an evolutionary mechanism that many historians argue is applicable to cultural change in general.[45] The evolution of HEA also stands on its own as a fascinating episode in the contemporary history of technology.

[45]See Basalla (n. 2 above) and the evolutionary epistemology of D. T. Campbell, David Hull, Karl Popper, and Stephen Toulmin. An excellent place to start is with the review article by Michael Bradie, "Assessing Evolutionary Epistemology," *Biology and Philosophy* 1 (1986): 401–59.