How to Plan Your Hi-Fi System

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The author offers a method for making comparative listening tests in order to evaluate performance of audio equipment on a quantitative basis as a logical means for choosing components.

WHEN ONE'S INTERESTS turn toward the acquisition of a high fidelity audio system, he is introduced to a comparatively new world of elusive values, and he most likely will find that to lay a sound plan for either constructing or assembling his system is a very interesting but involved task.

Aside from the barrage of claims and counter-claims of the equipment manufacturers, advice from all quarters is likely to appear to be in serious conflict. The beginner may be unable to plan effectively because the values of which so many speak glibly are subjective in nature and depend upon personal tastes and interests. Naturally, these different interests as expressed by different advisors can be mutually conflicting, and he has not been able to establish his own standards or recognize his own particular needs. The measures of system effectiveness are related to personal tastes.

The purpose of a plan is to provide the system which most nearly satisfies the listener's interests at a minimum cost. We all have heard of the fellow who, after spending much time, effort, and money to acquire a suitable system somehow fails to be satisfied; and after a while, has actually acquired enough equipment to assemble several systems. If your aim is not to "tinker," then some time spent in planning a system will pay off handsomely in the long run.

Regardless, whether we wish to design circuits or assemble a system from completed components, we first must establish some planning objectives or goals toward which to work. The second step is to choose individual components which will satisfy these objectives at a minimum of cost. The first and most important step is to set one's sights: if you aim too high, the budget suffers directly; and if you aim too low, the results will ultimately be unsatisfactory. Within the confines of the space here, we will spend most attention on the first step in planning, that of getting the objectives or goals outlined to satisfy personal tastes.

High fidelity means different things to different people, and a "good" system for one person may be a "bad" system for another. We may all have seen at least three kinds of enthusiasts which could be grouped about as follows: the "sound engineer," the "music critic," and the "interested listener." The "sound engineer" is the fellow who, above all, needs a variety of gadgets so that he can exercise complete control over the signal and compensate for any situation. In addition, he may require a multiplicity of inputs to his amplifier to give him flexibility in changing from tuners to microphones, or to any one of several recorders. He enjoys the thrill of being able to shape or modify the musical output to taste. Individuals in this category tend to emphasize the importance of the amplifier, preamplifier, and the auxiliary circuits; but so far as listening is concerned, frequently their needs are satisfied with an 8-inch speaker of moderate quality.

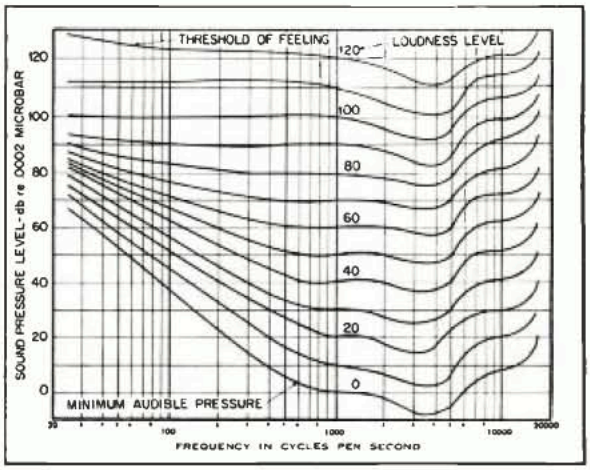

Fig. 1. The Fletcher-Munson curves of equal loudness at the listener's ear.

The second fellow is the perfectionist who demands the ultimate in performance and scrutinizes each individual unit to make sure that it is the best available within the state of the art. These people emphasize the importance of hearing every last note and overtone the music offers. The are impatient with the slightest noticeable distortion, and ask for accurate compensation for both the recording and the ear; some are concerned with the effects of the temperature and humidity of the room in which the music is played. Occasionally a few perfectionists tend to join a cult of "fanatics" who demand improvements beyond what the ear is able to hear. Another subclass of the "music critic" is the person who feels that the symphony concert must be duplicated in the home in both tonal range and volume. He requires the 30- to 80-watt system, while the average single speaker home system will be well served with a 10- to 20-watt system.

The "interested listener" is the one who aspires to have a musical system of a quality that is much better than is afforded by the average commercial radio and TV equipment, but he borrows from the "sound engineer" and the "music critic" for what they can contribute to his listening pleasure. He wishes to use his system to satisfy his personal needs which may range from a dance party or background music, to occasional serious attention to musical masterpieces.

Importance of Individual Taste

Because high fidelity means different things to different people, the first thing that a hi-fi sales agent will want to discover when you visit his shop, is what your individual tastes are, and what you expect to do with the proposed system. Naturally, he will get to the point regarding the size of your proposed budget, for he can cite systems that can be assembled for less than $100, as well as those which will cost over $1,000.

To the salesman, one may quite innocently state that he would just like to have a simple system that accurately reproduces what the microphone picked up in the first place. To this remark, an experienced hi-fi "expert" may present a

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disquisition on why this is very difficult, if not impossible. In addition, one expert proclaimed that some persons do not want to hear music as it originally sounded, but they prefer the modifications that are afforded by the electronic system. The guiding principle, they say, is: "let your ear be the judge," and if you get the impression that the original orchestra is present as the recording is played, then the system is "good"—this is the feeling of "presence." Some experts further assert that accurate quantitative analysis of sound reproduction for the listener is futile, because the listening pleasure derived from the sound system is largely subjective, and is purely a matter of personal taste.

Standard practice for evaluating system performance is to make a series of listening tests to ascertain the differences in the ways in which the same recording can sound from different systems. If the local hi-fi shop does not have some arrangement whereby different systems may be compared, then the beginner would be faced with some rather difficult choices, for it is virtually impossible in the final analysis to evaluate listening performance from advertising literature.

After a few listening tests, one can readily appreciate the advantages as well as the limitations of the subjective method of measuring listening pleasure or system performance. Qualities seem to be present in some systems that are not adequately described by the specifications. I found it virtually impossible at the outset to make any judgments on the basis of a few isolated demonstrations and without some coaching regarding what features were good or bad. The untrained ear can overlook a variety of desirable as well as undesirable features in a system. Without some experience, one can readily become confused when evaluating system performance by playing recorded music because one is exposed to a myriad of sounds in rapid succession that cover a wide range of frequencies and volumes, and a wide range of waveforms. Certainly, peculiarities or idiosynchrasies of the speaker, enclosure, amplifier, or turntable could be missed by the beginner; and poor performance could be judged as adequate. Experience and some instruction are, indeed, needed.

Because we rely on the ear to such a great extent, we must consider the ear as much a part of the entire system as the amplifier or the speaker. It is the ear that is either sensitive or insensitive to certain tones, or levels of volume. There is no point in paying attention to sounds that only the dog or the canary can hear, or that can be detected on an oscilloscope. The hi-fi equipment transforms the signals derived from a tuner or a recording into acoustic waves which excite the listener's ear. Hence, the first step in understanding one's needs and planning objectives is to learn something about what the ear actually hears.

The hearing characteristic of the average listener is shown in Fig. 1. These curves are called the Fletcher-Munson curves of equal loudness, and they illustrate how the ear—the physical termination of the hi-fi system—acts for various sound levels and various frequencies. Note particularly that as the loudness level of sound is decreased, the sensitivity of the ear at low frequencies changes with respect to the mid-frequency range: a sound at 0 db at 1000 cps is just as loud to the ear as a sound at 30 cps having an intensity 60 db greater. This is a factor of 1,000,000 in terms of acoustic power. However, the same two frequencies at the 100 db level both have the same loudness insofar as as the ear is concerned.

This characteristic of hearing plays a very important part in the hi-fi system, for it means that at a reduced level of sound a given musical selection will appear to lose its low tones; conversely, boosting the volume will increase the apparent intensity of the lower tones.

For high fidelity reproduction we wish to maintain a balance between the highs and lows so that the sound resembles the original production to get the feeling of "presence." But the original, such as a symphony orchestra, may in the concert hall be at a level of 80 to 90 db. In the home, the level is normally reduced to a range from 60 to 70 db; hence, the home system must accentuate the lows by a substantial amount—almost 20 db for a 35-cps note—to compensate for the ear's characteristics.

Accentuating this loss of low, tones with reduced volume is the reduction in performance of many components at low frequencies, and the difficulty of radiating such waves from speakers and their enclosures. Some speakers, for instance, may have a characteristic drop in power radiated below 100 cps, so that by the time the signal gets to 35 cps the radiated power is off by 10 to 20 db.

The rule "let your ear by the judge" is a fundamental one, but one that should be exercised with considerable caution and understanding of the way the ear reacts.

The basic need for control over the level of volume, and the amplification of the low frequencies in relation to the highs is certainly established experimentally if you conduct several listening tests. Adequate control over "selective" amplification is ordinarily provided by the "bass" and "treble" controls of the preamplifier or the first few stages of amplification.

Value of Listening Tests

The principal value of a series of listening tests lies in simultaneous comparison of different systems against each other. The facilities of several hi-fi shops are such as to allow one to synthesize a wide variety of systems simply by throwing a few switches. With such a facility, one may listen to systems ranging from the least to the most expensive.

For the purpose of planning, we recommend that one should approach the first series of listening tests in such a way as to establish his own preferences rather than attempt to make a selection of equipment. This author believes that component selection should be deferred until one has firmly in mind the standards of performance he feels are worth the cost in time and money. Only when one has an idea of the performance he seeks can he assemble a system in which the components make their full contribution and are still held to the minimum cost.

As a practical matter one is usually well acquainted with what might be called the "lower level" of performance because of familiarity with TV and radio. Based on this starting point, the tests described here were initiated to determine the best system performance available, and how various high fidelity systems compared with the best. Wide ranges of price and performance were found, and technique was sought to place them in a suitable line of succession for comparison. Assembled amplifiers ranging from $100 to $150 gave very high quality performance; speakers and their enclosures ranged from less than $40 to over $700, and the tonal range and generally pleasing quality of the sound varied widely. Turntables, on the other hand were almost universally of one make and model in the places visited, so there was no particular choice avilable in this item.

The techniques used to determine personal preference commensurate with the pocketbook was to make use of the several amplifiers recommended as best by the salesman, and then substitute speakers and enclosures to make up successive systems, because the speakers displayed the widest range of price and performance. We are, in effect, attempting to match the hi-fi equipment to the ear at best we can within budget restrictions.

Stressing the need for listening tests, and the inability of technical specifications to convey a measure of listening performance, one consultant asserted, "Now, in these multiple speaker units you will notice more depth of tone, a quality which we cannot adequately describe by our instruments, but which is, nevertheless present. That depth is a psychological effect caused probably by the sound coming from an area rather than from a point source."

Although not always the case, it is usually true that the systems with higher price tags gave a higher level of per-

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formance. How much quality is gained by an additional outlay of money is important for the planner to have in mind before becoming obsessed with any one particular system, or with the struggle to achieve the ultimate.

After reviewing several synthetic systems, one begins to realize that high-quality audio reproduction can be achieved. In fact, some of the more advanced systems will give a performance that is virtually indistinguishable from the original. The second significant point is that the cost of a high-quality system is likely to be a little more than had originally been estimated. The choice of components that will lie ahead will be rather delicate because the mistakes can be costly.

Although the actual measures of performance of a hi-fi system are subjective, the person who has gained a limited amount of listening skill should be in a position to make comparative tests and to place his subjective reactions on a quantitative basis. If such crude measures can be made, then one can rate different systems. With these ratings together with the cost data, one can then construct the "cost-effectiveness" curve which can be an invaluable aid to system planning. In the beginning we recommend that the rater confine his attention to the general impression of "listening pleasure" or "presence" and take up more detailed refinements at a later time. Initial tests of this kind are sufficient to convice some "interested listeners" that the systems of moderate quality are adequate for the purpose, but others will lay aside all thoughts of intermediate steps and plan for the highest standards of performance that are possible.

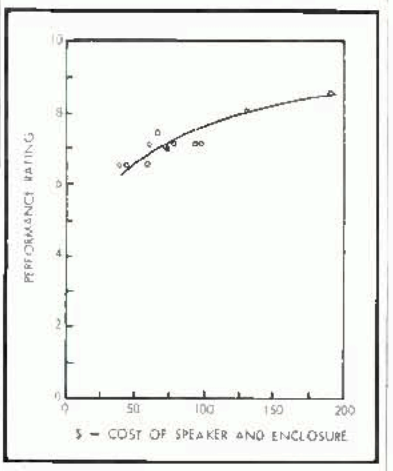

Fig. 2. Curve of cost vs. performance as constructed from the data in Table I, covering the test of the least costly systems.

TABLE I

COMPARISON OF SPEAKERS AND AMPLIFIERS — TEST No. 1

ENCLOSURE Type	Cost	SPKR No.	AND SPEAKER Cost	TOTAL COST	PERFORMANCE RATINGS L.F.	M.F.	H.F.	Overall
A	18.00	1	41.60	59.60	6	8	8	7
A	18.00	2	45.00	63.00	6	8	8	7.5
A	18.00	3	54.50	72.50	5	8	8	7
A	18.00	4	76.50	94.50	6	8	8	7.2
A	18.00	5	57.60	75.50	6	8	8	7.2
A	18.00	6	54.00	72.00	6	8	8	7
A	18.00	7	40.00	58.00	5	8	7	6.5
A	18.00	8	20.50	38.50	5	8	7	6.5
A	18.00	9	27.00	45.00	5	8	7	6.5
A	18.00	10	25.00	43.00	5	8	7	6.5
A	18.00	11	79.50	97.50	6	8	8	7
A	18.00	12	114.00	132.00	7	9	9	8
K	50.00	13	74.50	124.50	8	9	8	8.8

Williamson-type amplifier ($190.00), record changer ($68.00), and magnetic pickup not changed during test

Speakers tested included single-cone extended-range models, and two- and three-way integral models.

Enclosure types: A is bass reflex in kit form, unfinished plywood
K is Karlson-type, in kit form.

Typical Test Results

The results of two tests are tabulated in Tables I and II, and are plotted in graphical for in *Figs.* 2 and 3. These curves show a distribution of points up and down the scale of performance or effectiveness, plotted against the costs of the respective speakers and enclosures. The performance generally rises with cost. The total system costs could be derived by adding the amplifier and changer costs in each case. The most expensive system was $978, while the least costly was $296, but the lower figure could have been reduced by using less expensive amplifiers without affecting acoustical performance.

TABLE II

COMPARISON OF SPEAKERS AND ENCLOSURES — TEST No. 2

ENCLOSURE AND SPEAKER Type (Finished Unit)	TOTAL COST	PERFORMANCE RATINGS L.F.	M.F.	H.F.	Overall
(a) With amplifier and preamp at $190.00. Speakers include two- and three-way types					
BACK-LOADED HORN	244.50	7	9	9	8.5
BACK-LOADED HORN	276.00	7	9	9	8.5
CORNER HORN	300.00	10	9	9	9.3
CORNER HORN	720.00	10	10	10	10
INFINITE BAFFLE (Dual Spkrs)	100.00	8	9	9	8.3
INFINITE BAFFLE (Two-way)	126.00	5	8	9	7
(b) With amplifier and preamp at $203.00.					
INFINITE BAFFLE (5 Spkrs)	256.00	7	9	10	8
INFINITE BAFFLE (9 Spkrs)	450.00	9	10	10	9.5

Same changer ($68.00) and magnetic pickup used throughout.

The distribution of points shown is peculiar to only one rater. If some other rater was to evaluate the same systems, he would probably place the points in different positions, but he would most likely get curves of about the same shape after averaging the points. In conferring with other listeners, however, the most expensive system was consistently rated as the top in quality. This unit was arbitrarily scored as 10, thereby establishing a standard at the top of the scale. At the lower level, the table model radio and a radio phonograph were scored at about 3 and 3.5 respectively, but these scores are not shown in the data or curves. These latter ratings set a lower limit or standard of "low-cost" performance. The region of high-fidelity begins with an over-all rating of about 6. The over-all rating was derived from three separate components, one to evaluate low-frequency response and freedom from distortion, one for medium frequencies, and the third for the highs.

The two curves show the extremes available for home listening. The combinations between these extremes are many, and the measures that can be taken to reduce the costs of the systems of highest quality are not exhausted in these two initial tests. For instance, one would like to see whether a system could be assembled having a performance between 9 and 10, but at a substantially lower cost than those listed in the tables. By using the "do-it-yourself" kits for the more complex systems, if they are available, such costs can be reduced; but one may be forced to forego the styling and fine finish of the speaker enclosure and the auxiliary cabinets. Cost reduction by a factor of two is a reasonable expectation.

At this point, one may have enough information to stir his enthusiasm, but not enough to be sure of his precise needs so that the system can be laid out. There is still another step the beginner may take before making any major decisions. This step is not essential for one who has made up his mind but is recommended for those who wish to develop better judgment. This step is to construct an "interim system" which will permit the experimenter to observe over a period of time the factors of importance to him which affect the performance of the system. With a judicious choice of components, one could apply any items purchased for the secondary system to the more advanced one. This experimental approach has the advantage of allowing one to study his re-

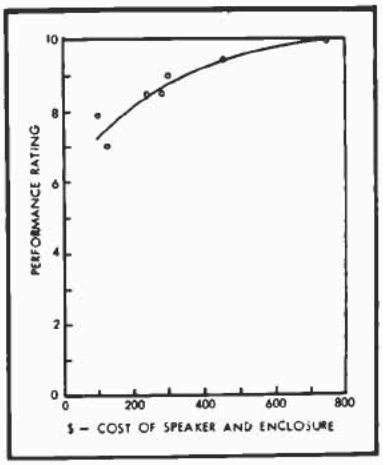

Fig. 3. Curve of cost vs. performance constructed from the data in Table II, covering the test of the most costly systems.

quirements more closely and to develop a better understanding of actual rather than fancied needs; it may also serve to stimulate more interest in still better performance. Another experimental approach is to take advantage of the free home trials offered by local shops. As much as you may like a piece of equipment in the store, sometimes it may not "wear well" at home.

A little rummaging around in the attic in my own case produced components that were adequate for the interim approach. For the dance party requirement, there developed a need for power output—undistorted—that was well beyond the ability of the secondary system. The audience was found to absorb substantial amounts of acoustic power, and in addition, create an ambient noise level which had to be overcome by the speaker output. The lack of low-frequency tones in the secondary system became apparent because the lows often carry the rhythm needed for dancing. For listening to concert music, the volume level had to be reduced to keep peace in the family, so the loss of lows was again accentuated. The lack of extreme highs caused no comparable deep concern, so the extended high-frequency coverage will be included in the final system if it can be gained for a modest cost.

If you have been able to establish a standard of performance that the hi-fi system must eventually meet, then it is time to turn attention toward the second step in the planning cycle, that of selecting the individual components in such a way that the over-all cost is minimized without sacrificing the performance standard. In principle, at least, the beginner could extend the technique of listening tests so as to arrange the components to suit his need. We know of no better way to choose a speaker, but selecting a particular amplifier depends to some extent on how much the experimenter borrows from the "sound engineer" and the "music critic." Many would be satisfied with a simple substitution test using the chosen speaker and enclosure, and make use of a home trial. Selecting an amplifier in itself can be a detailed study the scope of this discussion; in fact, much has already been written on this subject.

Thus, if one can arrive realistically at some conclusions regarding his requirements in relation to what he can afford, the task of selecting the units for the system is reduced to manageable proportions; and one's limited energies and funds are not misdirected into unproductive channels. These two approaches are advocated as aids to planning: The comparative evaluation of system performance by actual listening tests, and the improvement of personal judgment through experience with an experimental or interim hi-fi system. Æ

LOUDNESS, ITS DEFINITION

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ing ten components of equal loudness and a common frequency difference of 100 eps. The results are shown in *Fig.* 9. It will be seen that although the points corresponding to the different frequency ranges lie approximately upon the same curve through the middle range, there are consistent departures at both the high and low intensities. If we choose the frequency of the components largely in the middle range then this factor b will be dependent only upon Δf and L_k.

To determine the value of b for this range in terms of Δf and L_k, a series of loudness measurements was made upon complex tones having ten components with a common difference in frequency Δf and all having a common loudness level L_k. The values of Δf were 340, 230, 112, and 56 cps. The fundamental for each tone was close to 1000 eps. The ten-component tones having frequencies which are multiples of 530 was included in this series. The results of loudness

TABLE V

COMPARISON OF CALCULATED AND OBSERVED FRACTIONAL LOUDNESS (LAIRD, TAYLOR AND WILLE)

Original Loudness Level	Level for ½ Loudness Reduction		Cal. Level for ½ Loudness Reduction
	Cal.	Obs.	
100	92	76.0	84
90	82	68.0	73
80	71	60.0	60
70	58	49.5	48
60	50	40.5	41
50	42	31.0	34
40	33	21.0	27
30	25	14.9	20
20	16	6.5	13
10	7	5.0	4