PROPOSED PLANS FOR AUDIO LABORATORY

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PREFACE

I would like to express my grateful and deep appreciation to my adviser, Dr. Harold Fristoe, whose help and collaboration contributed much to the completion of this paper. It is to be noted that this project was originally suggested by Dr. Fristoe. It was an opportunity to work on such a project, and proved to be an interesting and profitable study. I also whish to express my thanks to Professor James C. Stratton for constructive criticism and assistance.

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CHAPTER I

INTRODUCTION

At one time, only manufacturers actually engaged in the production of audio equipment had any need for the facilities of an audio laboratory. These manufacturers primarily supplied such products as radio transmitters, record players, test equipment, components and similar articles.

As the development of the industry progressed, the need for additional knowledge of a fundamental nature became increasingly apparent. For example, present day vacuum tubes operate on the same basic principles which governed the operation of the very first tube made by the well-known "father of radio," Dr. Lee Deforest, on Christmas Eve 1906. However, the tremendously improved performance achieved by modern tubes has been made possible through the application of new knowledge, much of which has been uncovered since the invention of the first tube.

Such is also the case with the first gramophone and other audio equipment made by pioneers in this field.

Looking back over the past few years, one can say without exaggeration, that almost every minute some new development comes from the engineer's laboratory ready and available to the public.

This new knowledge, which made vacuum tube performance possible in the field of radio, in television and in countless other applications, was made available through research inspired by the realization of the need for new information.

Today's research programs, which are furnishing the new information upon which the continued growth of our industry depends, are mostly sponsored by industrial or government laboratories. The success of these programs and those of the future depends upon an increasing supply of trained scientists. At this time the supply is all too small.

Naturally these trained scientists receive their initial training from educational institutions. It is the responsibility, therefore, of such institutions to provide adequate facilities to such persons who have the enthusiasm to contribute to the betterment and improvement in their chosen field of engineering.

Unfortunately, at the present time, very few facilities are available to the student for special study or research in the field of audio engineering. Not only is this true at Oklahoma Agricultural and Mechanical College but it is also typical of the recognized Engineering schools throughout the country.

This situation is well summarized in a recent editorial.[1]

Education and Training

We are regularly bombarded with inquiries about where to study audio engineering; and just as regularly we have to advise the questioner that we know of no recognized institutions of learning where the subject is being taught. There are a number of technical schools - both resident and correspondence - which provide considerable training in the audio field, but none offers college-level courses in engineering with specialization in audio. We trust this will be changed before long - and suggest respectfully that the industry as a whole might sponsor a chair in audio engineering in some university.

As it stands now, the audio engineer is usually a man from some other branch of engineering who has by chance been drafted into audio work and who has learned the hard way.

We believe that the advantages accruing to the industry from an endowment at some recognized college would repay its cost many times over.

At this time, I shall take the liberty of saying that the above statement reflects the opinion of the members of the staff of the school of electrical engineering of this college.

The need of a complete audio engineering laboratory was felt by Doctor Harold Fristoe who initiated the interest in this study.

The purpose of this study is to present plans for an audio frequency laboratory suitable for graduate study, research, and development. It is designed to be used by one to three students at a time and provides all the test equipment necessary for most of the fundamental conventional experiments in audio engineering.

A typical design of necessary furniture is submitted in this paper; equipment with various connections is discussed; and room treatment, which makes possible numerous audio frequency experiments, is described.

CHAPTER II

PRELIMINARY CONSIDERATIONS

Before an intelligent evaluation of space, budget, equipment, and other requirements for a proposed laboratory can be made, the desired functions of the laboratory must be established. This is determined to a large extent, by the qualifications and number of students or personnel who will use the laboratory, as well as the type of work to be performed. Space and budget requirements follow.

Let us consider the functions of the laboratory. An audio laboratory may be established to serve either a specific function or a general function, depending on the needs of the particular institution. A majority of laboratories[2] handle one or more of the following jobs: Engineering Design, Research and Development, Quality control, and Measurements.

The need of this institution is for an audio laboratory that will provide facilities for special study "exclusively" in the audio field, such as research for theses, and the necessary equipment required to verify the theory in connection with the research projects.

It should be kept in mind throughout the study of these plans that, in this level of study only a few people use the laboratory at any one time.

In spite of the fact that our purpose is established, a brief discussion of each one of the above purposes should be made.

a) <u>Engineering Design Laboratory</u>

Experimental and pre-production models are assembled and tested in such a laboratory. This type of set-up may be required not only by the exclusive manufacturer of audio equipment but also by the manufacturer of end products. Such laboratories are equipped for certain types of machine shop work to facilitate the construction and assembly of models.

b) Research and Development Laboratory

Generally this type of laboratory is established with one or more long range projects in mind. Such projects may include the development of new circuits or techniques, new products, or fundamental research. A laboratory devoted exclusively to such work can generally be justified only in the case of large manufacturers. In smaller firms, research and development work is more likely to be handled by using the facilities discussed in the engineering design laboratory.

c) Quality Control Laboratory

Organizations engaged in the manufacture of electronic control equipment or components would find it worth while to establish a separate laboratory for quality control. By means of separate facilities and personnel used in this work, adequate quality control can be assured. Such laboratories will generally be equipped almost exclusively for measurements work with little or no machine shop equipment required.

d) Measurements Laboratory

This type of laboratory, like the quality control laboratory, is not required by all organizations but only by those concerned with specialized types of work. Some examples of such organizations are standard system bureaus, consulting engineers specializing in product tests and analysis work, graduate work, and similar work. Industrywise, the personnel of a measurements laboratory is likely to be highly skilled with a preponderance of graduate engineers, physicists, and mathematicians.

Therefore, for such an organization, the test equipment needed by the laboratory has to be of a precision type which is very expensive. However, much of the equipment concerned in our case which is discussed later in this paper, does not need to be of such a category.

Having briefly analyzed the different laboratories and their functions, we can easily see that a measurements laboratory is the one which can best handle the duties required by our O. I. T. institution.

With the responsibilities and nature of work of the proposed laboratory having been determined, we are in a position to start active planning based on those requirements. The actual planning of the laboratory requires the consideration of many factors, most of which are interdependent. These include, for example, availability of space, budget limitations, the type of work to be performed, the number of students, the amount of equipment and stock to be purchased, laboratory furnishings, laboratory layout, and other factors.

Laboratory layout itself depends on the number of students using the laboratory, space allotment, types and quality of equipment, etc.

Although the important factors are discussed individually in later chapters in this paper, it is seldom possible to consider any one factor as a separate item.

It is very essential that all the planning should be carried out in strict co-operation with the individual who shall be directly responsible for the operation of the laboratory.

CHAPTER III

WORK VOLUME

It may be difficult to find an engineer, technician or any other (student) who feels that any laboratory "is large enough." An audio laboratory or any other kind of laboratory could be as large as any person in the field could imagine. However, a compromise must be made between the "ideal" of unlimited space and a laboratory so small that efficiency and convenience are seriously impaired.

The size of the equipment on which work is to be performed will govern, to a large extent, the minimum area required by each laboratory worker. Keeping in mind that the largest piece of audio equipment to be tested in the laboratory (exclusive of laboratory test equipment) is about the size of an average television set or smaller, we can accept a minimum area of about sixty square feet per laboratory person as generally adequate. However, for the type of laboratory where there will be fewer than three students and in many cases just one at work, a larger unit area should be provided.

To calculate the minimum area[3] required for the proposed laboratory, multiply the number of students using the laboratory (in this case two students), by 60 square feet, a space of 120 square feet is sufficient. Again, a compromise can be made by means of arranging the furniture and the test equipment in such a way that space may be saved. An additional amount of area should be added to the 120 square feet for storage, for furniture, and for any space required for power equipment.

It should be noted that this approximate calculation of the minimum area required, was based on the needs of manufacturers where several workers are to be using the laboratory. However, in our case the area required is more likely to be governed by the equipment sets and other equipment such as large floor-mounted turntables or tape recorders as well as an additional area required by a special test room, which will be discussed later.

CHAPTER IV

LABORATORY LAYOUT

a) Location

Perhaps the largest effect on the efficiency of any laboratory's operation is the arrangement of facilities and location. Because of this fact, it is important that care and thought should be taken in selecting a suitable laboratory layout. While it is not an exaggeration to say that it is impossible to give a "general layout" that will meet the requirements of every organization or firm, it is practical to itemize the most important factors to be considered.

Although some of the details to be considered have been mentioned before, it is worth while at this point to discuss them more carefully. Such details are the space available for the laboratory, the type and size of the equipment on which work is to be performed, the amount of large equipment to be kept in the laboratory, light and other utilities, as well as tables, workbenches and similar laboratory furniture.

The location of the laboratory depends on the nature of work to be performed. For example, an engineering design laboratory used by a manfacturing company should specifically be located near the engineering and drafting departments. Because of the specialized nature of the work to be performed in our research and development laboratory, it may be located at any convenient spot but preferably away from heavy traffic areas. In any case, the laboratory location should be such as to permit future expansion of facilities if necessary and with all utilities such as electric power readily available.

Due to the fact that future expansion is one of the most important factors to be considered in the study of such plans, Dr. Fristoe had previously chosen the location of the laboratory in discussion to be established on the fourth floor of the engineering building. This location makes possible the association of the laboratory and the platform which is already established on the top of the same building equipped with most of the facilities necessary for communications between the two locations.

These represent some of the more important specifications. Although one can keep on asking for more and more details, one realizes that it would be impossible to make a complete layout without getting into complicated results. Therefore, it is necessary to draw the line somewhere and start examining what is available to reach a compromise.

b) Space Allotment

One room 18 x 14 x 10 feet will be adequate for most of our purposes. However, it is important that we take into consideration the few cases which require more room. Since the room available for this project is located on the fourth floor of the engineering building it would be of great advantage to have access to the platform located on top of the same building.

With all the facilities provided by the platform, such as available conduite, telephones, and other means that will serve our purpose in a very efficient manner, we can carry out some experiments requiring more space and more desirable acoustic surroundings than provided by the laboratory. An example of such an experiment which can be performed by using both the laboratory and the platform is the determination of loudspeaker characteristics. This type of experiment was recently performed by an audio engineering student by placing the speakers on the platform and the test equipment in the nearest room on the fourth floor of the same building.

c) Lighting

General illumination should be provided. Specifically, a light of 50 foot-candles on the work-bench level is not excessive and even higher light levels may be required if minature and sub-minature test work is carried out. The light fixtures should be located in such a manner that uniform illumination is obtained in order to prevent formation of sharp shadows.

In most cases either incandescent or fluorescent lamps may be employed. However, where highly sensitive equipment is tested, it is necessary that extensive shielding and filtering be made to prevent an excessively high ambient noise level (with fluorescent lamps). It should be noted that sometimes when experiments demand the use of oscilloscopes, a low level light is desirable. Therefore, individual insulated pull-cords switches on overhead lights would prove desirable (to permit reducing light level).

d) Laboratory Walls and Floor Treatment

This particular audio laboratory is to be used as a studio (at times) for various experiments such as recordings, determining microphone and speaker characteristics, and other experiments pertaining to sound.

Obviously, a room for such purposes should be designed to satisfy all the necessary requirements in order to perform the duties of a studio or a dead room. However, with all the complications involved in sound and acoustics, we may safely say that even a room originally designed and built for this purpose very seldom would perform exactly as predicted, for the simple reason that even the material used for sound treatment changes characteristics as it gets old, and ambient conditions have a marked effect.

It would be worth-while to note some of the historical locations used for arts where sound was the main problem without the present facilities of sound amplification. One such place is the amphitheatre of Greece which is believed to have top performance acoustically. From its history, it is believed that it performs better now than it did a thousand years ago. This is because the marble from which the seats are made has acquired a soft film caused by the heat of the sun and rain; hence its absorbtion coefficient has increased.

As was mentioned previously, it is difficult to predict the exact performance of a studio. However, using the theory of various authors, a room can be treated to have acoustic properties acceptable for our purpose.

Before any treatment is proposed, it is necessary to examine some of the basic theories of sound, and governing acoustic[4] factors.

Ambience or room tone is the general tonal character of a room, therefore, a recording made in the open air does not include ambience. Microphone placement in a room, distance from the sound source, and type of microphone, all determine the extent, nature and modification of the ambience.

Eigentones[6] or standing waves are the resonances produced by parallel walls in the room. The worst condition, for example, would be a cube because the resonance frequency would be the same in all directions. The lowest resonance occurs at half a wavelength. For instance, at 40 cps., the wavelength is about 28 feet. Thus a room 14 x 14 x 14 feet has a resonance at 40 cps and others at the harmonics of 80 cps and 120 cps plus diagonal resonances. As the size of an enclosed space is increased the resonant frequencies are lowered and take longer to build up. Hence, they are less objectionable.

It should be remembered that once the sound leaves the source, it is diffused throughout the room. It is then reflected by some hard surfaces such as plaster, cement, and wood, and absorbed by other soft surfaces such as rugs, drapes, etc. The degree of absorbtion depends not only on the material but also on the frequency or pitch of the sound. As an example a thick rug absorbs approximately six times as much of the loudness of the highest notes on the piano as it does of middle C. Similarly, low frequency sounds travel from the source in all directions, while high frequencies travel almost in a straight line.

Eventually the sound waves are attenuated to one unit of its velocity per second; (approximately one foot which is 1/1080, 1080 ft/sec. being the velocity of sound). The time required for this decrease of sound speed is known as the Reverberation Time of the room for a specified frequency and is measured by the time required for a sound, when suddenly interrupted, to die away or decay to a level 60 decibels (db) below the original sound. This decay is stated by Eyring[7] to be one millionth of the original sound intensity (-60 db) after stopping the source.

A steady condition is obtained when the energy absorbed by the walls equals the energy delivered by the source of sound. In the same way, when the sound is stopped, some time is required before the energy in the room is completely absorbed.

The Reverberation Time or Amount of Reverberation varies with the frequency and the shape of the reverberation-time/frequency curve can be controlled by selecting the proper amount and varieties of sound absorbent materials and by the methods of application. Room occupants must be considered inasmuch as each person contributes a fairly definite amount of sound absorbtion.

Computation of Reverberation Time. To compute the reverberation time, it is necessary to know the absorbtion coefficient of the material of which the walls, floor, and ceiling are made. Through various methods, acoustical engineers have been able to measure the absorbtion coefficient of almost any material used today for studio construction at different frequencies. All these coefficients are given in tables in many handbooks and text books.

Reverberation time at different frequencies may be computed from room dimensions and average absorbtion. Each portion of a room has a certain absorbtion coefficient dependent on the material of its surface and the method of application.

The absorbtion coefficient is equal to the ratio of the energy absorbed by the surface to the total energy impinging thereon at various audio frequencies. The total absorbtion for a given surface area in square feet (S) is expressed in terms of absorbtion units.

$$\text{Aav.} = \frac{(\text{Total number of absorbtion units})}{(\text{Total surface in square feet})}$$

Sound absorbtion units are expressed in sabins and represent a surface capable of absorbing sound at the same rate as does one square foot of perfectly absorbing surface, such as an open window. Absorbtion units are sometimes referred to as open windows (OW) units or sabins, the latter being arbitrarily named after Sabin.

$$T = 0.05\ V/-S\ \ln\ (1 - \text{Aav})$$

Where T is the reverberation time.

V = Room volume in cubic feet

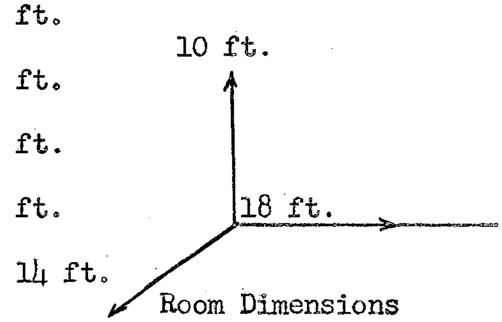
S = Total surface of room in square feet

Aav - Average absorbtion coefficient of the room.

Using the above equation, we can solve for the Reverberation time of this particular room as it is before any treatment. This will make it possible to find out about the present condition of the room and choose the proper material for correction.

Calculation of Reverberation Time of the room before treatment.

Walls = Plaster	(252 (360	Sq. ft.
Ceiling = Plaster	252	Sq. ft.
Windows = Glass	28	Sq. ft.
Floor = Cement	252	Sq. ft.



Room Dimensions

Freq.	Approximate Reverb. Time	Reverb. Time after Treatment with Floor Covered with Rug
in cycles/sec.		
128	2.86	0.84
256	1.27	
512	1.32	0.312
1024	1.45	
2048		
4096	1.13	0.214

SAMPLE OF CALCULATIONS

Freq. = 512 CPS

Surface Area Sq. ft.		Material	Absorbtion Coeff.*	Units
Walls and ceiling	864	Plaster	0.060	51.84
Floor	252	Cement	0.016	4.032
Windows	28		0.03	0.84
2 Persons	estimated		4	8
Chairs and small furniture	estimated		3	3
				67.712

Total surface = 1144 ft^2

$$Aav = \frac{67.712}{1144} = .059$$

$$R.T. = \frac{0.05\ Volume}{-S\ \ln\ (1-Aav)}$$

$$= \frac{.05x14x10x18}{1144\ln\ (1-.059)} = 1.32 \text{ approx.}$$

The above calculations may be found to be very rough approximations. However, an approximate idea is given as to what the room characteristics are before it is treated.

The reverberation time of the room as it is now, at a frequency of 128 cps. is 2.86 seconds and drops to 1.13 seconds as the frequency increases to 4,000 cps. (See Curve Sheet I, page 17).

From the graph Figure I (page 18) showing optimum reverberation for various room volumes, we can see that the reverberation time of the room is too large and it is necessary to apply absorbent material to reduce it.

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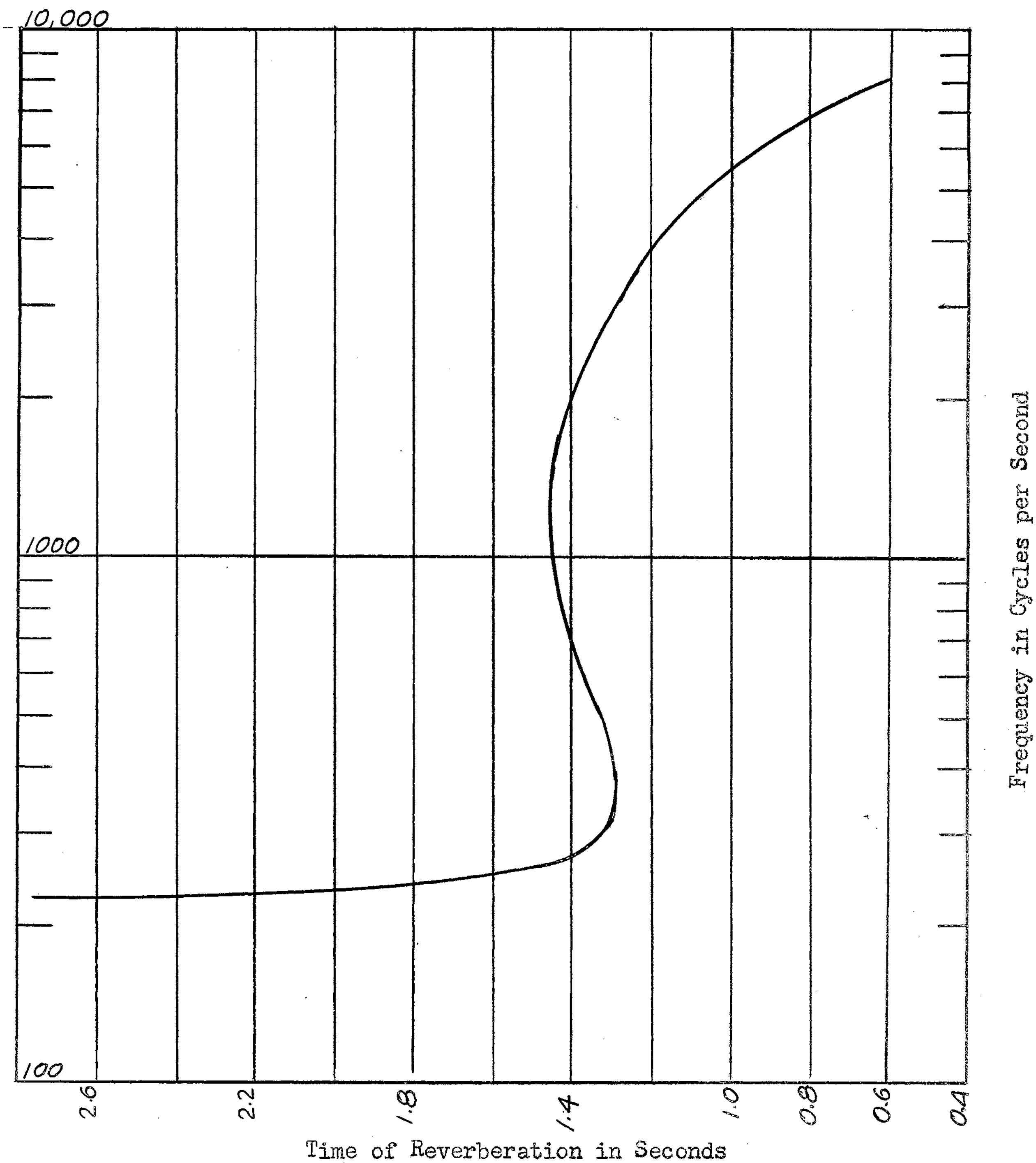
*See Appendix.

CURVE SHEET I

Reverberation Time Vs Frequency

Results Obtained Before Treatment of the Room



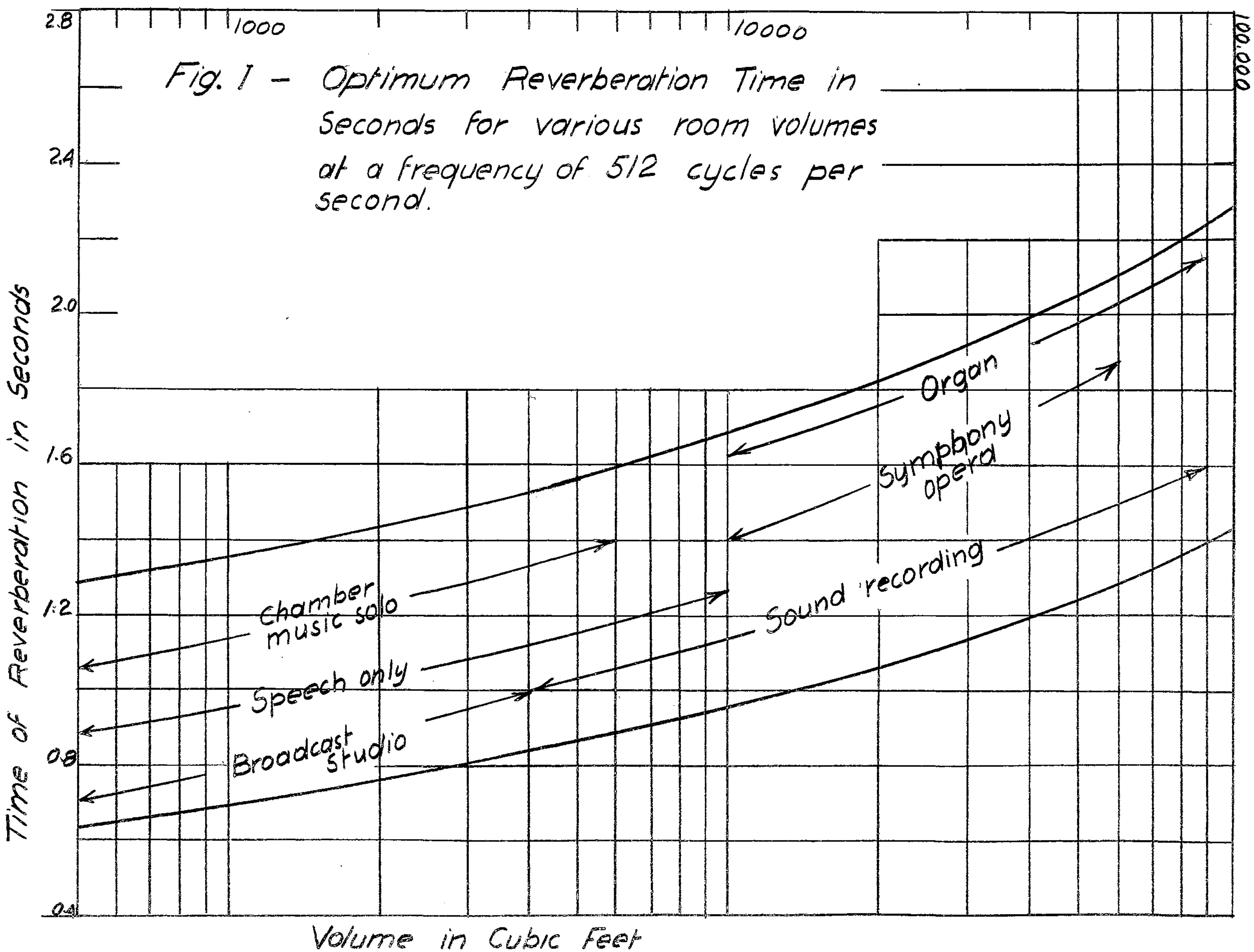


Fig. 1 – Optimum Reverberation Time in Seconds for various room volumes at a frequency of 512 cycles per second.

Optimum Reverberation Time.[8] For the most desirable reverberation time with (1) room size, and (2) use, such as music, speech, etc., see Figure I.

These curves show the desirable ratio of the reverberation time for a frequency of 512 cps. Any other frequency between 60 and 8,000 cps may be found by multiplying the ratio at 512 cps by the number in the vertical scale which corresponds to the frequency chosen.

Reducing Reverberation. From previous calculations of reverberation time it has been seen that the walls of the room made of plaster absorbs only 3 percent of the sound striking it. The remaining 87 percent will bounce back as secondary sound and be reflected a number of times losing the same precentage each time.

This problem can be controlled with the application of acoustical material, which has a higher absorbtion coefficient than that of plaster.

It is never desirable to eliminate all reverberation within the room. As it is shown in Figure 1, the reverberation time in a typical living room is about 0.5 second at 512 cps and the absorbtion coefficient is about 0.25. The reverberation time falls to possibly 0.3 second at 5,000 cps and rises to possibly 0.75 second at 200 cps. The reverberation time of the proposed audio laboratory should be between 0.3 to 0.8 second. For larger rooms this figure is as high as 2 seconds.

Application of acoustical material. A good method of applying acoustical material is to distribute it throughout the room as much as possible. This also indicates covering the entire ceiling of the room.

There are a number of methods of applying the acoustical material, all depending on the use of the room. For example, if the room is to be used for listening, adsorbents should be applied on the two long parallel walls and on one short wall. When the sound source is placed close to the untreated wall, less energy of sound is absorbed and reinforce reflections which reach the rear of the room. In considering the location of acoustical absorbents, the ceiling, rear, and side walls should be checked very closely.

A room corrected to give desirable reverberation conditions may be a poor hearing room. Since the nature of the experiments to be performed in the audio laboratory are such that can permit average results the issue can be treated as follows:

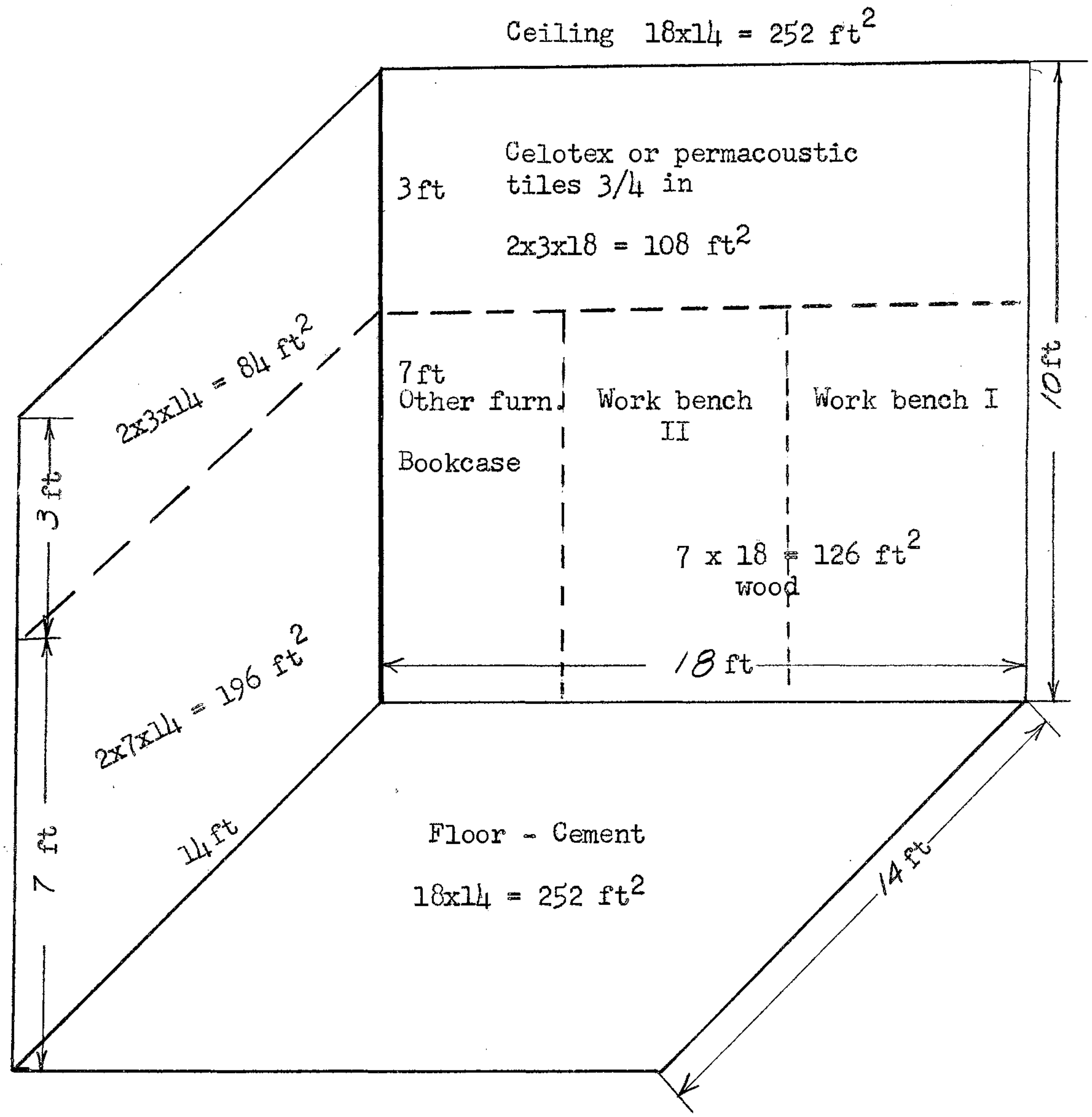
The windows can be covered with velour draperies. Part of the walls, approximately 8 feet above the floor, may be covered with permacoustic tiles 3/4 inch. The same material may be applied on the ceiling.

The floor may be left to be treated later, for it may prove to be to our advantage as it is now. However, if the acoustical conditions are not satisfactory and the reverberation time is still high, the floor can be covered with rubber 2/16 inch thick. This serves as absorbent material and fire-proofing.

Using these materials, we can proceed to calculate as previously the reverberation time of the room.

Figure 2. Room-surface Treatment

with Absorptive Material



Surface Area in Square Feet and Material Used

Permacoustic) or) celotex)	tiles 3/4 inch	444 square feet
Wood		126 square feet
Plaster		322 square feet
Cement		252 square feet
Draperies		28 square feet

Sample of Calculations of Reverberation Time

Freq. = 512 CPS

	ft^2		absorbtion coefficient	Units
Permacoustic tiles	444	x	0.74	328
Draperies	28	x	.35	9.8
Plaster	322	x	0.08	25.7
Wood	126	x	0.08	1.01
Cement	252	x	0.016	4.0
Bookcase) Tables) estimated				2
2 persons	2	x	3.8	7.6
				376.11

$$Aav = \frac{376.1}{1300} \frac{\text{(total absorbtion)}}{\text{surface area}} = 0.276$$

$$T = \frac{.05 \times 2520}{-1300 \ln (1-Aav)}$$

$$T = 0.298 \text{ seconds}$$

CALCULATED REVERBERATION TIME

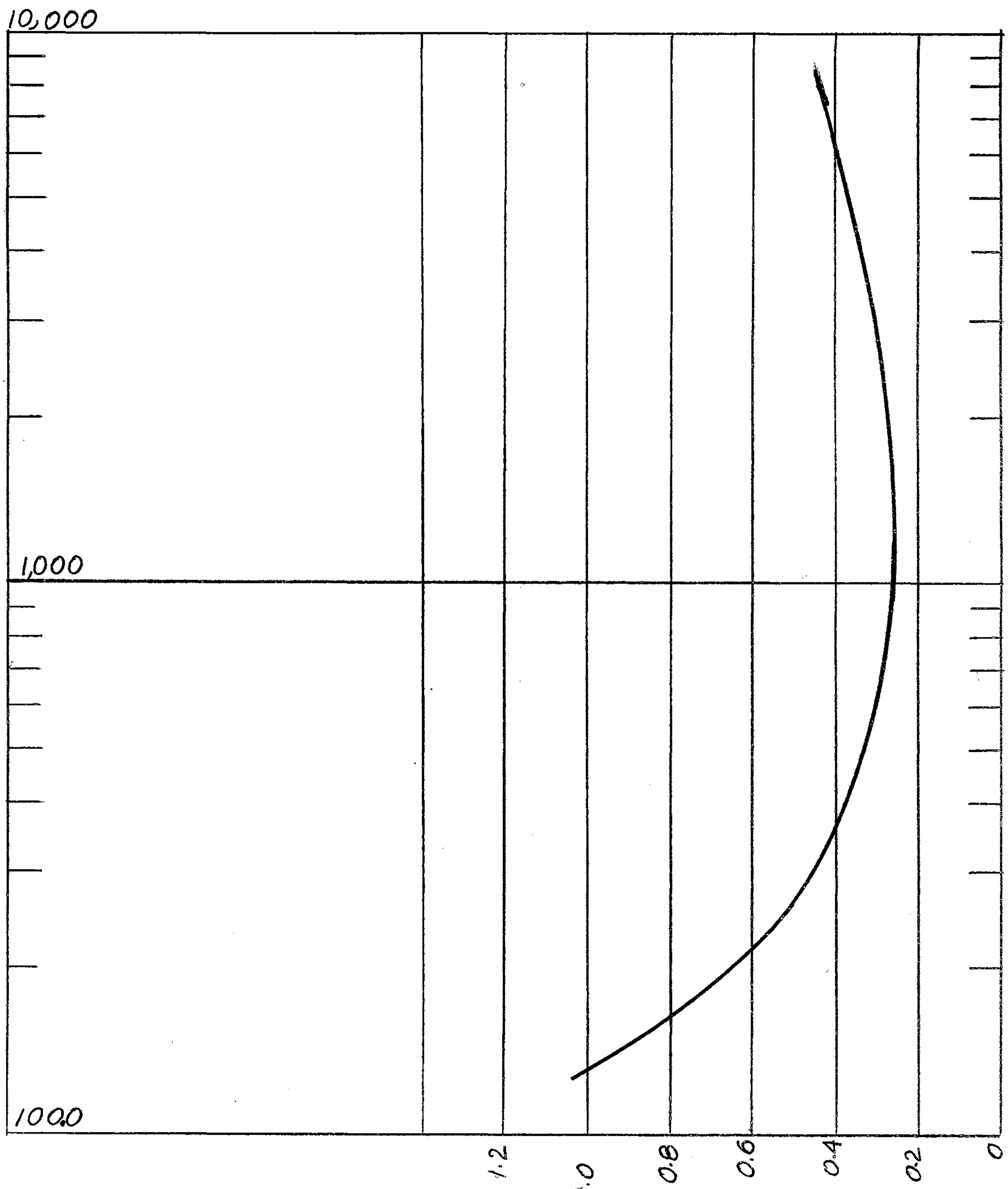
Sound Absorbtion Coefficients in Cycles/Sec.
and
Surface Area in Sq. Ft. Treated by Various Materials

Frequency Cycles/Sec.	Permacoustic Files 3/4" 444 Sq. Ft.	Wood 126 Sq. Ft.	Plaster 322 Sq. Ft.	Draperies 28'	Cement 252 Ft.^{2}	Small Furniture Estimated	Persons 2	Reverb. Time Cement Floor
128	0.19	0.05	0.038	0.05	0.01	2	1.4	1.06
256	0.34	0.07	0.049	0.12	0.012		2.25	0.474
512	0.74	0.08	0.60	0.35	0.016		3.8	0.298
1024	0.76	0.08	0.085	0.45	0.019		5.4	0.234
2048	0.75	0.07	0.043	0.38	0.023		6.6	0.29
4096	0.74	0.04	0.056	0.36	0.035			0.32

CURVE SHEET II

Reverberation Time Vs Frequency

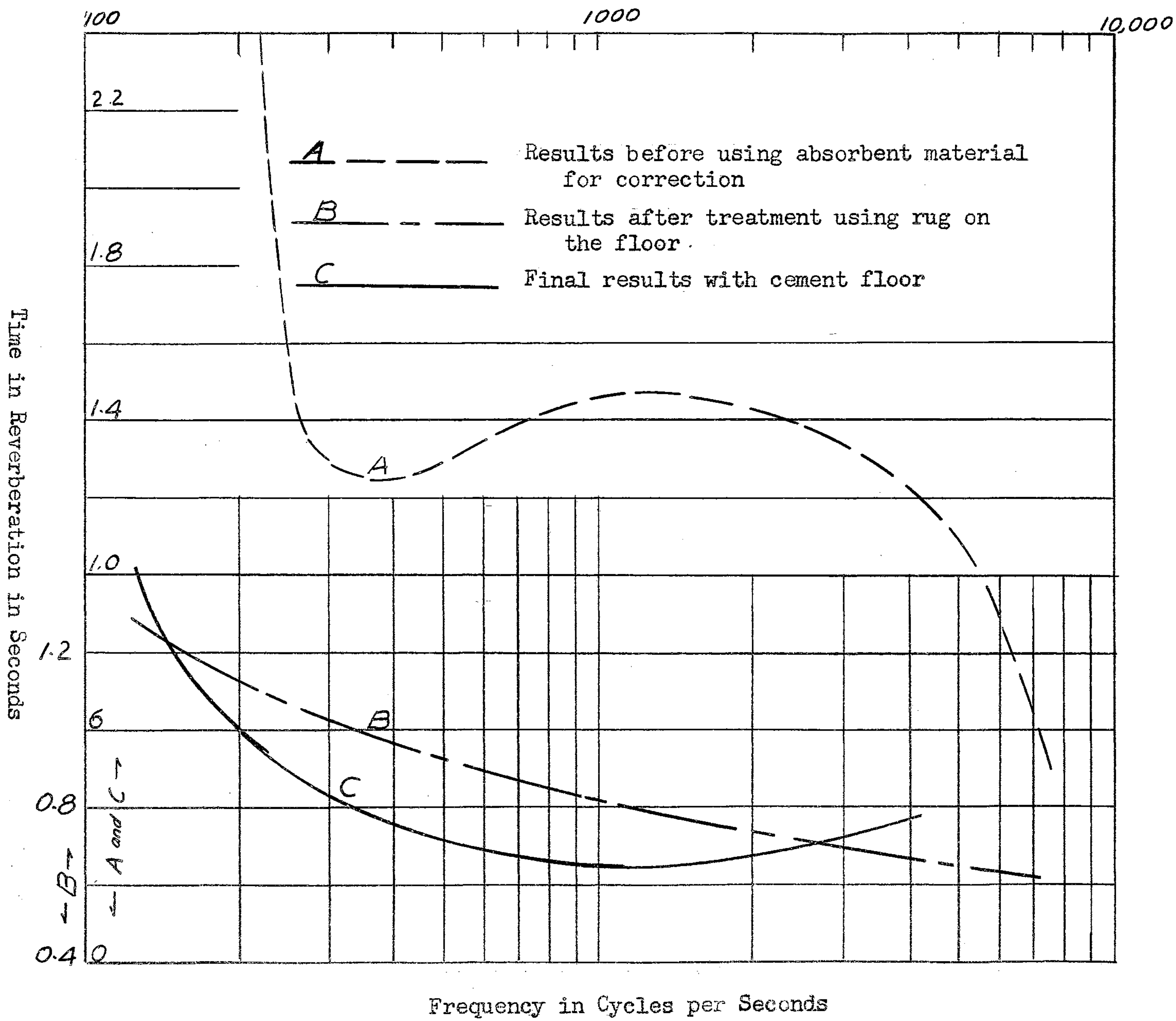
Results Obtained After Final Treatment



Time of Reverberation in Seconds

CURVE SHEET III

Reverberation Time Vs Frequency



The results obtained for Reverberation Time (see Fig. 2, and Curve Sheets 2 and 3) are plotted on Graph 3. These results are by no means ideal and the performance of the room or the experimental results may be slightly altered to meet various experimental requirements. With the addition or removal of a piece of drapery or placed in different spots of the room, different characteristics may be obtained. Moreover a corner diffuser may be installed with negligible cost, if necessary, for some experiments.

The behavior of sound in an enclosed room is a vast subject. These investigations do no more than touch the fringe of it. If they also touch one's imagination and help him to understand some of the problems associated with sound and acoustics conditions they serve their purpose.

e) Heating and Air-Conditioning

The laboratory being in an established building offers little choice in the type of heating system to be employed. However, assuming that the present heating system is proper, hot spots which are likely to be found in the room should not be overlooked. Hot spots along the work-benches and within the working area are not desirable for the simple reason that high temperatures will adversely affect the test equipment.

Because of the fact that dust is one of the undesirable factors, special care should be taken for its prevention since both dust and heat add to the damage of expensive test equipment which is likely to be placed in the room.

Because of the high temperature and high humidity in our location, air conditioning of the laboratory is a "must" rather than a luxury.

Air conditioning the laboratory will protect the equipment against changes in the accuracy and calibration caused by excessive humidity as well as provide comfortable working conditions. In designing the air conditioning of the audio laboratory the heat-generating electrical equipment turned on during working hours should be a factor kept in mind.

CHAPTER V

TOOLS AND SHOP EQUIPMENT

Regardless of the many facilities which may be obtained from other laboratories of the school of electrical engineering located near the proposed laboratory, a brief discussion is carried out as if these facilities were not available.

Whether the laboratory is large or small, it requires an adequate supply of shop equipment necessary for the operation. The amount of equipment, such as hand tools and heavy-duty tools, is to be determined by the nature of work to be performed in the laboratory. For example, when engineering design or research and development is to be carried out, some construction work and assembly are involved, hence heavy-duty tools are required. Obviously heavy-duty tools have to be kept in a separate room or shop while hand tools can be kept in the audio laboratory.

Tools and shop equipment normally required for electronics work can be separated into three classes or groups:

1) Hand tools.

2) Sheet metal tools.

3) Power tools.

a) Hand Tools

The basic tools required by each person using the laboratory may be summarized as follows:

1) Long nose pliers

2) Diagonal side-cutting pliers

3) Combination pliers

4) Electricians' pliers

5) Sets of both regular and Phillip's screw drivers

6) Set of spintite socket wrenches

7) Set of Allen wrenches

8) 8 or 10 inch adjustable crescent wrenches

9) A machinists' hammer

10) Dividers

11) Center punch

12) Scribe

13) Combination square

14) Hack saw

15) Wire strippers

16) Soldering iron or soldering gun

17) Tool box

18) Electric hand drill ($\frac{1}{4}$)

19) Set of drill bits

20) Set of tap and dies

21) Set of chasis knock-out punches (both round and square)

22) A pair of tin snips

23) One 1 inch micrometer

24) Additional chisels, punches and files

25) A manually operated coil winder

b) <u>Alloting Tools</u>

Perhaps one of the most important matters effecting the saving of time while using the laboratory is the arrangement of the tools. A laboratory may be equipped with more tools than actually required, and yet a considerable amount of time will be spent hunting for a particular article and because of this fact, care should be taken so that tools are properly arranged.

Several methods can be used in arranging tools. Industrialwise tools are allotted to individuals in sets and heavy-duty tools are substituted in different ways. However, in our case, a set of tools mounted on a rack placed in the laboratory would be sufficient. Special tools such as heavy-duty tools can be made available by other laboratories of the school or the main shop located on the first floor of the Engineering Building.

c) Sheet Metal Tools

Almost all electronic equipment involves sheet metal work; therefore, no matter how small the laboratory will be, some type of sheet metal working facilities is required. It is possible that for the limited construction work necessary, standard metal work can be obtained by almost any electronic distributors such as chassis, cabinets and amplifier foundations. However, relying on stock chasis or any other sheet metal work will prove to have limitations for the reason that some other new or different design is likely to be carried out in the laboratory which may not be found or even exist in stores. With this reasoning, it will be well to have available some of the basic sheet metal working tools such as box brake, shear, and notching punch.

d) Power Tools

No matter how small the laboratory, a drill press which can handle at least $\frac{1}{2}$ inch drill is necessary. A power-driven grinding wheel would be handy for sharpening drill bits and chisels.

The above equipment, hand tools, sheet metal work tools, and power tools are some of the basic tools required. However, it is not necessary that all these tools be purchased for the laboratory since many are available from other laboratories. In fact, the only ones necessary are the hand tools which must be exclusively available for use in this laboratory. In a case where some special work is to be done which requires special heavy equipment, it will be more economical and probably save time to have the piece made by a private machine shop.

CHAPTER VI

STOCKING THE LABORATORY

A stock of smaller components is important for any laboratory regardless of size or of function. Generally, a laboratory devoted to engineering design and similar work where construction is involved will, naturally, require a larger quantity and variety of electrical and mechanical components than a laboratory designed for measurements and research work. The variety of such components will depend on the experiments to be performed and will vary from time to time according to the project which each individual will choose to study. It is, therefore, difficult to predict both the quantity and variety of small components necessary. It is always a good policy to start out with the minimum possible parts and purchase others as they are needed.

The purchase of additional components for different projects will generally increase the variety and quantity of laboratory stock. This will tend to overstock the laboratory and the result may be crowding and confusion which may be prevented by cleaning house once in a while. During house cleaning obsolete and defective parts may be disposed of.

Many of these small components may be used over and over again, therefore, some of them will become defective. A good inventory control system should be instituted when the laboratory is established. Several standard methods may be used. Regardless of the method employed the inventory system should accomplish the readiness of identification and location of any desired component as well as provide a quick check of parts remaining in stock.

Like test equipment, small components or parts may be divided into three major groups, namely:

Electronic components

Hardware

Chemicals

<u>Electronic Components</u>

Components included in this group are carbon resistors, wirewound resistors, potentiometers, switches, capacitors, etc. Carbon resistors should be stocked in different wattage ratings such as $\frac{1}{2}$ through 2 watts in most of standard values with additional quantities of the more popular sizes.

Wirewound resistors may be stocked in the 5, 10, 25 watts sizes as found to be necessary but in smaller quantities than carbon resistors.

Potentiometers should be stocked in the popular sizes and tapers together with a supply of separate switch sections.

Switches are usually available with different pole arrangements in light and heavy-duty styles, and in toggle, slide, pushbutton, lever and rotary types. A preliminary stock of toggle, slide, and pushbutton switches in single pole single throw (SPST.), SPDT., DPST., DPDT., should be kept on hand.

Capacitors as well as resistors are available in almost any electronic parts distribution store in suitable assortments. Such assortments are ideal for preliminary stocking. Assortments of capacitors include paper and ceramic as well as mica and electrolytic capacitors.

Other electrical components:

Fuses

Pilot lamp-bulbs

Batteries

Filter chokes

Relays

Variable capacitors

Selinium rectifiers

Tubes

Meters

Transformers

Loudspeakers

Microphones.

The above list of components and other parts may be purchased as they are needed with the exception of those most widely used. These should be included in the stock from the very beginning.

It is often found that once the laboratory has been established for quite some time most of the above components are acquired as they are needed.

Hardware

The laboratory should be stocked with wire in both solid and stranded types in various sizes and in different types of insulation.

An assortment of plastic insulated wire in different colors in 20 or 22 gauge is satisfactory for most wiring purposes. For filament wiring, of course, a heavier gauge of wire is required. In the field of audio there is adequate work to be done in sub-minature components. Therefore, much lighter gauge wire than 20 is needed. Enamelled wire for coils is sometimes necessary.

Special types of wire may be necessary from time to time. Such wire is of special insulation to provide protection against moisture, high-voltage break-down and other unusual circumstances. With the exception of common wiring and coil wiring, the purchase of special wire or cable can best be made at times when needed.

Among other items, some of which may be found in containers ready for stocking are:

Tube sockets
Knobs
Terminal strips
Spagetti tubing
Electrical insulating tape
Plugs
Connectors
Fuse holders
Pilot lamp-sockets
Binding posts
Line cord plugs
Test leads
Clip leads
Rosin core solder
Non corrosive soldering paste
Machine screws
Sheet metal screws
Insulating washers
Cable clumps
Lock washers

The above items may be purchased in one of two ways, either in assortments where saving is possible or in very small quantities as they are needed. However, regardless of the quantity to be purchased, the stock system should readily permit the location and identification of any item desired.

Chemicals

Cement and cleaners are some of the most important chemicals necessary for any laboratory.

For good cleaning purposes cement solvents and thinners are used. In addition, carbon tetrachloride and probably special cleansers may be required.

Some of the popular cements are, bakelite cement, rubber cement, rubber to metal cements, and others.

CHAPTER VII

LABORATORY FURNITURE

It is apparent that the workbenches of any laboratory are the most important pieces of furniture. Therefore, it is altogether proper that these items be discussed in detail. Visits to a number of laboratories in industry and colleges as well as the service shops established that no standard workbenches were found in use. The workbench is subject to several modifications and it is arranged in different ways to fit the requirements of each individual laboratory.

Some of the laboratories which employ a large number of workers are using continuous strips along the wall. These are quite satisfactory for many types of production work. However, these types have some serious disadvantages, when used by two or three persons simultaneously. There would be interference when incomplete experiments were left to be continued at a later time.

One of the most popular arrangements is the workbench made up in units about 5 to 8 feet long. Two units of this type, arranged to fit the room, will give a private work area to each person using the laboratory. This type is preferred for our purpose to any other standard type workbench.

For the sake of individual privacy which is highly desirable in our laboratory where some precision measurements requiring considerable test equipment are necessary, the workbenches built in units may be installed around the two walls. Another portable bench may be added to form a console.

Perhaps an ideal arrangement for this laboratory would be the installation of two unit-built benches along one wall and one portable bench which is suitable for permanently mounting less frequently used pieces of test equipment. This may be rolled alongside the permanent workbenches when needed.

In any case, three units of workbenches would be adequate for this laboratory provided that some other pieces of furniture are available to be used for storage.

For some types of work, particularly when one tests sensitive equipment, it is necessary that the work area be shielded as much as possible from stray fields, from noise signals and other undesired signals. Such an area may be provided in one of two ways, either by shielding a room completely or by building a screened and shielded test booth. If a shielded booth is chosen, it is necessary that good electrical bonds are provided between all pieces of screening. To complete the shielding between doors or other openings, metal stripping may be used. Moreover, the undesired signals coming through power connections should be taken care of by using line filters.

These are some of the methods that can be applied for shielding a laboratory. However, in our case shielding is no problem at all due to the fact that the whole building is already semishielded. Also the nature of work to be performed in the audio laboratory is such that does not require complete shielding, therefore the present condition of the room may be considered satisfactory.

As was stated earlier in this paper, it is important that six lineal feet of workbench space be provided per laboratory worker in addition to any special areas such as portable workbenches, for it is to be noted that tests which are to be carried out over a long period would have to be kept connected without interference.

Construction of Workbenches

Preference over different methods of construction, as well as the types of workbenches, must be examined. Sometimes metal workbenches are used for some types of work. However, they are undesirable because they have to be insulated completely. Hence the cost is higher.

Generally, workbenches made of heavy wood and constructed in such a way as to provide a level top are preferred over any other type. Since a smooth surface on the work area is desirable, the workbench should be covered with some leveled material such as $\frac{1}{4}$ inch tempered masonite or similar hardboard. Some preference also may be given to an inlaid linoleum top (using battleship grade) over the hardboard, provided that no hard work is to be performed on the benches.

The height and depth of the workbenches are mostly a matter of individual preference and can be modified at will to fit in the room, in order to save space. Suggestions on this matter include a 4 to 6 foot height and about 3 to 3.5 foot depth with one or two shelves of 18 to 24 inches located above the workbench top. It would be an advantage if the base of the shelves is inclined at a slope of about 5 to 20 degrees with a frame of 3/4 inch to hold the test equipment. This provides convenience in reading the equipment meters such as power supply, etc.

For workbenches design see Figure 3.

In conclusion it is a good policy to use good electrical bus bars on any type of bench chosen.

Other Laboratory Furniture

There would also be a number of pieces of furniture such as drafting

Figure 3. Main Workbench. Unit built.
Workbench No. II should be similar to the main bench.
Shelves are proposed to be arranged with a slope so that the meters of the instruments can be read easily.
The size of the workbenches could be changed at will.
☐ A C plugs installed 1 foot apart.

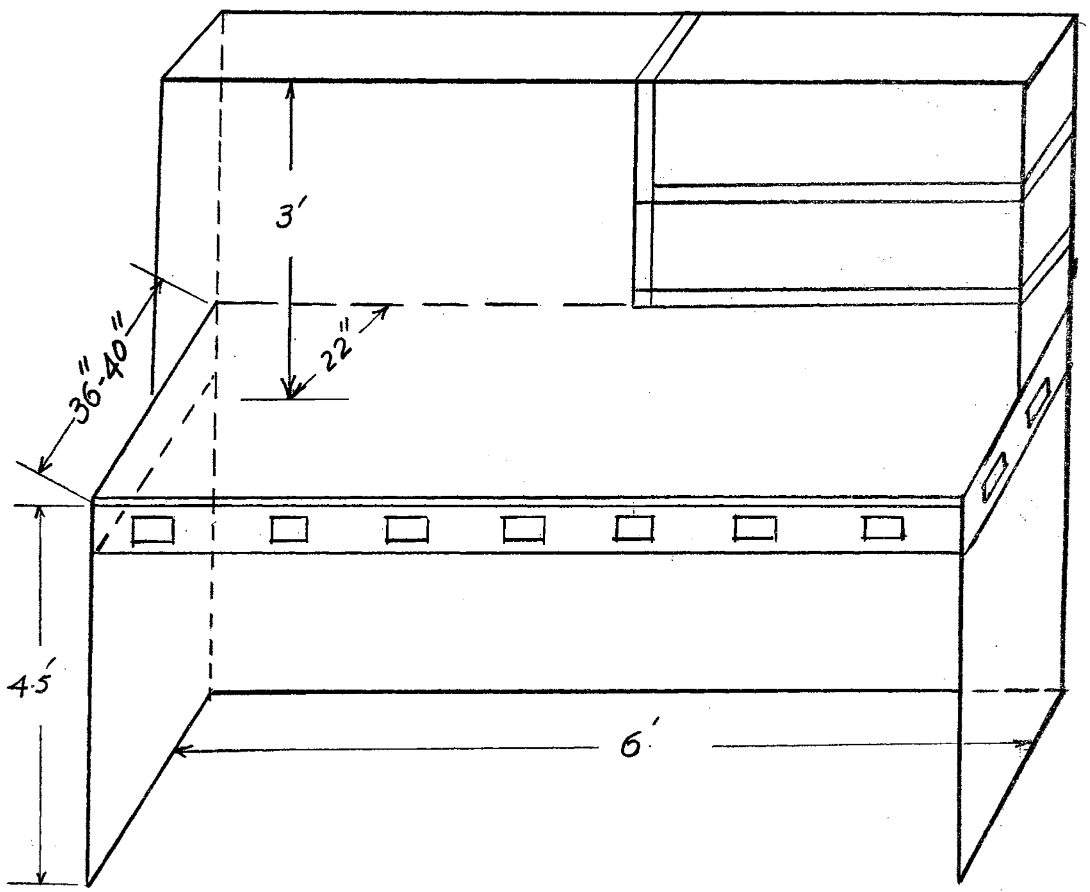
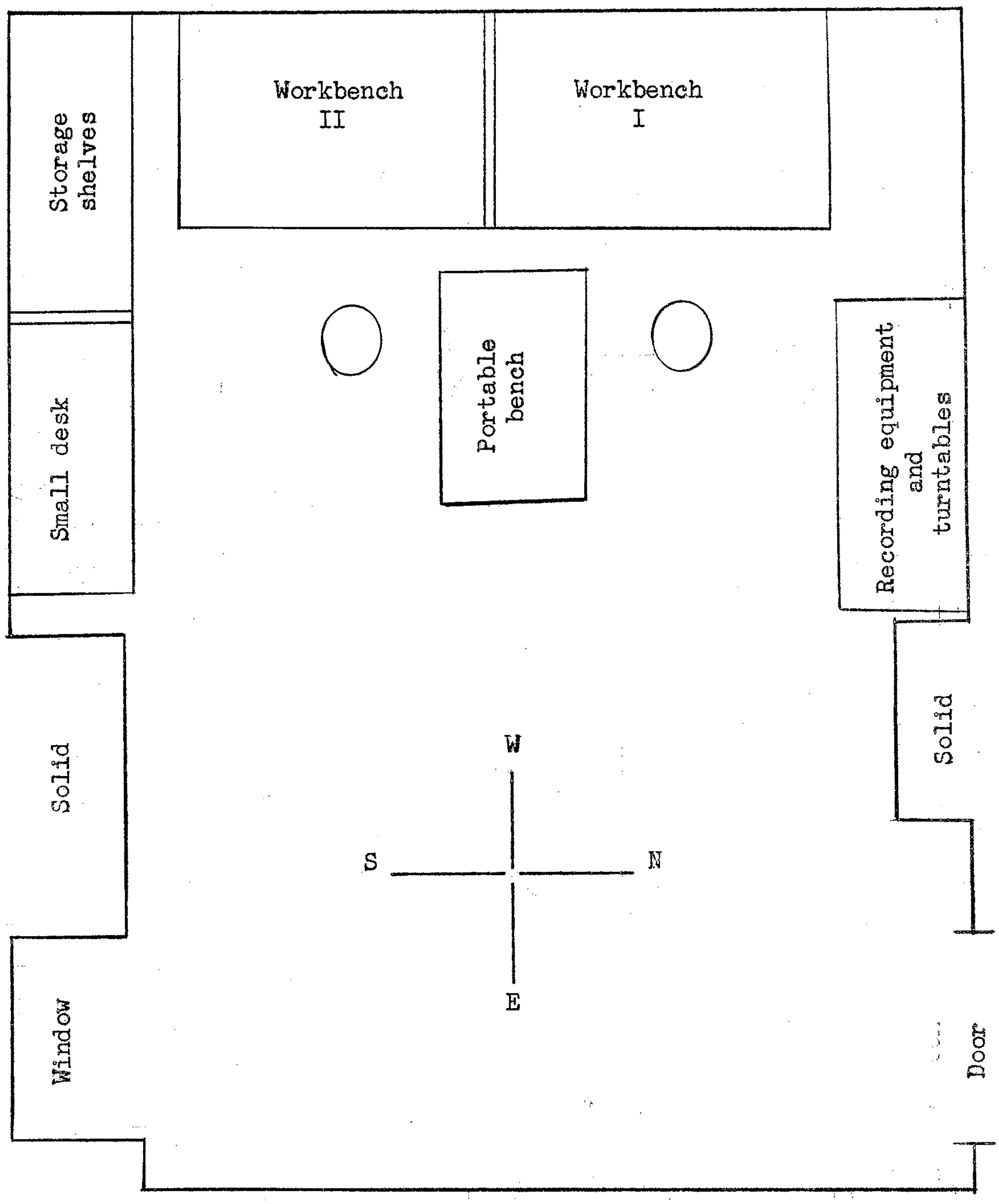


Figure 4. Block diagram showing the floor of the room and arrangement of the furniture.



tables, desks, bookshelves, cabinets, and other items necessary for the laboratory. However, most of this furniture may be eliminated due to the fact that such facilities are available in other rooms located near the laboratory. For any laboratory specific items required are bench stools, waste baskets, bookshelves, equipment shelves and cabinets, a small drafting table and one or more desks with chairs, etc.

For our purpose, however, a small desk would prove to be useful for study and other purposes. Two to three stool type revolving chairs would also be most convenient.

A small rack for keeping different types of wires is necessary. A complete rack of shelves used for storage of different components such as resistors, condensers, and other items is recommended.

Distribution Panel

Perhaps one of the most important factors entering into our study of plans for a proposed audio laboratory is the consideration of efficiency and flexibility. A laboratory may be equipped with more test equipment than actually is necessary and still be difficult for efficient performance of experiments. On the other hand, with a minimum amount of equipment and with a reasonable arrangement of a distribution panel, it is possible to perform most of the tests without moving some of the heavy test equipment. Therefore, it is necessary that power distribution be considered just as carefully as any other item.

It is desirable that any laboratory have a separate Electric Distribution Panel handling the laboratory outlets. This panel should be located in the laboratory or in a nearby room. Some distribution panels are equipped with fuses, others use circuit breakers. The latter are preferable when heavy line currents are used.

It is possible to supply the audio laboratory with various kinds of power through distribution panels located in a nearby electrical engineering laboratory. This may prove to be more economical yet the saving for such distribution may not be enough to justify the elimination of a separate electrical distribution panel.

Standard Power Outlets

Standard power outlets are items of which we never have enough. However, a minimum of one double outlet per foot of bench space will be adequate for many types of work as this permits greater flexibility when making tests or experimental setups. One standard power outlet per 4 to 5 feet on the walls may not be too many.

For the sake of safety and other factors, a ground "bus" along the back of the workbenches would prove very helpful.

Special Power Outlets

For some types of work it is necessary to have special power outlets such as dc and higher-than-60 cycle ac.

As has been pointed out previously a proper distribution of power of any kind may increase flexibility of the laboratory and it may also eliminate the necessity of such expensive equipment as power supplies. Another interconnection system may be used so as to supply various quantities of power from one power supply unit to different spots in the laboratory and outside of the laboratory to a nearby room. This will make possible the permanent installment of the power supply unit, likely to be the largest unit of laboratory equipment.

Using the proper wire for each particular kind of power, one outlet per two feet of workbench space is satisfactory.

CHAPTER VIII

TEST EQUIPMENT

Types of Test Equipment

Generally, electronic test equipment may be classified (a) according to frequency range over which the equipment may be used and (b) according to the basic measuring function of the instrument. For example, where frequency breakdown is used, the equipment may be grouped as follows:

1) Direct current instruments
2) Audio instruments
3) Radio frequency instruments
4) VHF instruments
5) Microwave and other instruments

Where instrument breakdown according to function is to be employed a system of grouping may be used which falls into the following headings to be discussed later in this chapter.

1) Component substitutes
2) Component measuring instruments
3) Electrical unit measuring instruments
4) Frequency measuring instruments
5) Waveform analysis instruments
6) Signal generators
7) Miscellaneous

Selection of Test Equipment

It is obvious that expenditures for test equipment represent one of the most important factors in establishing an audio or electronic laboratory. Because of this fact considerable thought must be given before purchasing the equipment of the laboratory. It is necessary to make sure that adequate equipment is available for the work required and to avoid, if possible, highly specialized but seldom-used instruments which might possibly be substituted. It is true that some experiments can be performed by several methods, either by using all test equipment that we desire to have, or by using the minimum equipment available and applying the necessary ingenuity.

An average engineer will tend to stock the laboratory with the maximum possible equipment, while the man behind the budget will tend to minimize test equipment requirements to the point where the laboratory will be below the necessary requirements or under-equipped for the necessary work to be performed.

The "ideal" is a compromise between the two extremes--a situation in which the laboratory is equipped with the very necessary pieces of equipment to start with.

In general the executive who is to approve expenditures for test equipment and the engineer who is to select the equipment must work very closely. Their collaboration will result in purchasing the instruments best suited without overlooking important instruments.

In our case the items of equipment proposed are listed separately at the end of this chapter and Dr. H. Fristoe, immediately in charge of the laboratory, decides which one of the instruments is to be purchased, substituted or borrowed from other laboratories under his supervision.

In choosing the test equipment listed, the following questions are raised by our study:

1) The basic problem is whether the instrument is essential to perform our work or if there is a suitable substitute available.

2) How often must an instrument be used? If this instrument is seldom used, is there another way to perform the experiment by using less expensive equipment?

3) The years of service expected from the instrument.

4) The degree of accuracy necessary for the work in relation to what tolerance can be permitted. This information determines the cost of many types of equipment, for in many cases the cost is directly proportional to the instrument's accuracy of calibration and stability.

5) Finally, is suitable equipment available in "kit" form to do the job?

The last question is important as far as cost is concerned since test equipment in kit form generally costs from one half to one third as much as factory-built equipment although the accuracy is not as high.

Cost of Equipment

It would be almost impossible to make even an approximate guess as to the cost of test equipment necessary to outfit properly an audio laboratory, because the cost of equipment varies widely with the nature of work to be performed and the accuracy of measurements expected. In general, however, the more accurate the measurements to be made and the more specialized the field, the more expensive the test equipment which is required.

Considering some figures based on "factory-built" equipment, an approximate estimate would total between $4,000 and $5,000 of equipment necessary for the audio laboratory. If "kit" type equipment is used wherever possible, the cost would be reduced sharply.

It is possible to perform experiments with kit-type test equipment and obtain accurate results within 5 percent error, which may be satisfactory for our purpose.

Kit Type Equipment vs Factory Built[9]

It has been noted from the above statements that when the equipment purchased in kit form is used in the laboratory, an appreciable amount of saving over the same "factory-built" equipment results. It is possible to equip almost completely a small laboratory with kit type equipment, and the cost will not be greater than that of one or two pieces of factory-built equipment.

This is the chief advantage of kit type equipment. There are, however, some disadvantages to its use, for test instruments assembled from kits are not so accurately calibrated as those made by the factory. Another consideration is the cost of labor in assembling kit type instruments. This cost will vary with the units to be assembled. Normally the most complex unit does not require more than a few hours of work.

From personal experience one finds the following important disadvantage to be considered in regard to factory built equipment. That is, in addition to the higher cost compared to the kit type, deliveries are usually too slow. Promises usually ran from two to three weeks for delivery, while 2 to 3 months are not uncommon. The kit-type material may be available immediately, hence delivery is a lot faster.

Taking the several factors mentioned into consideration, it would be to our advantage to substitute "kit" type instruments where such instruments are not calibrated such as oscilloscopes, power supplies, resistance substitution boxes, decade resistor and condenser boxes, and other units. Generally, these are found to perform just as satisfactorily as factory built equipment with similar specifications.

As a rule there will be only a few units of test equipment that cannot be substituted for kit types. These instruments are the ones to be used where accurately calibrated instruments are needed. In these cases factory-built units are definitely preferred over kit instruments.

Finally, it is safe to say that kit type instruments can be used for routine experimental work, for line testing, for equipment maintenance and similar work. The factory-built instruments can be used for final design work, development, for precision and checking the calibration of the kit equipment.

Component Measuring Equipment

Under the classification of types of test instruments previously discussed, the following units can be grouped according to their function. Instruments falling in this group are those to be used for checking the electrical characteristics or determining the condition of components. Such instruments are ohmeters, tube testers, condenser checkers, impedance bridges, wheatstone bridges, Q meters, etc.

Component Substitutes

Instruments in this group are those which can be used to perform as accurate substitutes or replacements for conventional electrical or electronic components during test and experimental work. These instruments which were discussed under the "factory vs built" units include variable transformers, power supplies, resistor and condenser decade boses, and standard inductances.

Electrical Unit Measuring Instruments

Instruments of this group are those used to determine electrical values. Such instruments include voltmeters, ammeters, wattmeters with scales ranging from minimum to maximum required for audio work, as well as fluxmeters, impedance meters, phase meters and similar units.

Waveform Analysis Instruments

This group includes instruments which are found to be used for other purposes than those of determining the characteristics of signal waveforms and sometimes frequency. In analyzing the waveform of a signal, some of the instruments commonly required are oscilloscopes, intermodulation analyzer, distortion analyzer, harmonic analyzers, and others.

Frequency Measuring Instruments

This group includes instruments used to measure frequency of ac signals, such as frequency meters, spectrum analyzers, counters, etc. Of course, instruments to produce such signals and waves with specific characteristics are necessary and can be grouped in signal generators. Such instruments are signal generators, square wave generators, sine wave generators, voltage calibrators, and audio frequency oscillators.

Miscellaneous

Under this heading are instruments used to measure physical objects or constants. Also included are items used as special accessories to the instruments grouped above, for example, electronic switches, oscilloscope cameras, etc.

It is obvious that some of the instruments can be used for many different tests. Therefore, it is difficult to determine the actual amount of equipment necessary for the audio laboratory. However, there are certain minimum test instruments that almost all but the most specialized laboratories will find necessary.

General purpose test instruments are listed below, along with some of the more specialized types. However, this list of equipment should not be considered as final, for there might be experiments to be performed later of such nature which either is not known in the audio field, or because of some new development taking place in the audio field. For example, "transistors" presently have been introduced to replace vacuum tubes in some kinds of work. Despite this fact, transistors at this time do not have an important role in the audio field because of their imperfect characteristics. They may sometime be perfected to the extent that their use will be of advantage. For like reasons, the equipment list includes only the most necessary items for a good start.

List of Test Equipment

1) Power supply
2) Oscilloscopes (General purpose)
3) Audio Oscillator
4) Audio Power Output meter
5) Frequency meter (audio)
6) Audio signal generator
7) Audio amplifier
8) Bridge - Wien or other type (impedance)
9) Bridge for L - C - R
10) Harmonic wave analyzer
11) Distortion analyzer
12) Intermodulation analyzer
13) Q meter
14) Adjustable auto-transformer
15) Calibrated attenuators
16) Variable attenuators
17) Filters, low and high pass
18) Condenser checker

19) A. C. VTVM

20) General purpose VTVM

21) Set for analyzing tube characteristics

22) Test speaker (standard for tests and comparison)

23) Standard test microphone

Other equipment. One of the most versatile items that has contributed more than any other medium to the audio field in the recent years is the magnetic tape recording and sound reproduction. Sound engineers have been quick to recognize magnetic tape as a big stride toward perfect sound recording. In a short period of time this medium of recording has been developed to the extent that it overshadows any other.

It is believed that there is more room for improvement, and it is quite likely that in the very near future, tape recorders will be as common in the home as radio and phonographs are today. Therefore, it is strongly recommended that some facilities along that line should be available.

Equipment necessary: Tape recorder; recording rack; turntable with all the accessories for disc recording (recording mechanism, recording head, microscope); and a small stock of tapes and blank discs.

CHAPTER IX

CONCLUSION

In the past few years a number of methods in various events such as fairs and exhibitions of audio equipment have been used to promote the field of audio engineering.

The improvement of the audio field over a remarkabely short time is commendable. However, nothing has been done in establishing this field as a specialized course of study in any of our institutions of college level today.

In preparing this paper naturally a source of information was sought in one of the magazines which serve the audio field. Reviewing some of the issues of this magazine during the past few years reveals the fact no one has taken the initiative to introduce this field into the higher education level.

The following is a quotation of the editor's report from the Audio Engineering Magazine.

Audio Fair[10]

Technical sessions of the convention offered a long list of papers, and attendance at these meetings averaged around 250. The society may justly be proud of its first effort and of the interest shown by those who came to hear and see.

Of greater importance, however, is the justification shown to those who have had faith in audio for these past years. Audio engineering is the result of this kind of faith, and while the overwhelmingly large attendance may have been a surprise to many, it was not to those of our readers who were able to be present. Audio is established as a separate science or art - or a combination of both - and is beyond doubt one of the most interesting to those who follow it. The fair did much to help this general recognition of audio, and we now look forward to a bigger and better Fair in 1950 - the one exhibit designed expressly for the unique requirements of audio equipment.

Since 1949, only bigger fairs have taken place. Five years later, January 1954, the editor's report from the same magazine (see editor's report, page 2) proves that nothing has been accomplished yet to change the situation. Therefore, the effort of establishing an audio laboratory in the school of Electrical Engineering in this institution may be considered to be the first stride toward a goal for a specialized field.

Particular effort has been spent to emphasize the facilities required for most of the fundamental tests and measurements in the audio field.

Among the principal factors entering the study of such plans are space and budget limitations. Therefore, the proposed plans were divided into groups in an effort to consider most of the factors required in establishing an audio laboratory regardless of its size, and then determine how many of these requirements were available, or could be substituted in order to reduce unnecessary expenditures.

Some consideration has been given to items such as furniture, workbenches, treatment of the room, lighting, etc.

The completion of the proposed audio laboratory may require more than just supplying working space, thest equipment tools, components and furniture. Regardless of the amount of time and effort spent in planning laboratory requirements beforehand, it will be found that one or more items are overlooked in the initial planning.

It should be remembered that new instruments are being developed constantly by all major manufacturers. Because of this fact and because of the rapid technical advances in the field of audio engineering, a new test instrument may become obsolete in a short period of time. On the other hand, some instruments may serve satisfactorily for a long time. New components, such as transistors, may also be developed to the extent that they will contribute to the advancement of the audio field. Therefore, some future expansion will be necessary.

It is safe to say that the proposed plans for the audio laboratory are merely plans for a good start. As outlined, they provide all the facilities for most of the fundamental conventional tests and measurements in the audio field, with a reasonable investment.

This is perhaps the most practical way to start a specialized laboratory, for it will permit future expansion when necessary with modern equipment without discarding old units.

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A P E N D I X

APPENDIX I

Table of Acoustical Coefficients of Materials and Persons

Description	Sound Absorbtion Coefficients in Cycles/Second						Authority
	128	256	512	1024	2048	4096	
Plaster	0.038	0.049	0.060	0.085	0.043	0.056	P. E. Sabine
Rug Axminster	0.11	0.14	0.20	0.33	0.52	0.82	Wente and Bedel
Each Person	1.4	2.25	3.8	5.4	6.6		Bureau of Standards
Concrete	0.01	0.012	0.016	0.019	0.023	0.035	V. O. Knudsen
Draperies 18 oz/sq. yd. (cotton)	0.05	0.12	0.35	0.45	0.38	0.36	P. E. Sabine
Permacoustic or celotex tiles 3/4 inch	0.19	0.34	0.74	0.76	0.75	0.74	Johns Marville Sales Corp.
Wood	0.05	0.07	0.08	0.08	0.07	0.045	

Reference Data for Radio Engineers 3rd Edition, p.p. 522, "Sound in Enclosed Rooms."

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