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# WPI Music Division Recording Facility Construction

An Interactive Qualifying Project Report
Submitted to the Faculty
of
WORCESTER POLYTECHNIC INSTITUTE
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by


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# Abstract

The purpose of this IQP was to provide the greater WPI community with a controlled, fully equipped, on-campus recording studio. The main objectives were to acoustically analyze the environment, then to design and incorporate acoustical solutions and to create a live-capture sound system. The objectives were met, and suggestions were made for future improvements. This facility was constructed in Spaulding Recital Hall and adjoining rooms, and is to be operated by the WPI Music Division.

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# 1. Introduction

This past year, the capabilities of the WPI Music Division have grown drastically. As the product of this Interactive Qualifying Project, the greater WPI community now has access to a controlled, fully equipped, permanent on-campus recording studio. This facility was designed and installed by the two member IQP team of Samuel Brown and Michael Drnek. It is located in the lower level of Alden Memorial Hall on the WPI campus, and is to be maintained and operated by the WPI Music Division.

The Interactive Qualifying Project, "Recording Studio – Design and Application," was conducted by two WPI undergraduates. The project spanned from B Term 2004, through D term 2005.

During this time frame, the Recording Environment (Spaulding Recital Hall) was structurally, functionally, acoustically, and aesthetically analyzed. The physical problems were then identified, and practical solutions were designed and implemented, within the limitations of the project. Lastly, the recording and communication hardware was integrated into the Recording Studio, creating a versatile recording environment for the WPI community.

## 1.1 WPI Music Division Background

The Music Division at WPI has never been livelier. Its many performing ensembles, academic classes and projects, and student organizations constantly fill Alden Memorial Hall with life and energy. Since it is assumed that the Recording Studio will be used by all of the WPI performing ensembles and music academia, it must be flexible enough to accommodate a large variety of performance groups and applications.

### 1.1.1 Applied Music Division

The WPI Jazz Group consists of three ensembles - Stage Band, Jazz Ensemble, and a Jazz Workshop. Stage Band is a traditional jazz band, featuring full horn sections and a wide variety of musical literature. The Stage Band performs regularly both on and off campus, and takes every opportunity to increase exposure of the WPI music department. The Jazz Ensemble is a small "jazz combo," which features four horns and three rhythm section players, and focuses mainly on improvisation and musical exploration. The Jazz Ensemble performs in venues ranging from formal programs at Mechanics Hall, to informal programs in the WPI dining halls. Both the Stage Band and Jazz Ensemble undertake foreign concert tours every two years. The Jazz Workshop is an organized and explorative ensemble that doesn't perform publicly, and is open to all students of all proficiency levels.

The WPI Symphonic Group includes Concert Band (75-90 musicians), Brass Ensemble (10-15 musicians), Orchestra, and the Medwin String Ensemble (4-16 musicians). The Brass Ensemble performs frequently on campus and on tour and is open to students who perform on trumpet, trombone, euphonium, French horn, tuba, or tympani. Renaissance antiphonal music is included in the repertoire. The Concert Band is a large ensemble comprised of traditional wind, brass or percussion instruments that performs several regional concerts a year as well as on tour. The String Ensemble performs music for string orchestra both on campus and on tour. Members of the string ensemble also comprise the string section for the full orchestra.

The WPI Choral Group contains Men's Glee Club (65 Singers), Alden Voices (a women's chorus of 25 singers, and Concert Choir (65 mixed voices). The Glee Club is the oldest student organization on campus. Both the Glee Club and Alden Voices tour Europe and also perform on campus. They perform music in many styles and from many periods of the vast repertoire of music for both men's and women's ensembles. Several times each year Alden Voices and the Men's Glee Club join forces as the WPI Festival Chorus to perform major choral works.

Other performing music groups are, the WPI African Percussion and Dance Ensemble (10 performers), Interstate 8 (an all women's a cappella group), Simple Harmonic Motion (an all men's a cappella group).

With the permanent installation of the new Recording Studio, all of the performing groups can record themselves in a much more ideal environment, with greatly increased control over the finished product.

Every year, an amazing amount of students at WPI choose to do projects in music. Many of these projects can take advantage of the new permanent Recording Studio at WPI, created through this IQP. Academic classes (MU 3611 - Computer Techniques in Music; MU 3612 - Computers and Synthesizers in Music; MU 3613 - Digital Sound Design) also can utilize the new facility, as it will allow students to apply the concepts they are learning in classes to a real recording environment. Student led organizations (Recording Club; Interstate 8; Simple Harmonic Motion) will also use the new space.

### 1.1.2 Academic Music Division

During the course of each academic year, many students complete their Sufficiency or Interactive Qualifying Project in the Music division of WPI's Humanities and Arts department. In addition, students participating in performance ensembles often choose to Minor in music, as a supplement to their Sufficiency. It is expected that performance based projects, as well as projects in Arranging and Composition will use the new recording facility heavily. In the 2005-2006 academic year, a new course will be offered in arranging and orchestration in which final projects may be recorded. In addition, Sufficiency Performance Projects and Music Minor Capstone Projects now have the Recording Studio as an integrated tool.

Undergraduate students looking to explore different aspects of music often register for Independent Study Projects (ISP), under the supervision of music faculty. ISPs allow students to do creative projects in an unlimited variety of areas that aren't available for study in traditional classes. Similar to ISPs, but on a much larger scale, Interactive Qualifying Projects provide a unique opportunity for WPI undergraduates to become fully immersed in a project, seeing it through from concept to completion. The permanent installation of a Recording Studio at WPI will open up myriad projects for students. Some examples of immediate projects (both ISP and IQP) include: Acoustical analysis and design, microphone and speaker selection and placement, live-capture, digital multi-tracking, and Mix-down/Post-production work. These projects will facilitate the further development of the Recording Studio over the years following its initial completion, providing an increasing number and variety of projects for WPI students.

Aside from the Applied and Academic gains from the new facility, WPI as a whole can benefit from the Recording Studio. With an easily accessible and permanent recording facility, WPI can increase its visibility to prospective students as well as the academic community, through more effective promotional materials. Also, the electrical engineering department has much to gain from the new Recording Studio, opening up the opportunity for classes and hands on learning experiences, creating a true interdisciplinary opportunity.

## 1.2 Audio Recording at WPI, Prior to Permanent Studio Installation

Previous to the completion of the Recording Studio, audio recording at WPI was difficult, costly, and very limited in all aspects of production. Every recording was done exclusively live, and on-site, generally during live concert performances. Critical recordings were done by Dr. Charles Paquette, whose expertise made the best of the non-ideal situations encountered when recording for WPI ensembles.

General recording services were often performed by students, either in the WPI Recording Club, or for hire through the Federal Work Study program. The success of these recordings was dependent upon student interest and aptitude, which varied from recording to recording.

For all recordings at WPI, there were many limitations and drawbacks. There was very little control over the sound capture quality or the finished product, and the Recording Environment was far less than ideal. Available hardware and software was very limited and of amateur quality.

For years, the performing ensembles have wished for better acoustics in their rehearsal space, Spaulding Recital Hall. The poor acoustics of the performance environment were caused mostly by the physical limitations of this rehearsal room. The more notable limiting factors directly effecting recording quality included poor sound isolation, crowd and mechanical noise, limited microphone placement, and limited aesthetic options during the capture.

Prior to the completion of the Recording Studio, it was difficult and costly to record performing ensembles at WPI, and there was very limited control over the quality of the final product.

## 1.3 Project Background

In undertaking this project, the team identified the needs of the WPI Music Division, while considering the project's limitations. The team established that WPI desired a versatile, robust and flexible Recording Environment and Control Room, dedicated recording equipment (hardware and software), and a secure space to store all of the equipment. The project's limitations dramatically shaped the outcome of the project, and simultaneously gave the team a clear focus on the objectives. The architectural properties of the building (Alden Hall) were identified to be the main challenge in the design of the Recording Studio, but could not feasibly be changed, due to monetary and aesthetic constraints. If this project was funded to include changes in the permanent architectural properties of the environment, there would still be labor union implications and time constraints (the space couldn't be out of commission for an extended period of time as it is a very vital rehearsal and performing space for WPI's music division). The team's main objectives were to assess the needs of the school, develop a cost effective design that would correct the acoustics of the space, and integrate the Control Room and Recording Environment to create a fully functional, permanent Recording Studio.

## 1.4 Grants and Donations

This entire project has been made possible by numerous and incredibly generous donations. Without the support from the community and dedicated WPI music faculty, this project would never have seen light.

The majority of the equipment that is being used in the Recording Studio was donated by Mr. Daniel Foley, whose intense passion for the realization of this new Recording Studio was a key factor in its completion and success. Mr. Foley has donated the main DAW (Digital Audio Workstation), a pair of high-end condenser microphones, hardware effects, studio monitors, access to software (acoustical modeling and analysis), numerous odds and ends necessary for the studio's functionality, and an enormous amount of his time.

A valuable resource, Mr. Mark Dailey has also donated his time for in-studio training and consulting.

From the Shannon Fund, which was set up for the purpose of providing funds for broad based music division acquisitions, the WPI Music Faculty allocated $1500 for general expenses incurred in the development of the studio, and has expressed a willingness for ongoing financial support in the future.

Most importantly, WPI's own Music Division has been critical throughout the entire project. After years of discussion of possible uses for the large space adjacent to Spaulding Recital Hall, the music faculty allocated it to be the Control Room of this project. Many faculty members have committed themselves to the success of the new Recording Studio, making themselves available throughout the entire project. With their expertise, experience, and guidance, the WPI music faculty has been instrumental in the development of the Recording Studio.

## 1.5 Project Implementation

In developing and installing the new Recording Studio, the first major objective was to identify and address all of the problems, keeping in mind that not all of these problems could be solved within the spectrum of this project, due primarily to time and monetary constraints.

The IQP team analyzed Spaulding Recital Hall (which would become the Recording Environment), and also the large room adjacent to Spaulding (which would become the Control Room). This was done through general acoustic research, interviews, and CAD Modeling. Additionally, the team had acoustic specialists visit the site to give their opinions on the space and its limitations, and suggestions for correcting the problems with the space. The team also referred to an extensive report (Previous IQP, Andrews et al) detailing the acoustic properties of Spaulding.

The primary issues that the team discovered with the Recording Environment are as follows: Sound insulation and noise isolation from the outside environment (traffic, weather, concurrent events or rehearsals in the building, mechanical noise from the Heating Ventilation and Air Conditioning system), Reflection of sound (standing waves, resonance, flutter echo, reverberation, absorption of sound) and areas where either too much bass was emphasized, treble de-emphasized, or too little where the treble was emphasized and bass de-emphasized.

After much research, a plan was designed for the Recording Environment using solutions that were within all of the limits of the project. This team's solution had to fit within the time allotted to this IQP and had to be inexpensive. Meeting their criteria, a cost effective solution was implemented which provided a significant boost in clarity and sound quality in the Hall, while still maintaining appropriate aesthetics. Another aspect of this team's design for the space was to find diffusive materials, which don't absorb the acoustical energy in the room, but rather reflect the sound to promote more natural and even energy patterns. The solution needed to be cost effective and aesthetically pleasing. The corners of Spaulding recital Hall also needed to be treated to absorb lower frequencies that conglomerate in the corners.

To complete the project, the team needed to integrate the Control Room and Recording Environment, to produce a functional Studio, which could easily be expanded upon in the future. All of the hardware used in the studio needed to work seamlessly, without a natural view from Control Room to the Recording Environment. To do this, the team identified ideal settings for live-capture using the available microphones, and considered the many types of ensembles that used the space. The team professionally installed cables running from the Control Room to the Recording Environment, through the walls and ceiling, to facilitate communication between the two spaces. In the Control Room, all of the equipment was to be installed and connected in the most ideal and functional manner. The team needed to establish a communication system between the rooms, to allow the two spaces to operate seamlessly. Much testing needed to be undertaken to assure that the two rooms functioned together very well, and that the design and installation of the Recording Studio rooms were optimal.

## 1.6 Benefits to the Greater WPI Community

The greater WPI community will benefit as a direct result of the completion of this Interactive Qualifying Project. Undergraduates gain a valuable resource that will be used to reliably and professionally document performances and class work, including but not limited to Major, Minor, and Sufficiency recitals, student ensembles, and academic compositions. The Recording Studio will be used to supplement existing classes, providing a hands-on learning environment for cutting edge audio capture, recording and production techniques and technical/artistic principles. It also opens up an ever-growing list of possible future academic projects and classes.

This IQP also benefits the WPI Music Division as a whole, facilitating cross departmental opportunities, notably with the Electrical Engineering department. The studio provides a foundation for Audio Engineering projects and hands-on application. The Recording Studio will also function as a resource for producing quality public relations and promotional material, increasing off-campus visibility. This project will also allow for increased involvement with the Greater Worcester music community, by providing non-profit music ensembles with a facility in which to rehearse and record.

# 2. Literature Search and Review

Before any physical work could be done on the project, the team had to fist do extensive research on acoustics, audio, and recording technologies. This research was performed by consulting print and electronic resources, speaking to experts, and visiting locations where professional recordings are made. All of this was performed from November to December 2004. After completion of the literature search and review, the team was well prepared to begin informed construction of the Recording Environment.

## 2.1 Literature Research and Lectures

WPI's Gordon Library had a wealth of literature on topics relevant to this project. The team used Crocker's Handbook of Acoustics and Everest's Master Handbook of Acoustics extensively while researching analysis and treatment of the Recording Environment. Ballou's Handbook for Sound Engineers was also a valuable resource for both acoustical and audio information; it was consulted while designing the acoustic treatments, and again while designing the sound system. The team also used Eargle's Handbook of Recording Engineering to a great extent while researching generalized sound system design. All of these books provided the team with a firm knowledge base, so that they could be well-informed while consulting experts and performing on-location research.

In addition to consulting the above-mentioned literature, the project team attended two lectures on audio technology that were hosted by the WPI Music Division. These lectures, entitled *Multitrack Recording: From the signal chain to tracking* and *Demystifying Audio Specifications: Am I getting ripped off or is this the deal of a* *lifetime?* were given by Mark Dailey and Dan Foley, respectively. Dailey's lecture was instrumental in the design of the sound system, while Foley's helped the team make informed decisions when making purchases.

It is also important to note that this project team built on the work of two previously completed Interactive Qualifying Projects. The first project, entitled *Acoustical Analysis of Spaulding Recital Hall*, by Andrews et al, provided the team with invaluable information on the acoustical characteristics of the Recording Environment. All acoustic treatments the team used were derived directly from that project. Additionally, another IQP team made up of Michael Milner and Sean Blandin had designed a *Live Recording Handbook for WPI Music Ensembles*, which informed this project team on how the Recording Environment would ultimately be used by performing groups. This allowed them to tailor the environment to best accommodate live-capture recordings of specific WPI ensembles.

## 2.2 Location Research

Early in the research process, the team identified Mechanics Hall in downtown Worcester as a valuable educational resource. Joseph Chilorio, who has served as Mechanics Hall's chief recording engineer and technician for the past 28 years, graciously invited the team for a comprehensive tour of the hall. On the team's visit, Mr. Chilorio detailed the hall's history, and thoroughly explained the design and integration of the recording space and control room.

In addition to touring Mechanics Hall, the team visited Berklee College of Music in Boston, MA. Through the connection with Dan Foley, an invitation was extended for an in depth tour of the recording facilities. Founded in 1945, Berklee is the world's largest independent music college and is at the forefront in music technology and recording practices.

### 2.2.1 Mechanics Hall

"Called "*the showpiece of a city where the arts thrive,*" by Horizon Magazine, Mechanics Hall has been judged by architectural historians as the nation's finest pre-Civil War concert hall" (Mechanics Hall). The Worcester County Mechanics Association was formed in 1842 as a non-profit organization, which educated the city's industrial workers. The Association provided classes in the mechanical arts in addition to hosting cultural and political events which were open to all members of the community. By 1857, the Mechanics Association required a building of its own, and hired Elbridge Boyden to design and construct Mechanics Hall. When it was finished, the new building represented the state-of-the-art in mechanical systems and construction techniques.

During the mid-20th Century, Mechanics Hall became run-down and its health took a great toll as a result of years of neglect and misuse (it was rented for professional wrestling matches, roller skating, and the like). In 1977, when a decision needed to made whether to tear down the building or repair it, the city of Worcester "rallied, raising $5 Million to restore the hall." The dilapidated hall was revitalized by "the first community-wide effort to reverse the decline in downtown Worcester" (Mechanics Hall).

For nearly 150 years, the Hall has been a cultural cornerstone in Central Massachusetts and regarded as one of the four finest concert halls in North America (among the top 12 among European and American halls).

When Mechanics Hall was constructed in 1857, before the widespread use of electricity, it was necessary for the speaker to be clearly audible throughout the expansive hall, without amplification. This quality is experienced today, as the team observed during their interview with Mr. Chilorio.

Mechanics hall is primarily used to perform and record classical music, but is well suited for other performances, such as jazz.

The acoustic characteristics of Mechanics Hall are nearly ideal for a space of its size, beauty, and application. The intricately detailed walls and ceilings act as diffusers by reflecting and dispersing the sound in many directions. The reverberation time of the hall changes dramatically depending on whether it is fully occupied or empty. At maximum capacity, the acoustic reverberation time of the hall reduces from 3.5 seconds to 2.5 seconds, which is ideal for a concert hall its size which features mostly classical use. The reverberation time is also reduced by the conscientious use of highly absorptive seating throughout the balcony. Too long of a reverberation time in a concert hall can quickly muddy the sound, while an ideal reverberation time can add richness, life, and color to a performance. This characteristic is sought after by major recording labels, and has brought Telarc International, Sony Classical, and Koch International to Mechanics Hall many times.

During the revitalization process, one of the largest obstacles was designing an efficient heating, ventilating, and air conditioning system (commonly referred to as HVAC) that wouldn't hinder the experience of musicians and visitors. The Mechanics Hall HVAC system moves an impressive amount of air while remaining virtually inaudible. This is achieved through the use of large diameter ducts and vents (which reduce air speed while maintaining flow rate), as well as physically isolating the machinery from the recording environment. Two of the large vents are located behind the dark screens on either side of the organ piping, and are visible in Fig.2-1. By reducing noise from the HVAC system present in Mechanics hall, recordings and performances retain their natural sound without obtrusive inference.

Fig. 2-1 Mechanics Hall

The recording studio in Mechanics Hall, located in the Fuller Wing, is removed from the recording space, but remains fully capable through a complex and well designed communications system. The recording studio is comprised of two separate rooms. One houses all of the recording, mixing, and mastering equipment and hardware, while the other was designed primarily for listening purposes.

Fig. 2-2 Main Mixing Board (with view into listening room)

A soundproof window separates the hardware room from the listening room, while providing a clear sight line. This is shown in Fig. 2-2. The hardware room is equipped with comprehensive digital and analog systems for two-track stereo recordings. Some of this equipment is shown in Figs. 2-3 and 2-4. Acoustics within the hardware room are of little concern, as it is primarily used for operating and storing the noisy equipment. The room is treated minimally with absorptive material to slightly deaden the space, and to reduce machine noise.

Fig. 2-3 Analog Recorders

Fig. 2-4 Equipment Rack, Digital Recorders

The soundproof, acoustically designed listening room is used for monitoring the recording sessions, listening to playbacks and making editing decisions. Within the listening room, a balanced acoustic characteristic is achieved through the use of many acoustic principles. A blended use of diffusive elements, bass traps (i.e., the in wall Helmholtz resonator), and absorptive materials creates a listening environment that allows for distortion free sound coming from the professional level studio monitors. Also, careful use of furniture aids in acoustic manipulation of the space.

The diffusers used in the listening room are wall mounted, with logarithmically derived absorptive/reflective patterns beneath their visually pleasing surfaces. These diffusors are shown in Fig. 2-5.

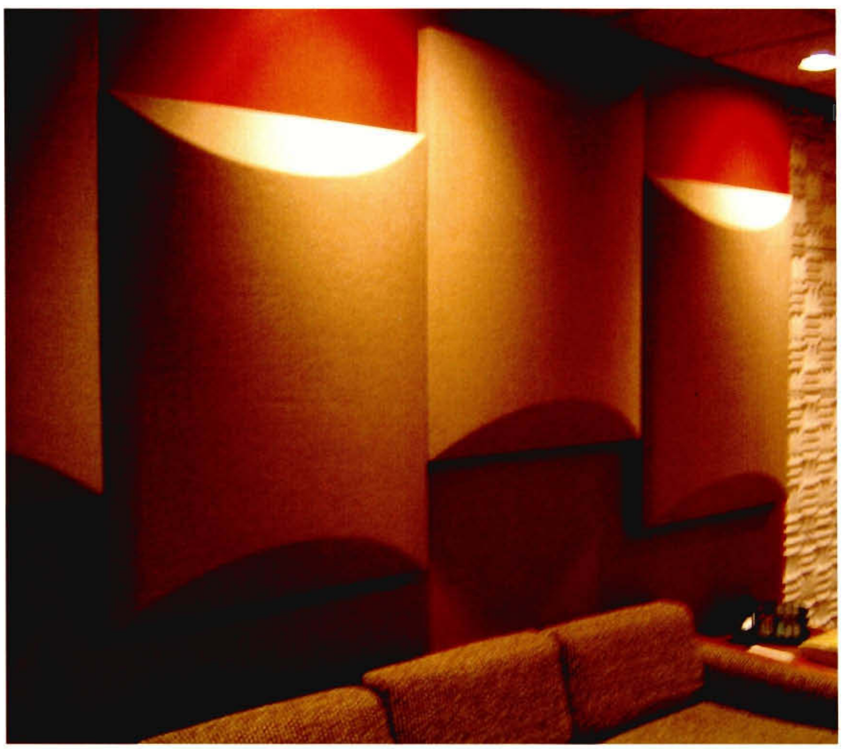


Fig. 2-5 Diffusors in Listening Room

The in-wall Helmholtz resonator, shown in Fig. 2-6, isolates and eliminates lower problem frequencies.

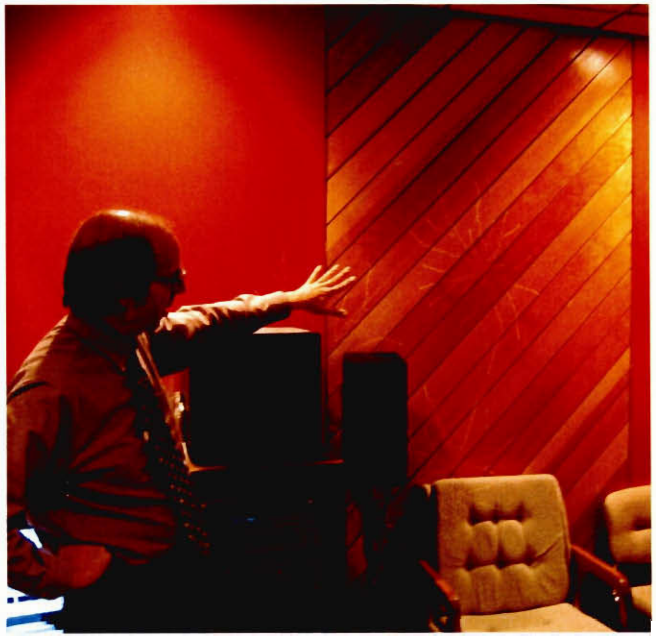


Fig. 2-6 Helmholtz Resonator Bass Trap

Absorptive materials are used on the walls and ceiling, which reduce the amount of overall sound energy in the room. The thick foam on the wall also reduces low frequencies. These treatments are shown in Figs. 2-7 and 2-8.

Fig. 2-7 Thick Absorptive Foam on the Wall

Fig. 2-8 Absorptive Ceiling Tiles

To produce accurate stereo sound, high end studio monitors are each paired with their own power amplifier. These speakers are designed for a natural, balanced output in all frequency ranges, and are positioned to create an equilateral triangle with the listener (to achieve ideal stereo imaging). The large ported enclosure houses a bass driver, while separate, adjustable midrange and tweeter enclosures rest on top. Adjustability allows the speakers to be tailored to each specific environment and listening position. One of these speakers and its amplifier are shown in Fig. 2-9.

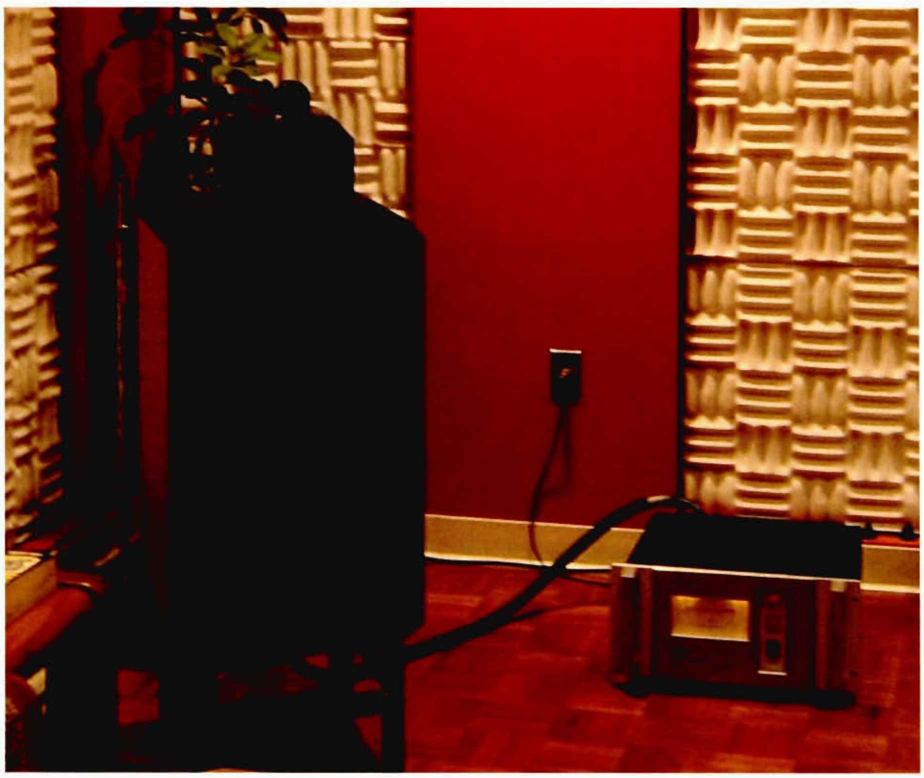


Fig. 2-9 Left Studio Monitor and Amp

The physical structure of the listening room is its biggest asset. The room was designed to avoid many of the problems associated with parallel acoustic reflections, which are a nuisance in most recording and listening environments. (The ceiling and floor, as well as the left and right walls, were constructed unparallel to avoid standing waves).

The advanced audio and video communication system in the control room of Mechanics Hall is a valuable asset that allows it to function as if it were in much closer proximity to the recording space. The communications system allows the operator to remotely control several live video cameras, providing a detailed and variable view of the performers, crew, and equipment set-up. The operator can listen to and respond to members of the recording environment, allowing effortless adjustments and corrections. In Fig. 2-10, a view of the stage is shown on the listening room's main display.

Fig. 2-10 Communications Center in Listening Room

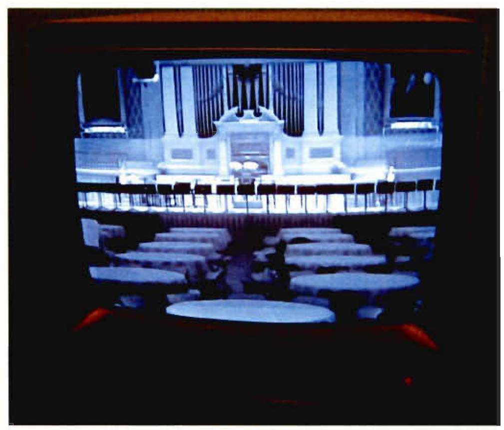


Fig. 2-11 Separate Equipment Room Display

The equipment room also has a large display with controlling capabilities, as shown in Fig. 2-11. By combining this powerful communications device with advanced, full featured recording equipment, Mechanics Hall created a powerful and versatile control room.

From their visit to Mechanics Hall, the team acquired valuable information that directly impacted their design of the Recording Studio. The team witnessed the value of a completely integrated recording space and control room, and optimal use of acoustic treatments. In addition, the position of the playback speakers in the control room allowed for an ideal listening position, which the team used in the design of their Recording Studio.

### 2.2.2 Berklee College of Music

The facilities at Berklee of Music represent what can be accomplished with a virtually unlimited budget. Berklee has multiple fully equipped recording studios (each with a separate recording environment and control room), numerous dedicated editing/mastering/listening environments, and a large, well educated faculty.

Professor Anthony Hoover, an Assistant Professor in the Music Production and Engineering Department, led the team on a tour of the facilities at Berklee. The Music Production and Engineering Department oversees the college's recording studio complex, which consists of 10 lab facilities. This complex includes four 24-track control rooms, two 8-track mix-down control rooms, a digital audio/video postproduction editing suite, and two 8-track and one 24-track teaching rooms. Three of the control rooms are tied to the Berklee Performance Center for live recording, and all of the studios are networked to allow sharing of data and hardware equipment. Professor Hoover led the team through a few of the larger studios, notably Studio A, Studio B, and Studio L3.

Sound isolation between environments is critical to all of the studios at Berklee College, due to the closely packed nature of the facilities. In addition, the HVAC systems used are carefully designed for optimal acoustic properties. The vents are lined with Owens Corning fiberglass (type 475) insulation to prevent noise resulting from mechanical vibrations and airflow. This is shown in Fig. 2-12.

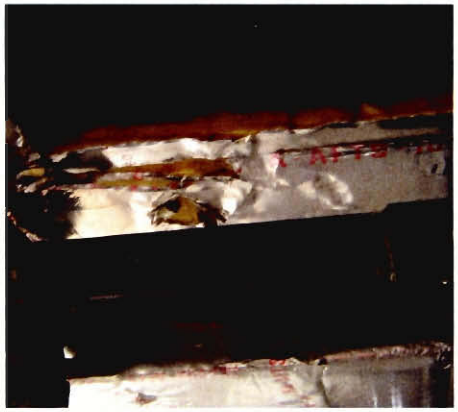
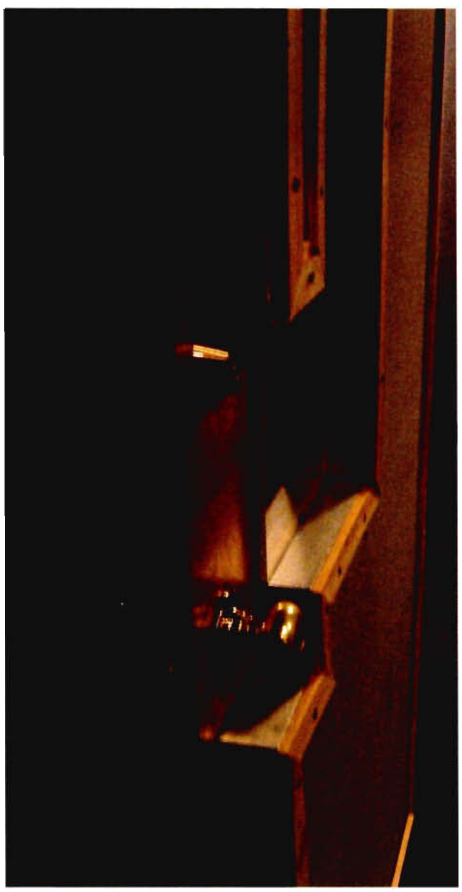


Fig. 2-12 Fiberglass Lined HVAC Ducts

Soundproof viewing glass between rooms is complemented by soundproof doors, as can be seen in Fig. 2-13.



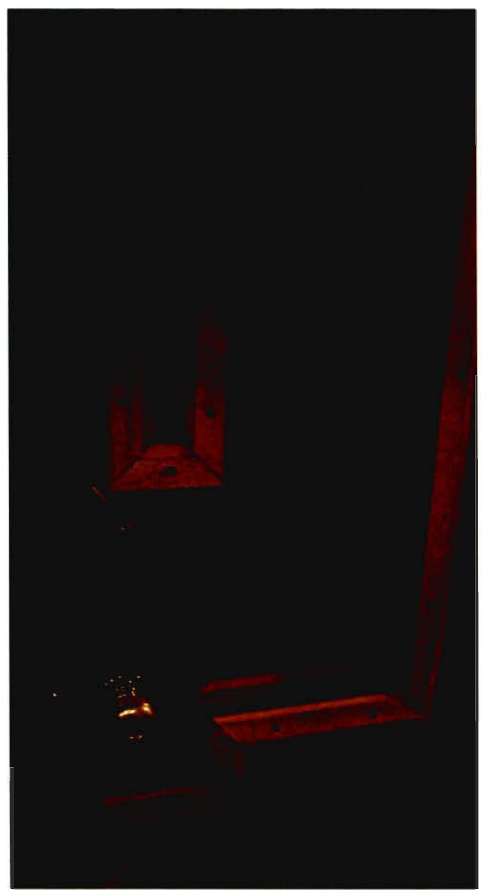


Fig. 2-13 Soundproof Doors Separating Environments

Studio A is comprised of a large recording space, a separate isolation booth, and control room. This studio is used for many different purposes and needs to be easily adapted for varying applications. In the recording space, the perforated ceiling tiles act as diffusors. Carpets and acoustical wall panels are ready to be used in any desirable configuration, but remain out of the way when not needed. These can be seen to the right side of Fig. 2-14, which shows the interior of Studio A. The corresponding control room is shown in Fig. 2-15.

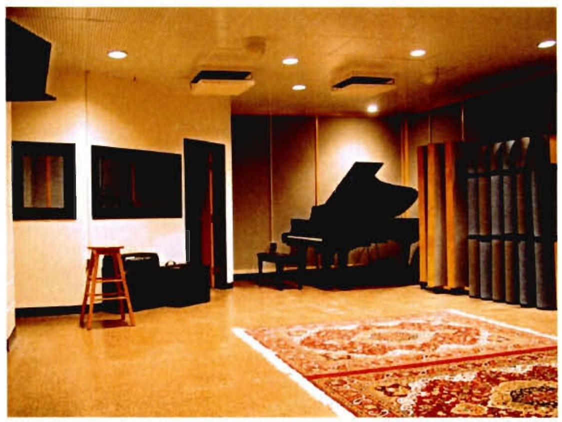


Fig. 2-14 Studio A: Recording Space and Isolation Booth[1]

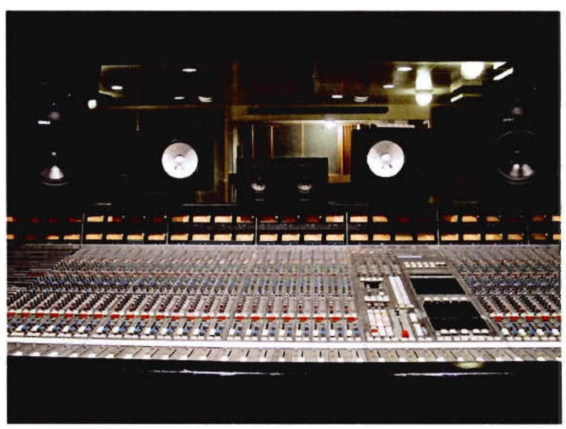


Fig. 2-15 Studio A: Control Room[2]

[1] http://classes.berklee.edu/mpe/studios/images/studio_a_2.jpg
[2] http://classes.berklee.edu/mpe/studios/images/studio_a_1.jpg

Within the control rooms at Berklee College, a vast amount of hardware and software is available. The equipment found in Studio A is very similar to Studio B. Studio L3 adds a number of educational tools, and doesn't have an accompanying recording environment. The equipment found in Studios A and B is outlined below.

The main console is a Solid State Logic 4036G 36x32, which controls all of the signals received from the recording environment. Software titles installed on the Apple Macintosh G5 workstation include Digidesign Pro Tools, MOTU Digital Performer, Bias Peak, Emagic Logic Pro, Propellerhead Reason, Native Instruments Kontakt Sampler, and Roxio Toast Titanium with Jam. There is a Struder a820 Multi-track recorder, and a variety of stereo recorders, including Struder A810, a Pioneer RT-701, a Panasonic SV-3800, a Sony TC-KA1ESA, and a HHB CDR-830 Plus.

Playback is achieved with a Pioneer Elite Universal player which handles CD-RW/DVD discs. A multitude of Outboard Gain Devices include a Behringer Composer MDX 2100, dbx 165A, Drawmer DS-201, two EL8-X Distressors, Tech 21 Sans Amp PSA-1, two UREI 1176LN, two UREI LA-4s, two Universal Audio 6176, and a Valley People 610. Equalization is handled with a GML 8200, and a Summit EQP-200A. Delay, Reverberation, and Effects units include a Lexicon 480L (with LARC), a Lexicon PCM-42, two Roland SDE-3000s, a Studio Technologies Ecoplate II, a Yamaha SPX-90II, and a Yamaha SPX-1000.

In the studio, the following microphones are available: two AKG C 460Bs, two Audio Technica 3032s, two Audio Technica AT-4050/CM5s, an Electro-Voice RE-15, three Electro-Voice RE-20s, two Electro-Voice RE-55, a Fostex M80-RP, a Fostex M85-RP, a Fostex M88-RP, two Radio Shack PZMs, four Sennheiser MD 421s, two

Sennheiser MD 441s, five Shure SM-57s, two Shure SM-81s, two Tram TR-50s, two AKG C 414EBs, two Audio Technica AT-4050/CM5s, two Crown PZM 6-LPB, and a Shure SM-7B.

Several direct boxes, including an Audience, two Countryman Type 85s, and two Jensens are used. In the control room, an array of monitors include: Tannoy System 15 DMT IIs, Genelec 1031 As, Yamaha NS-10Ms, and Auratone 5 PSCs. In the recording environment a Struder monitor is used. Powering these monitors are several amplifiers. The main control room amplifier is a Bryston 4B, while the main studio amplifier is a Crown D150A. Additionally, two Crown D-75s are used to power playback of cue mixes in the studio. In-studio musical instruments include a Yamaha Diskclavier, a Fender Deluxe, a Fender Bassman 100, and a Fender Cyber Twin. A MOTU MIDI Timepiece AV is used for MIDI synthesis (Berklee Recording Studios).

The interior of Studio B can be seen in Fig. 2-16.

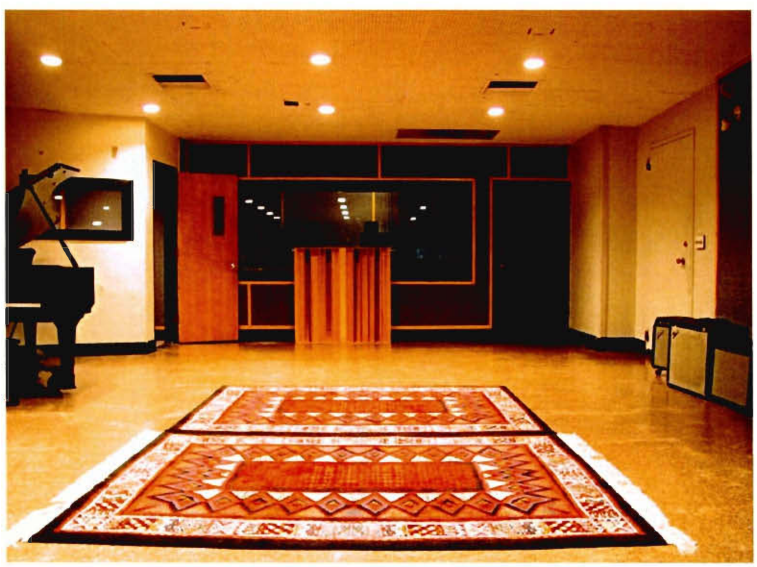


Fig. 2-16 Studio B: Recording Space[3]

[3] http://classes.berklee.edu/mpe/studios/images/studio_b_2.jpg

Noticeably different in layout from Studio A, Studio B has permanent diffusive elements spanning the length of the wall between the control room and the recording studio, and also intermittently throughout the room. These diffusers are constructed from wood, and their dimensions are based upon algorithms identified to diffuse sound energy ideally for the particular space they are in. Some of these diffusors can be seen in Fig. 2-17.

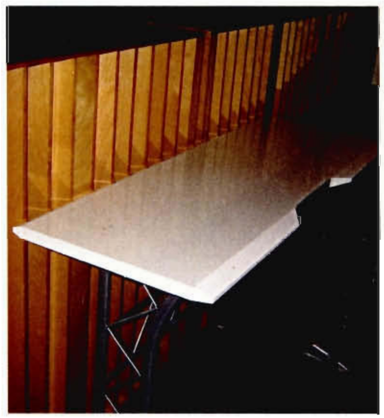


Fig. 2-17 Studio B: Diffusors

The control room of Studio B is noticeably smaller than that of Studio A, but can still accommodate several technicians comfortably. This control room is shown in Fig. 2-18.

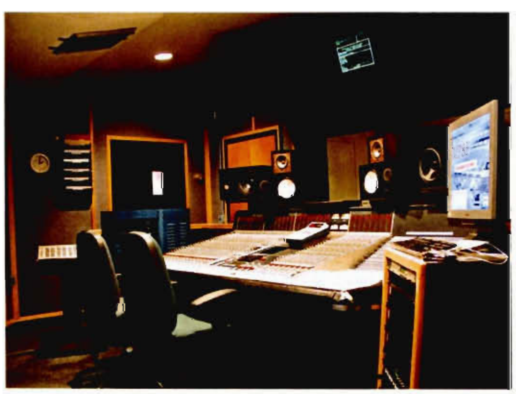


Fig. 2-18 Studio B: Control Room[4]

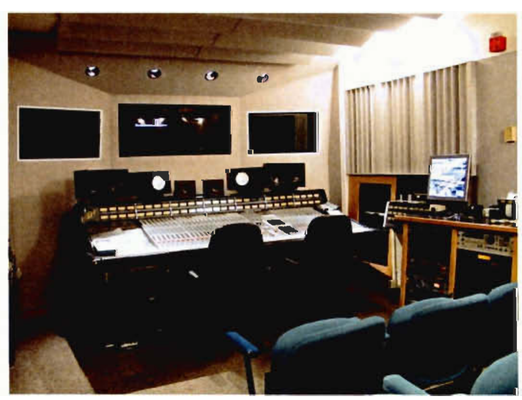


Fig. 2-19 Studio L3[5]

[4] http://classes.berklee.edu/mpe/studios/images/studio_b_1.jpg

Very different in function, Studio L3 provides a hands-on learning environment with stadium style seating that allows a large number of students the opportunity to observe at once. This studio is shown in Fig. 2-19. The focus in Studio L3 is primarily on sound manipulation and creation techniques, as opposed to live-capture. Diffusive elements are installed along the side and back wall, as well as the ceiling. Some of these can be seen in Fig. 2-20. The front of the space is covered in super-absorbent material, with angled walls which house some of the speakers and displays. A "live-end / dead end" effect is achieved, which allows for ideal acoustic characteristics within the listening environment. In addition, the space beneath the seating is tuned to trap bass frequencies, intelligently utilizing otherwise wasted space. One of the openings to this space is shown in Fig. 2-21.

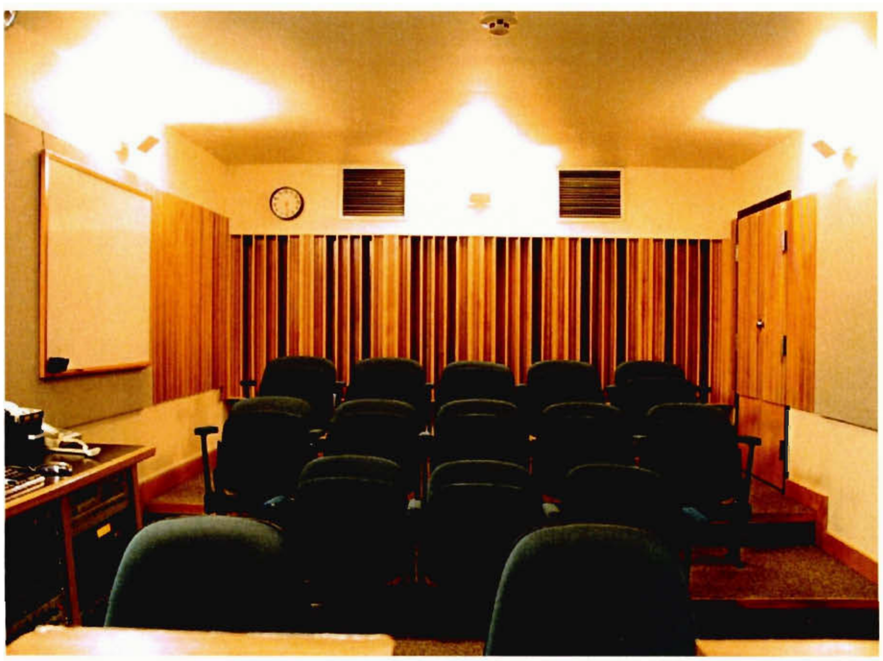


Fig. 2-20 Studio L3: Seating and Rear Diffusive Elements[6]

[5] http://classes.berklee.edu/mpe/studios/images/studio_13_1.jpg
[6] http://classes.berklee.edu/mpe/studios/images/studio_13_2.jpg

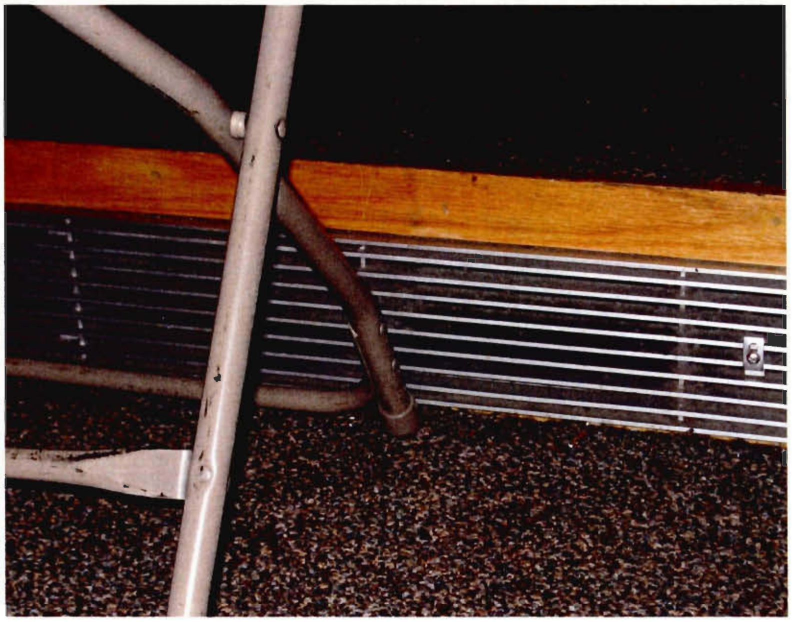


Fig. 2-21 Cavity under Seating (doubling as a bass trap)

After the tour of the facilities, the team and Professor Hoover ventured back to his office. There, Professor Hoover gave the team very valuable suggestions, which were specially tailored to the project's small budget. He noted that "many books can suggest how to treat an environment, but these treatments and inherent effects on the environment are usually based upon ideal settings and materials." In most cases, different treatment approaches to the same space can result in pleasant acoustic characteristics.

To the team's surprise and delight, Professor Hoover underlined the idea of avoiding the use of costly "traditional treatments" in favor of common objects and furniture. As he pointed around his office, he asked the team, "Do you see any foam in here? The couch you are sitting on is very good at absorbing acoustic energy, and the bookcases along this wall diffuse sound very effectively. The room doesn't need look like a studio to sound ideal." This mentality opened up new avenues for the team, where creativity and resourcefulness could lead to many more options for their project.

After viewing the facilities at Berklee College, the team considered using acoustic diffusers on the ceiling of Spaulding Recital Hall, the possible use of a thick rug, and also using the bass trap created by Andrews et al. (Due to budget and time constraints, the purchase of a rug was not permitted, and the bass trap was not used as reorganization and cleanup of Spaulding Recital Hall was needed, which exceeded the scope of this project.)

## 2.3 Acoustical Analysis

When analyzing the acoustical characteristics of an enclosed space, a great number of alternatives are available. These alternatives include both computational and mechanical techniques, employing both hardware and software tools. Though the calculations and measurements involved in the process are strictly quantitative, whether the characteristics of any environment are acceptable is ultimately a qualitative decision. However, this subjectivity can be disregarded when collecting and analyzing acoustical data. Subjective judgments are reserved for the design and testing of appropriate solutions.

### 2.3.1 Analysis of Reverberation (Decay) Characteristics

Reverberation time can be calculated from a number of standardized equations, all of which employ the room dimensions and the absorption coefficients of room surfaces (Crocker 998-999). Shown below is Eq. 2-1, the Sabine equation, which is the most popular of these reverberation time equations.

$$RT_{60} = \frac{0.049V}{Sa}$$

Eq. 2-1 Sabine Equation

where

$RT_{60}$ = reverberation (decay) time, seconds

$V$ = volume of room, cubic feet

$S$ = total surface are of room

$a$ = average absorption coefficient of room surfaces

$Sa$ = total absorption, Sabins

The Sabins for common construction materials are typically well-documented. Unfortunately, computational techniques for measuring reverberation are not as accurate in smaller rooms as they are in larger environments, such as concert and recital halls. The complex sound field in adequately large environments introduces sufficient randomization to allow for the statistical averaging techniques inherent in the derivation of reverberation equations (Everest 162-164). In smaller spaces, however, this averaging cannot be done with an appropriate level of accuracy. Computations such as the Sabine Equation, therefore, are non-ideal for describing the reverberation characteristics of Spaulding. Additionally, there is a significant lack of documentation on the construction materials used in Spaulding. This makes the use of the aforementioned computational techniques even less practical for the purposes of this project; it would prove extremely difficult to obtain accurate absorption coefficients for the surfaces in Spaulding without extensive, further testing.

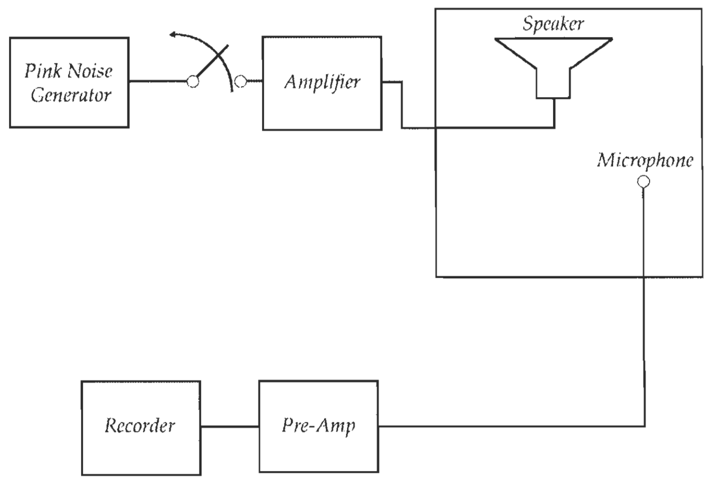



Fig. 2-22 Schematic for Reverberation Measurements[7]

A "brute force" method of measuring reverberation time across several frequency octaves is outlined in Fig. 2-22. An amplified, wideband pink noise signal is used to drive a rugged loudspeaker, which is placed facing a tri-corner of the room. In this way, all the resonant modes can be excited, because they all terminate in the corners (Everest 339-342). An omni-directional condenser microphone is then positioned in the room, at tripod height and optimally in the tri-corner opposite the speaker. (Note that fewer directional effects come into play when a smaller microphone is used.) The loudspeaker is switched on and the room is filled with sound; then the loudspeaker is switched off and the sound is allowed to decay. The signal picked up by the microphone is amplified and fed through critical octave filters before being recorded for analysis. This procedure is repeated for multiple microphone positions. Reverberation time can be determined by observing how long it takes for the peak signal to decay by 60 dB(A).

[7] Everest 139

Though this technique is straightforward and intuitive, it is tedious and prone to human error. For each octave band being analyzed, at least 5 delay readings must be recorded for each microphone position then averaged, thus providing a more accurate statistical picture of the behavior of sound in the room (Everest 141). It is obvious that the number of necessary measurements can quickly become impractical. It is also rarely possible to realize the entire 60 dB(A) decay, due to noise in the room, though this problem can be partially alleviated by dual filtering – once during recording and once during analysis/playback.

Due to the limitations inherent in the computational and manual techniques described above, there is little reason not to use software or dedicated hardware to perform reverberation analysis. This project team considered both computational and manual techniques, but did not have to perform either. At the time of this IQP, extensive reverberation analysis on Spaulding was already performed in software by Andrews et al. They used an MLS (Maximum-Length Sequence) technique as described below in the section on **software measurement and analysis**.

### 2.3.2 Analysis of Modal Resonances

Much like reverberation, there are both computational and manual techniques for measuring modal resonances within closed spaces. A derivative of the wave equation, shown in Eq. 2-2, can be used to calculate the modal resonances in critical frequency ranges (Hall 186). Note that axial modes are afforded greater importance than tangential and oblique modes when designing recording environments, though the effects of all modes must still be taken into consideration (Everest 328). Indeed, every modal frequency determined using Eq. 2-2 is only part of a bigger picture, when considered as a part of the entire complex sound field in the room. Because of this, computational techniques are only useful to a certain extent, and experimental values must be determined in order to provide an adequate representation of truly problematic resonances.

$$\text{Frequency} = \frac{c}{2}\sqrt{\frac{p^2}{L^2} + \frac{q^2}{W^2} + \frac{r^2}{H^2}}$$

Eq. 2-2 Rayleigh's Wave Equation for room resonances

where

$c$ = speed of sound; 1,130 $ft/s$

$L, W, H$ = room length, feet, and height (in feet)

$p, q, r$ = integers $(1,2,3,\ldots,n)$

vectors $< p, q, r >$ correspond to room "modes"

Possible problem modes may be determined by observing the distribution of normal modes obtained from Eq. 2-2. Zero-spacing of modes, or degeneracy, can create significant colorations. Modal frequencies in critical bands should be at least 5% of their frequency apart to avoid such undesirable effects. At the same time, modes separated by more than 20Hz from the next axial mode tend to be isolated acoustically, and more likely to cause resonant boosts. Since experimental values for problem modes were previously determined and cross-correlated with computed values by Andrews et al., this project team did not determine any modes computationally.

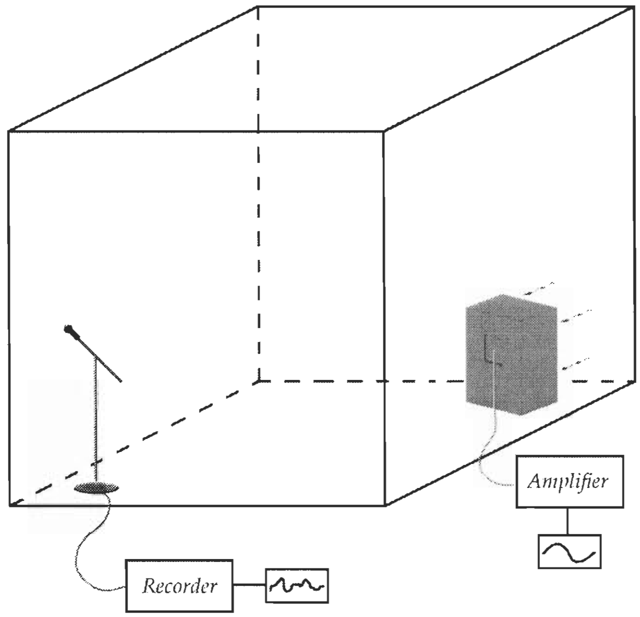



Fig. 2-23 Manual Measurement of Modes

A manual technique for the experimental verification of modes is outlined in Fig. 2-23. A swept sine-wave signal is used to drive the loudspeaker, rather than pseudo-random pink noise. The speaker is placed in a lower tri-corner of the room, exciting all resonant modes, and the omni-directional condenser microphone is placed in the opposite tri-corner. In this way, the frequency response of the room is picked up by the microphone and is recorded for later analysis (most likely in software). Sharp peaks or valleys in the magnitude spectrum indicate possible problem modes in the room. From study of this equation it is obvious that the higher the octave, the greater the number of modes that must be considered.

Mode decay can be measured using the same technique used for measuring general decay time, except a sine wave of the target modal frequency is used to excite the room rather than pink noise or a swept signal. The procedure must be repeated for each desired modal frequency, and is thus exhausting and tedious. Note that bandwidth is a significant factor when considering the interaction between modes. Mode bandwidth is inversely proportional to the reverberation (or decay) time, and any harmonics of modes have the same bandwidth of their fundamentals. The simple relationship between reverberation time and bandwidth is shown below, in Eq. 2-3.

$$\text{Bandwidth} = f_2 - f_1 = \frac{2.2}{RT_{60}}$$

Eq. 2-3 Relationship between reverberation time and modal bandwidth

Andrews et al. employed a much preferable software technique to analyze modal resonances and decays. In order to locate problem modes, they measured the frequency response of the room through the MLS technique previously mentioned. In order to determine the decay of each mode, they used a frequency generator to drive the speaker shown in Fig. 2-23 and used a computer program to then analyze the signal captured by the microphone. As with reverberation analysis, the techniques Andrews et al. used are far more efficient and accurate than the "brute force" methods described above.

### 2.3.3 Software Measurements and Analysis

Acoustical analysis in software is typically performed using one of two widely accepted techniques: Time-Delay Spectrometry (TDS) or Maximum-Length Sequence (MLS). Each technique has relative strengths and weaknesses, though MLS is generally proves more robust and versatile than TDS. Both involve performing exact measurements on an existing space. However, it is also possible to do acoustical analysis in software through modeling. Modeling is most useful when exploring the effect of possible solutions before implementing them. Andrews et al. used a combination of MLS and modeling during the analysis stages of their project, and their conclusions are still relevant to Spaulding. This is because Spaulding has not undergone any significant structural changes since the completion of their project.

TDS uses a variable-frequency excitation sweep signal coupled with a receiver to record the reflective characteristics of a room. The receiver has sweep tuning which is synchronized with the excitation signal, and a time delay is inserted between the signal and the receiver. The purpose of this delay is threefold: it compensates for the relatively slow speed of sound, allows certain reflected components of the signal to be isolated during measurement, and it allows the receiver to be detuned for noise, reverberation, and any unwanted reflections. These characteristics are a function of the fact that the receiver only records sound that reaches it at an exact time after the initial excitation, thus isolating a single reflected component of the signal and rejecting everything else (Ballou 147).

The swept tone that is used during TDS measurements is used over a period of time, injecting more energy into the room than techniques that use impulse excitations (e.g., pistol shots). This increases the signal-to-noise ratio in the measurements, and it prevents the non-linear effects associated with the high sound-pressure levels inherent in impulse excitation. TDS is particularly useful in measuring the frequency response of specific reflections or sound sources in a room, but new readings must be taken whenever a new time window or delay is desired.

MLS uses a pseudo-random binary sequence to excite a room with a test signal that resembles white noise. The binary sequence, whose derivation is beyond the scope of this project, is precisely known and generated recursively from a logical relationship

(Everest 509). Much like TDS, the excitation signal is played for a period of time, thus increasing the signal-to-noise ratio and preventing nonlinearities. For a schematic of a typical MLS measurement setup, refer to Fig. 2-24. Once a room's response to the test signal has been recorded, an algorithm known as the *Fast Hadamard Transformation* is used to determine the generalized impulse response of the room (Everest 510).

The impulse (or time) response of a room can be used to determine the effect of specific reflections and to aide in microphone or speaker placement. Additionally, all other linear input-output parameters of the complex sound field in the room can be derived from the impulse response. Due to the wealth of information that is stored in the impulse response, MLS is often considered to be superior to TDS.

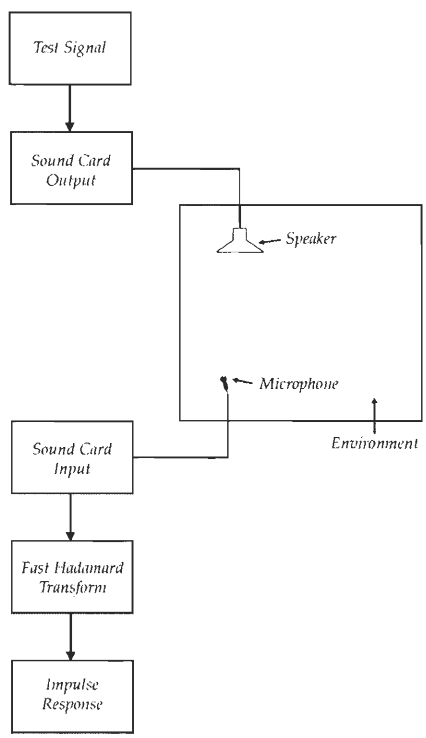



Fig. 2-24 Maximum-Length Sequence Measurement Setup[8]

[8] Everest 510

The frequency response of a room can be calculated using a Fourier transform of the time response. This is particularly useful in determining how the room "colors" the sound inside of it, and can be used in conjunction with other readings to affirm the presence of trouble modes. It is advantageous to note that graphs in 1/3-octave increments approximate the sensitivity of the human ear and average out the irregularities caused by many complex room reflections.

Resonances can most conveniently be determined by observing delayed frequency response graphs, where resonances manifest themselves as sharp peaks. A resonance can be separated from an irregularity if the general shape and position of its peak remains constant across several time-delayed graphs. This shows that frequencies at the given peak are not decaying uniformly with the rest of the frequencies in the room, thus evidencing the presence of constructive interference due to room reflections.

In addition to analyzing time and frequency response graphs, it is also useful to observe energy-time curves which can easily be generated in software using either TDS or MLS readings. Graphs of such curves are generally used to determine the relative energy levels of initial signals to their reflections and to background noise. This often makes energy-time curves instrumental in the placement of microphones and speakers, because the specific effect of reflections at different points in the room can easily be determined.

It is also important here to note that reverberation and decay rate can also be measured in software. The techniques involved are similar to those described in **Analysis of Reverberation (Decay) Characteristics**, except that the received signal is fed directly into a computer instead of a digital sound recorded or level meter, so that the data may be directly analyzed by the software. Acoustical analysis software can describe the decay rate over variable frequency bands with a single reading. This makes software analysis far more efficient than the "brute force" method mentioned previously in this report.

### 2.3.4 Evaluation of Diffusion

A diffuse sound field presents a number of distinct advantages. Though modal boosts are inevitable in any enclosed area, sufficient diffusion can cut back on unpleasant colorations due to such resonances. Diffusive treatments are very useful because they can be used to reduce any problems caused by unwanted reflections, without "deadening" the sound of a room. This is because diffusion reradiates energy rather than absorbing it. The study of diffusion is a relatively new facet of the science of acoustics, and diffusive properties are hard to measure in any discrete sense (Everest 266-269). However, a general understanding of the diffusion occurring in an enclosed space can be gathered through a collection of related measurements.

In a perfectly diffuse sound field, there are no fluctuations in the steady-state response of the enclosing system (or room). Any changes in relative sound pressure levels across the frequency spectrum indicate non-ideal diffusive conditions. Additionally, study of the frequency domain decay shape can point to lacking diffusion within a room. Decays with the same, smooth character over all frequencies denote a diffuse sound field, those that vary across frequency bands do not. Beating, especially in the lower frequencies, also points to lacking diffusion.

A perfectly diffuse sound field is also characterized by an exponential decay in the time response of the room, which is a straight line on the corresponding SPL vs. time plot. Deviations from this straight line indicate lesser levels of diffusion; deviations may be caused by resonant modes that are not properly absorbed or adjoining rooms that are not sufficiently isolated.

Lastly, the spatial uniformity of reverberation time is a useful indicator of how diffuse the sound field within a room is. This can uniformity can be analyzed by exciting the room in question with a constant signal, then rotating a highly directional microphone in various planes while recording its output. In a truly homogenous sound filed, the microphone output would also be constant. Any output deviations from the input signal reveal a non-diffuse sound field. This technique, however, is best suited to large spaces and rather ineffective in most small recording studio applications (Everest 275). Therefore, it is of little use for this project.

## 2.4 Acoustical Treatment

The complexity of acoustics, combined with its fundamental subjectivity, makes the process of selecting appropriate acoustic treatments particularly challenging. Selecting treatments for Spaulding was further complicated by the monetary, physical and aesthetic limitations outlined in the **Introduction**. This project team first considered a number of standard alternatives before selecting those that would best suit the specific needs of Spaulding.

### 2.4.1 Sound Insulation/Isolation Alternatives

There are a number of readily available techniques for improving the sound isolation of any given environment. Before considering interior solutions, this project team researched possible exterior solutions. Aside from significant structural changes to Alden Hall, the only available option was to place thick shrubbery (e.g., cypress hedge) flush with the exterior of the South wall of Spaulding. Such shrubbery has useful absorptive characteristics and, consequently, considerable potential for attenuating exterior noise. This proved impractical because Spaulding is too high above ground level; plantings would not have been tall enough to have any effect.

In addition to exterior walls, common sources of sound leakage within an enclosed space are windows and doors. Glass is one of the least insulating of all common construction materials. Though the insulation of a window can be improved by using heavy plate glass and isolating the window from its frame with rubber strips, the best and most effective solution is to use double windows such as the one shown in Fig. 2-25. Note the use of panes of differing thicknesses and the absorbent material mounted between the panes. A gain in insulation can also be achieved by mounting the panes at slightly different angles.

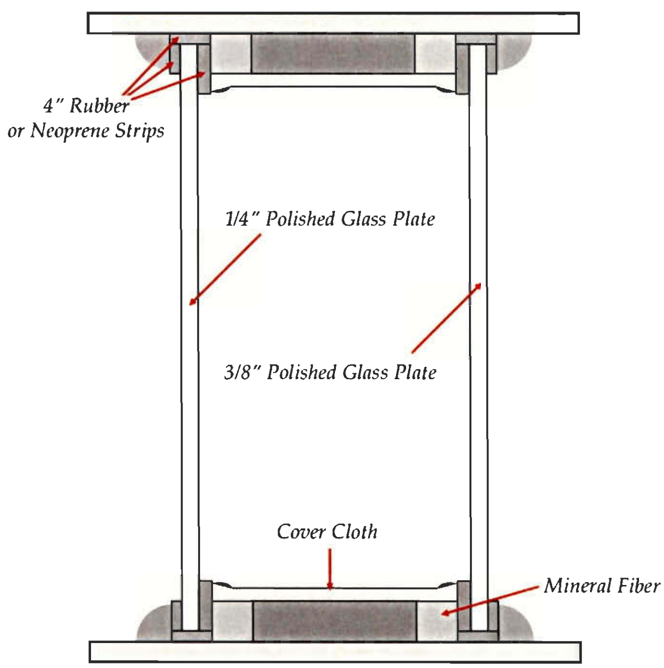



Fig. 2-25 Double-Paned Window Construction (illustrated techniques also apply to single-paned windows)[9]

[9] Everest 177

Most standard doors are also a weak point in the sound isolation characteristics of a room, though there are a number of measures that can considerably improve their performance as insulators. Filling hollow doors with sand is an effective and economical insulating technique. Heavy plywood (e.g., ¾") should be used for door panels whenever possible. Padding both sides of a door with roughly 1"-thick foam rubber, "quilted" with upholstery tacks, can also lead to slight improvements (Everest 176).

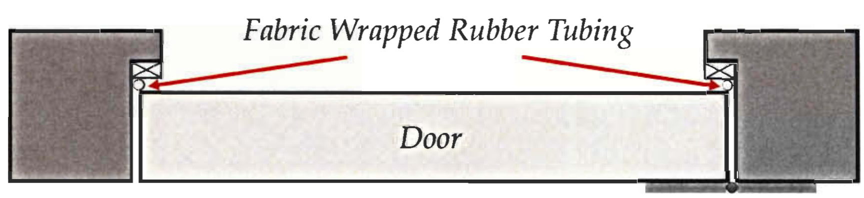



Fig. 2-26 Acoustically Sealing a Door With Compressible Rubber Tubing[10]

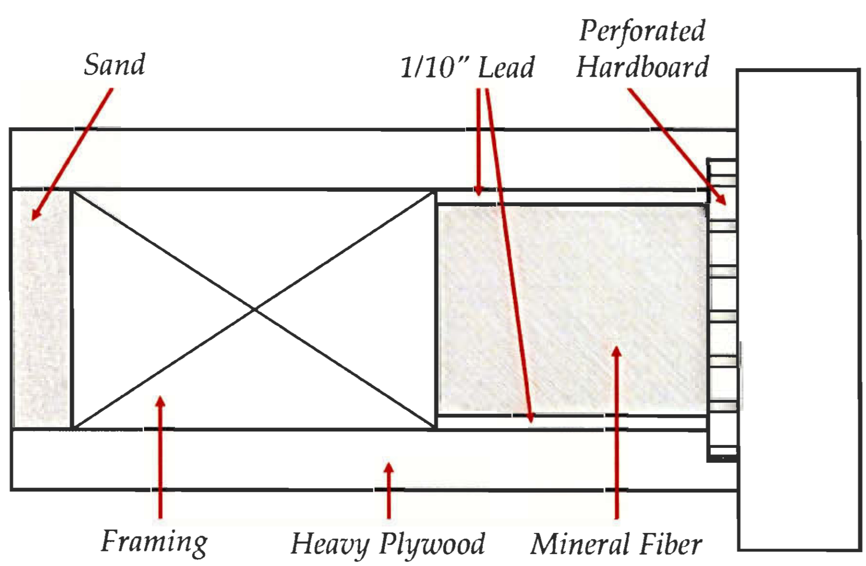



Fig. 2-27 Acoustically Treated Door Jamb[11]

[10] Everest 178
[11] Everest 177

Besides altering the construction of doors in the ways mentioned above, treating their edges presents a further gain in room isolation. There are two easy ways to do this. The first way is to line the edges with rubber tubing, roughly 1" in diameter (note that this requires a raised sill). Weather-stripping can also be used as an alternative to rubber tubing. See Fig. 2-26 for an illustration of this technique. The second way is to build an absorbent edge around the periphery of the door; this traps sound passing between the door and jamb. Fig. 2-27 illustrates this second technique.

The best way to alleviate the sound leakage associated with any ingress to a room is to create a "sound lock" at each entrance. Sound locks operate on the same principle as double windows; each lock is a small vestibule with a door of moderate sound-transmission loss installed at either end. The space between the doors significantly cuts back on the transference of sound energy, more so than a single door could.

Though placing sound barriers outside a room and treating doors and windows offer significant benefits in the realm of interior sound insulation, the most effective means of isolation all involve specific room construction and placement techniques. These include construction of double walls, use of "floating" floors and ceilings, and the placement of a room where none of its walls are flush with the exterior of the building. All of these topics are beyond the scope of this project, and impractical if not impossible to implement in Spaulding hall. Hence the focus remains to be on treatments which can be performed on an existing, non-ideal space such as Spaulding.

### 2.4.2 HVAC Alternatives

The HVAC system is usually the primary source of background noise in any room. This can be a result of air turbulence, noisy machinery, and/or vibrations in the ductwork. All of these issues must be taken into consideration during construction phases, in order to properly minimize their detrimental effects to the sound field in a room meant for recording. However, this project team had to work with the existing space they were given. The system currently installed in Alden Hall is noisy, inefficient, and consists of small ducts with fast-moving air. These constitute the worst possible conditions. Any radical changes in the HVAC infrastructure were not feasible, for both logistical and economic reasons. Less intensive, yet still effective, alternatives had to be pursued.

The easiest way to reduce noise due to air turbulence is to remove any grilles from where the ducts empty out into the room in question. This decrease in turbulence also increases the partial reflection of the noise inside the duct back towards its source. This is because a plane wave passing from a small space into a larger space is partially reflected back from whence it came. This effect is significant only when a straight section of ductwork 3-5 diameters in length precedes the grill, but – under the specified conditions – can help with reducing the amount of machinery noise transmitted into the room. Flaring out the ducts upstream from the grills will also slow the velocity of the air entering the room, thus further reducing any noise caused by turbulence.

Fig. 2-28 illustrates some minimal ductwork modifications that can reduce turbulence even further, by minimizing and compensating for any irregularities in the ducts. These modifications include installing deflectors at sharp corners, rounding off any sharp corners, and installing airfoils to reduce airspeed. All are quite inexpensive and easy to install.

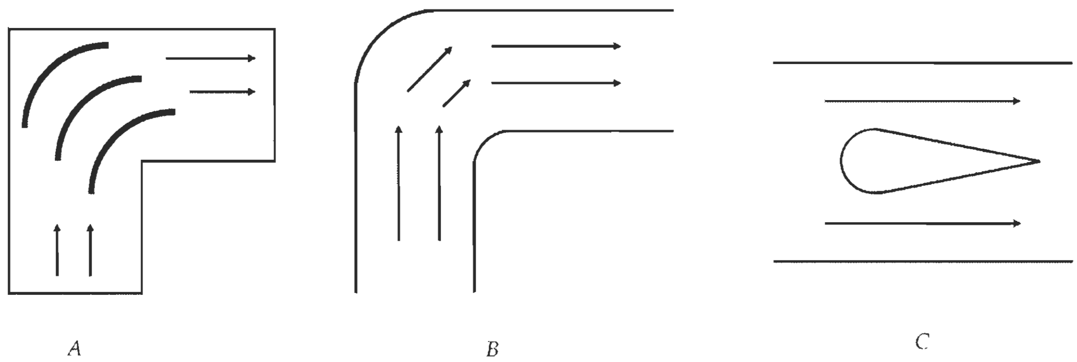



Fig. 2-28 Turbulence-Reducing Duct Treatments[12]
A) Deflectors
B) Radius Bend
C) Airfoil

Simply lining ducts with broadband absorptive material can also decrease noise levels (this particular technique is more effective with rectangular ducts than circular ones). De-coupling the ducts from the HVAC machinery (e.g., via rubber sleeves) further cuts down on machinery noise transmitted though the ducts, and also reduces noise caused by low-frequency vibrations along the ductwork (Ballou 87-90).

One of the simplest and most effective treatments for HVAC systems, albeit slightly more structurally intensive than the aforementioned techniques, is the plenum silencer. A plenum silencer consists of a large chamber placed in the duct path and lined with low-density (e.g., 3 lb/ft$^3$) glass fiber. An example of such a treatment is shown in Fig. 2-29. Plenum silencers contribute significant attenuation of noise across most of the audible frequency spectrum, and are particularly useful when placed directly after fans. They are one of the most economical treatments available for HVAC systems.

[12] Everest 392

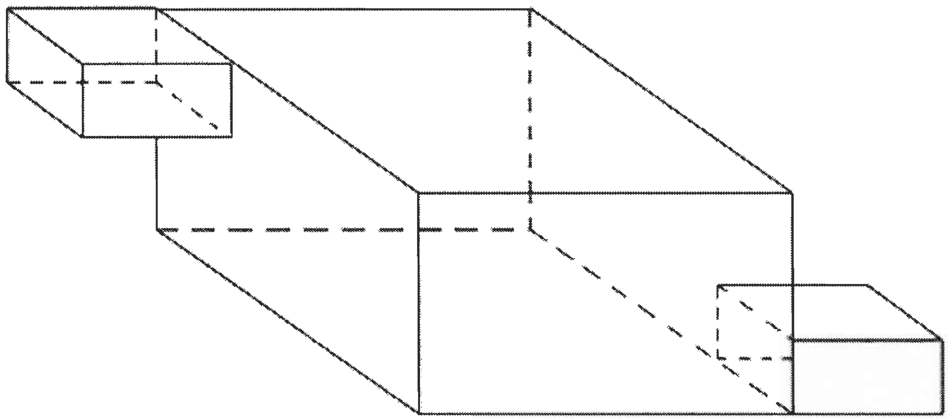


Fig. 2-29 Typical Plenum Silencer

### 2.4.3 Lighting Alternatives

Appropriate lighting is an easily overlooked aspect of the acoustics in a room, one that must be taken into account like any other. Fluorescent lights should be stringently avoided because of the substantial noise they create, and any currently installed should be replaced with incandescent bulbs. Dimmers are often used in performance spaces for aesthetic reasons, and to prevent overloading circuits that drive powerful, halogen lights. Dimmers produce unacceptable electrical interference that creates noise in audio circuits, and they also typically cause lights to "buzz" or "hum." This problem can be solved in environments that serve as both recording and performance spaces, by installing separate studio lighting that runs on a different circuit. Alternately, use of the dimmer can be discontinued altogether.

### 2.4.4 Non-Adjustable Acoustics Alternatives

A common acoustic treatment is the use of draperies to "deaden" the sound in a room by imparting significant mid- and high-frequency absorption to the space. The amount of absorption can be increased by increasing the number and depth of the folds in the curtain. Additionally, hanging the draperies at a distance from the walls can lead to useful low-frequency absorption. This is because the space between the walls and the drapes acts as a resonating chamber, with maximum absorption at ¼-wavelength spacing (Everest 195).

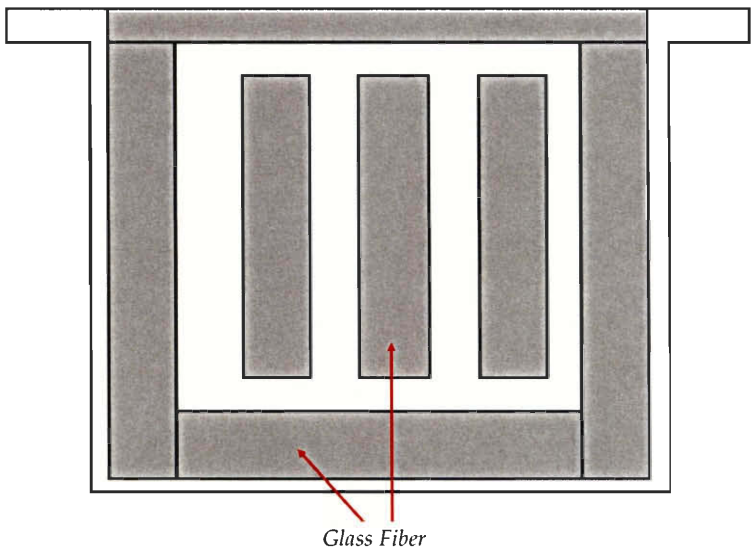



Fig. 2-30 Bass Trap[13]

The construction of another common acoustic treatment, the bass trap, is illustrated in Fig. 2-30. Bass traps are used to reduce standing waves in the lowest two octaves of the audible frequency spectrum. They consist of a tuned cavity of ¼ the target frequency's wavelength and a mouth opening on top that is typically semi-cylindrical in shape. Semi-rigid glass fiber board is placed across the opening and the cavity inside the trap is lined with absorbent material. Though bass traps are quite effective, they require great depths for low-frequency absorption. This results in very large traps (e.g., 7 ft deep

[13] Everest 204

for 40 Hz), and severely limits placement options. In most studios, bass traps are placed in corners, between walls, or above ceilings (Everest 203-205).

Diaphragmatic absorbers can be "tuned" to target specific frequencies, and are thus very useful for treating specific acoustic problems within a space. They use a flexible diaphragm which is designed to vibrate at a particular frequency, and there are two basic types: panel and polycylindrical (Everest 208-209). The designs of two panel absorbers are displayed in Figs. 2-31 and 2-32. Design of polycylindrical absorbers is discussed in the text below.

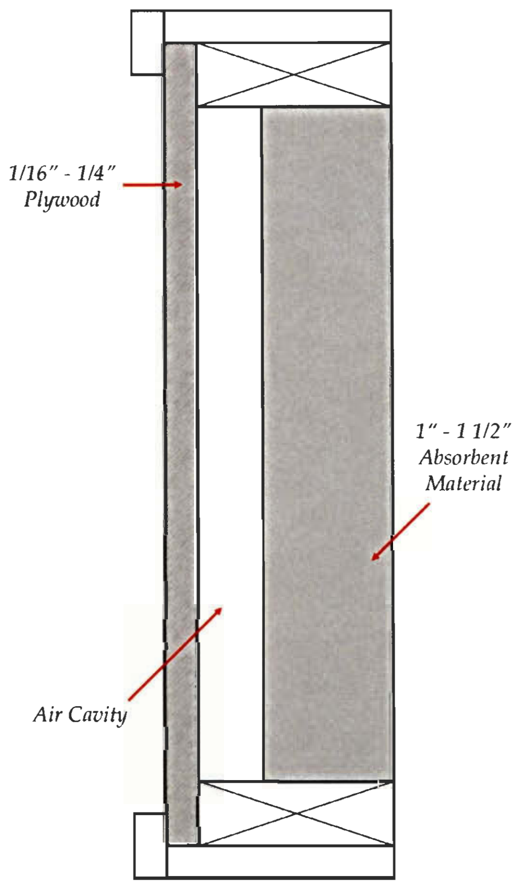



Fig. 2-31 Wall-Mounted Panel Absorber[14]

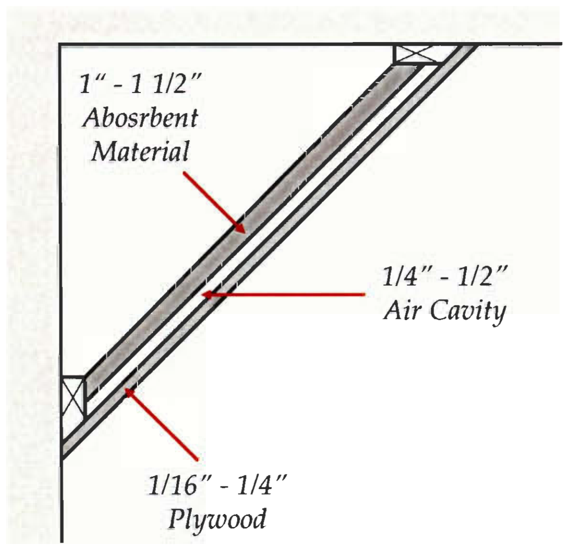



Fig. 2-32 Corner-Mounted Panel Absorber[15]

[14] Everest 209
[15] Everest 210

As shown above, panel absorbers are typically constructed from a ¼"to $^{1}/_{16}$" plywood panel fastened to a wooden framework that is placed a specified distance from the wall. In this case, it is the distance between the panel and the wall that determines the frequency at which peak absorption occurs. The relationship between distance and frequency is shown in Eq. 2-4.

$$f_0 = \frac{170}{\sqrt{m \cdot d}}$$

Eq. 2-4 Peak Panel Absorber Frequency

where

$f_0$ = frequency of resonance, Hz

$m$ = surface density of the panel, lb/ft$^2$

$d$ = airspace depth, inches

Absorptive material (e.g., 1"-1½" glass or mineral fiber) can optionally be attached to the wall behind the plywood facing decreases the Q of the absorber, as long as care is taken to maintain ¼" to ½" spacing between the facing and absorbent. Panels can also be alternately mounted either horizontally or vertically in corners, where the varied depth behind the absorber results in a broader peak absorbance. Since modes terminate in the corners of a room, properly tuned corner-mounted absorbers can be quite effective in minimizing trouble modes. If undue reflection of mid- to upper-frequencies from the facing of the absorber is an issue, properly spaced glass fiber board on the facing can reduce such problems (Everest 209).

Polycylindrical absorbers – or polys – act much like their flat-paneled counterparts, but they also present some unique advantages. They are typically constructed from a plywood or hardboard (e.g., Masonite) skin wrapped around semicylindrical bulkheads that are flush to the wall. Optimally, the vertical spacings of these bulkheads are random, thus allowing for varied low-frequency resonance within the polys; this generates broadband, low-frequency absorption. Low frequency absorption can further be increased by filling the cavities behind the polys with absorptive material. The main advantage to polycylindrical absorbers is the fact that they simultaneously facilitate a diffuse sound field, along with liveliness and brilliance. These factors tend to oppose each other in rooms with flat surfaces. This, combined with their absorptive characteristics, make them a common element in many modern recording and performance environments.

An often overlooked acoustical treatment is common building insulation, which can be used as a membrane-type absorber (Ballou 110-111). R-19 (6-inch) or R11 (3.5-inch) insulation is best for general absorptive purposes, and is readily available at most hardware stores (Everest 213). Such insulation typically comes with a Kraft paper backing, and positioning this paper either away from or towards the surface it is mounted on presents disparate and useful results. When the paper faces away from the wall, higher frequencies are shielded, creating a mid-range absorption peak. Otherwise, absorption is nearly perfect above 500Hz. Also, it is generally advantageous to cover the insulation with a protective (and aesthetically pleasing) layer of fabric.

A very effective and well-documented acoustic treatment is the Helmholtz resonator, which is designed to absorb a specific frequency through controlled resonance. There are several variations built from the basic concept behind its operation; these include perforated panel absorbers, slat absorbers, and specially designed Low-Q resonators. Each variation is best suited for a slightly different application, and each has certain advantages and disadvantages.

Perforated panel absorbers are constructed much like the diaphragmatic absorber shown in Fig. 2-31. However, holes are drilled into the plywood facing and the cavity behind it is partitioned with egg-crate-like dividers made of wood or corrugated paper. The resonant (or absorbent) frequency is determined by the hole diameter, hole spacing, cavity depth, and panel thickness. This relationship is shown in Eq. 2-5. It is also important to note that, in much the same fashion as with diaphragmatic absorbers, the introduction of acoustic resistance (e.g., glass fiber boards) in the cavity broadens the absorption curve (Everest 218-224).

$$f_0 = 200\sqrt{\frac{p}{d \cdot t}}$$

Eq. 2-5 Perforated Panel Peak Absorbent Frequency

where

$f_0$ = frequency of resonance, Hz

$p$ = perforation area percentage

$t$ = effective hole length

= panel thickness + 0.8 * hole diameter

$d$ = depth of cavity, inches

Slat absorbers behave much like their perforated panel counterparts and are constructed in a similar manner, except their facing consists of a series of slats rather than perforated plywood. Their resonant (or absorbent) frequency is determined by cavity depth, slat thickness, slat area, and slot area. This relationship is shown below.

$$f_0 = 216\sqrt{\frac{p}{d \cdot D}}$$

Eq. 3-6 Slat Absorber Peak Absorbent Frequency

where

$f_0$ = frequency of resonance, Hz

$p$ = slat area percentage

$D$ = cavity depth, inches

$d$ = thickness of slats, inches

Helmholtz resonators should ideally be placed at high-pressure points of the frequency they are targeting. If the resonator is being used to tame a problem mode, it would probably be most effective if placed in a corner. However, it is relatively easy to manually locate such high-pressure points by exciting the room with a sine wave of the target frequency and then exploring with a sound level meter.

### 2.4.5 Adjustable Acoustics Alternatives

An important design consideration for this project team was the fact that Spaulding Recital Hall had to remain feasible as a performance space after its acoustic treatment. This had a number of ramifications, and placed limitations on any structural changes or additions. By considering treatment alternatives that could be adjusted to fit the varying needs of a space, this team was able to present a number of solutions that could fit both the recording and performance-based acoustical requirements of Spaulding.

Draperies were previously mentioned in section 2.4.4 as a viable acoustical treatment, and hanging them from a track offers the added benefit of adjustability. Placement of acoustically treated surfaces behind the drapes allows for variable adjustment of the ambience of the room. Surfaces with little absorption (e.g., hard plaster) placed behind the drapes would offer a different, live response when the drapes are pulled away. Alternatively, resonant structures with maximum absorption in the lower frequencies would complement the effect of the drapes. In such a case, adjusting the drapes would allow for the complimentary varying of mid- to high-frequency absorption. One such set-up is shown in Fig. 2-33. There are a great number of different combinations possible between the drapes and the treatments placed behind them, allowing for solutions that can be specifically tailored to the space being considered (Everest 473-474). Also, selecting which draperies are pulled can potentially provide useful partitioning.

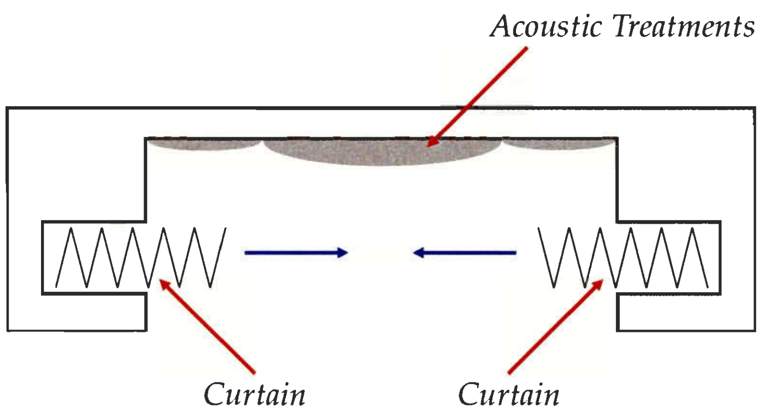



Fig. 2-33 Adjustable Draperies[16]

Acoustical wall panels can also be made adjustable, in such a manner as is illustrated in Fig. 2-34. The treatment displayed consists of a perforated hardboard facing, mineral fiber layer, and air cavity. Such panels can be hung directly on the wall, and contribute to general, broadband absorption (the cavity behind the facing acts as a

[16] Everest 474

low-frequency resonator). Removing the panels from the wall leads to more “live” acoustics.

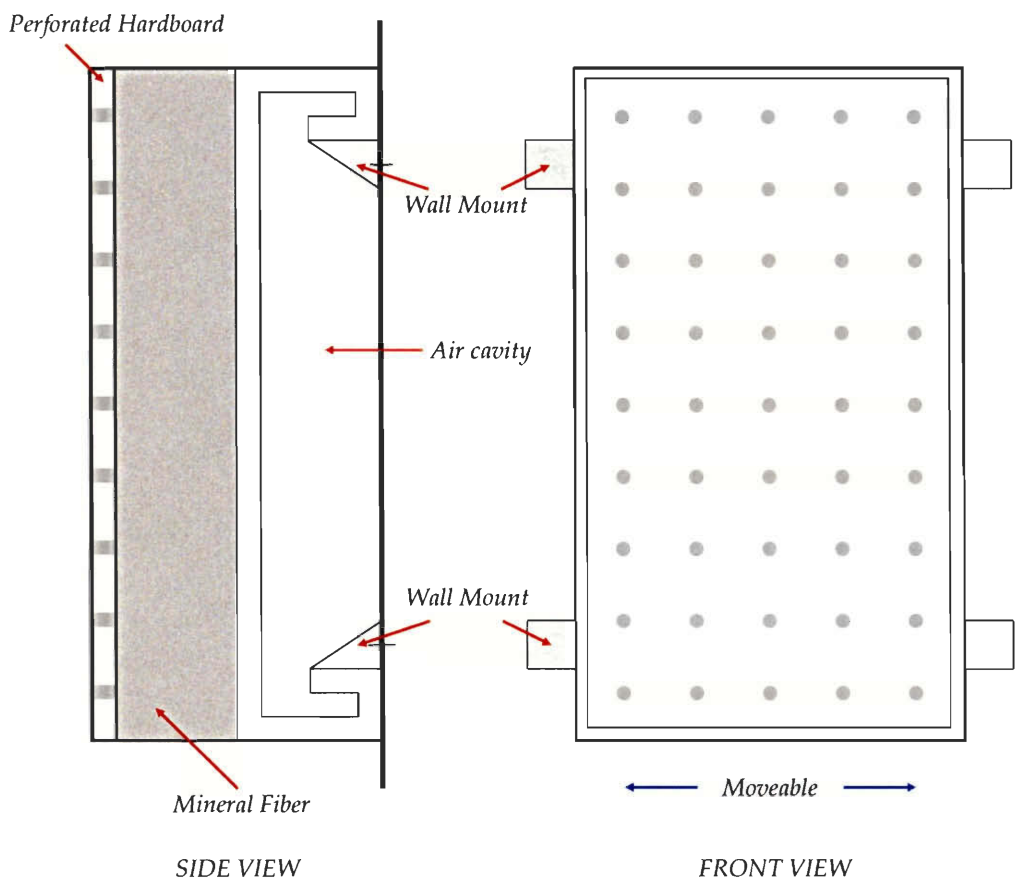



Fig. 2-34 Adjustable, Absorptive Wall Panel[17]

Free-standing acoustical flats are perhaps the most common of all adjustable acoustical treatments. The example shown in Fig. 2-35 is constructed from a 1” x 4” lumber frame and a plywood backing, and is filled with low-density glass fiber board. Typically, acoustical flats are faced with fabric for both protective and aesthetic reasons.

[17] Everest 477

Though not optimal for treating entire rooms, strategic arrangement of flats can efficiently provide local control of acoustics.

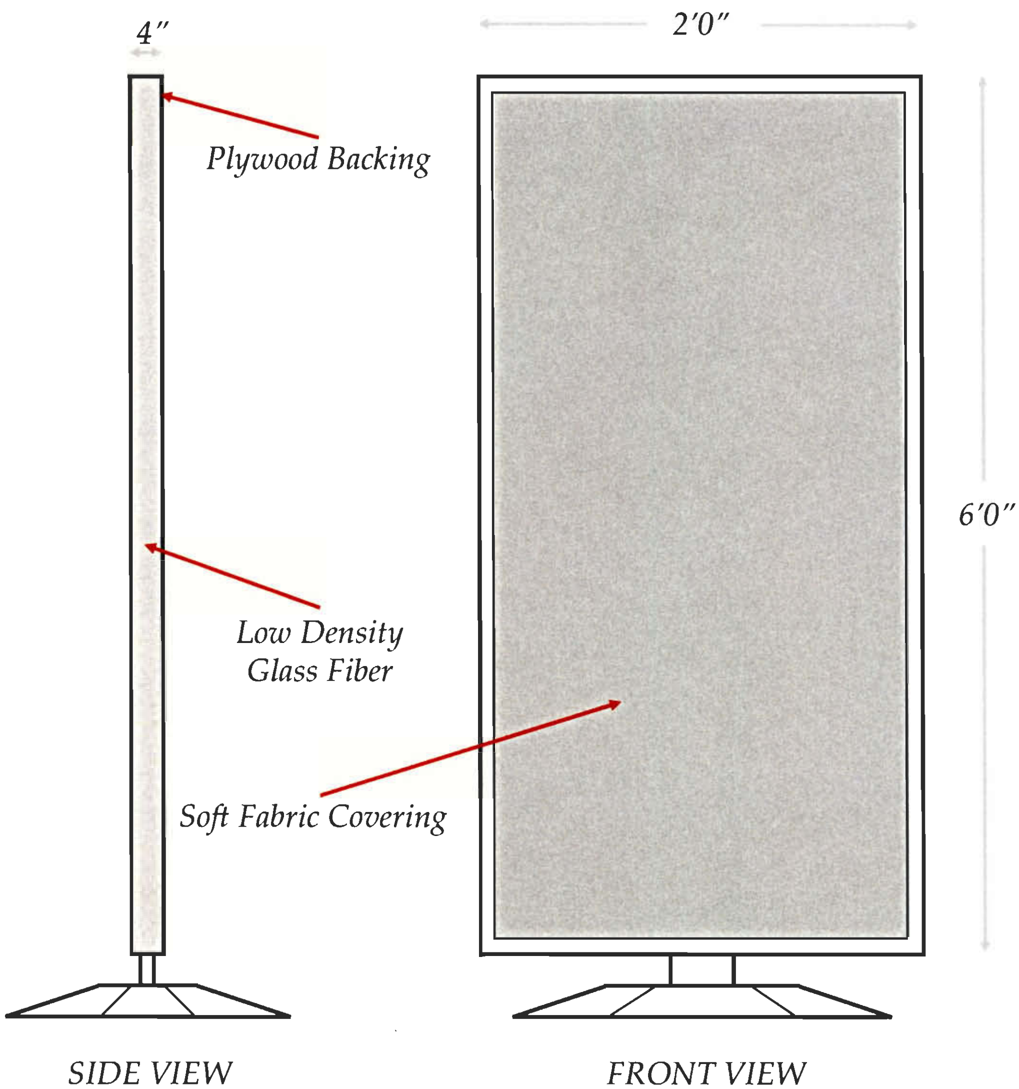



Fig. 2-35 Free-Standing Acoustic Flat

Hinged panels are a useful variation on the wall-mounted panels described earlier in this section. Such panels are made so that one side is hard and reflective (e.g., plaster, plasterboard, plywood), and one side is soft and absorptive. They, too, are mounted directly on the wall and allow for selectively more live or more dead acoustics. Two examples are shown in Fig. 3-36. Hinged panels are both effective and inexpensive to implement.

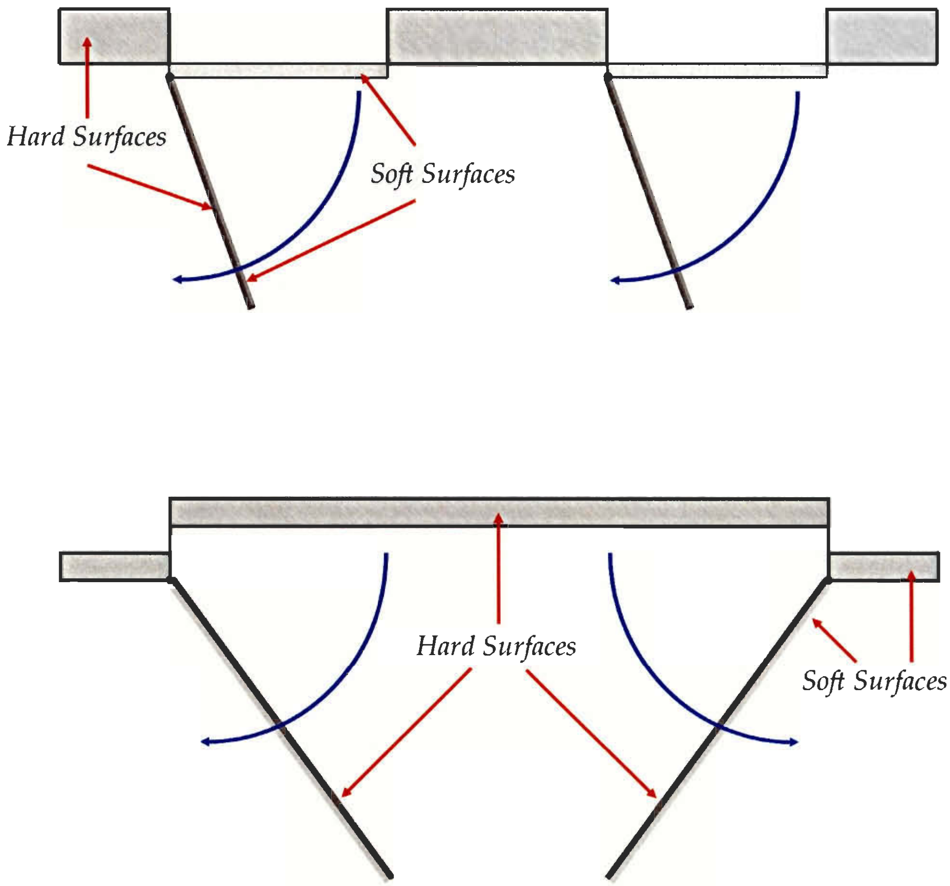



Fig. 2-36 Hinged Wall Panels[18]

The most flexible of all adjustable acoustic treatments are louvered panels, such as the ones displayed in Fig. 3-37. These treatments consist of adjustable panels placed in front of low-density glass fiber board. The fiber can be of varying thicknesses and the panels can be made of any material – either hard (e.g., hardboard, glass) or soft (e.g., wood), and either solid or perforated. Additionally, the angle of the louvers can be

[18] Everest 479

adjusted, allowing for varying levels of absorption or reflection. Because of all these variable parameters, a useful solution for almost any space can be designed using louvered panels. Placing louvers at varying angles can also contribute to diffusion.

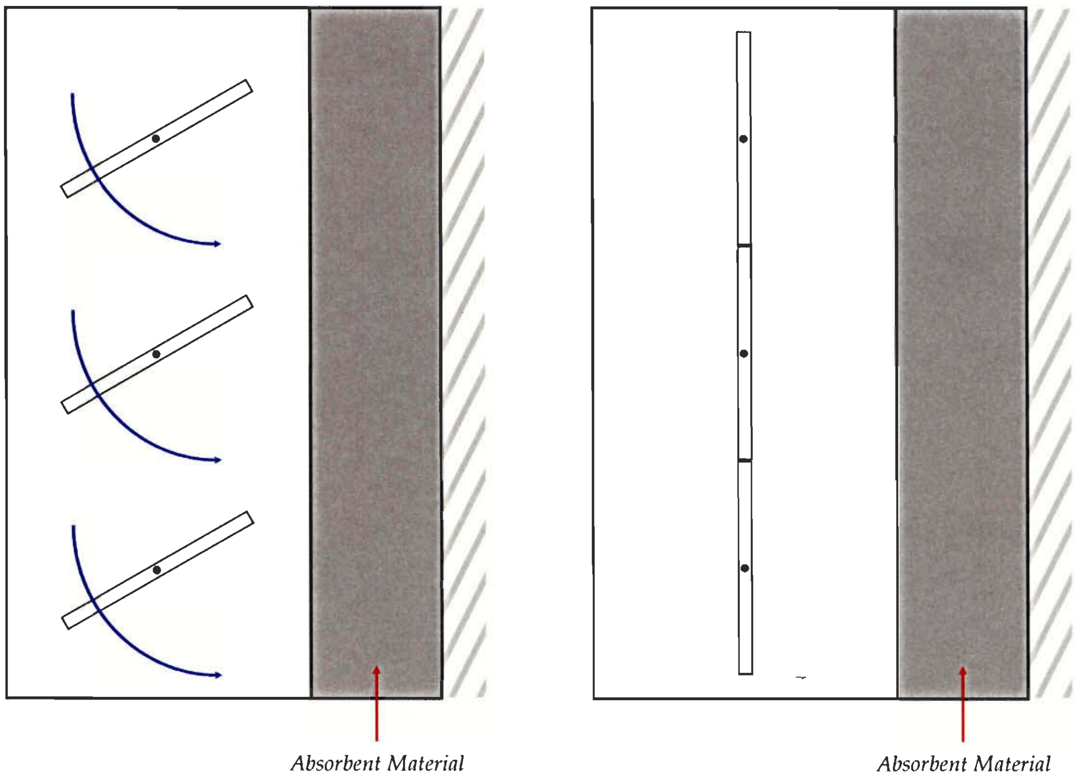



Fig. 2-37 Louvered Panels[19]

A final adjustable treatment worth mentioning is the rotating element. Such elements consist of rotating panels, typically with absorptive material on one side and reflective material on the other. More than two sides can create added flexibility and complexity. For example, a three-sided element could have diffusive, absorptive, and reflective characteristics, all contained in a single treatment. Rotating elements are typically placed next to each other along a wall, and care should be taken that the panels fit tightly, in order to avoid coupling the recording or performance environment with the

[19] Everest 480

space behind the panels. Though such elements are extremely flexible, they are also space-inefficient. This is because a significant volume is required per treatment, in order to allow for rotation.

### 2.4.6 Diffusive Treatments

Diffusion is an important aspect of the acoustics in any enclosed space. In general, any surface irregularities contribute to diffusion, and would be extremely beneficial in a room like Spaulding. Distribution of absorption modules of varying types can also contribute to a diffuse sound field. As mentioned above, polycylindrical treatments provide good special diffusion of surface reflections. However, they also absorb higher frequencies and can display comb-filtering artifacts (Everest 287).

$$\text{Well Depth Proportionality Factor } = n^2 (\text{mod } p)$$

Eq. 3-7 Quadratic Residue Diffuser Well Depth

where

$n = 0, 1, 2, 3, \ldots, \text{n}$
$p = \text{a prime number}$

The optimal diffusive treatment is the modern quadratic residue diffuser. Such treatments provide optimal special diffusion, uniform frequency distribution, and constant energy with respect to the scattering angle. They are composed of a series of wells whose depth is dependent on the series described in Eq. 3-7. The largest well depth is tailored to be ¼ the longest wavelength to be diffused, while the well width is equal to ½ the shortest wavelength. Quadratic diffusers can be designed to provide either hemi-disc or hemi-sphere diffusion of incoming sound waves. RPG Diffusors, Inc., is the leading manufacturer of these treatments.

## 2.5 Sound System Design

The sound system is the means by which audio originating in the recording environment is captured, transmitted, processed and recorded. As with the design of acoustical treatments, much consideration must go into the design of this system. The path that audio signals travel, from the point of capture to the point of recording and/or playback, is known as the signal chain (Dailey). Each part of the signal chain must be considered both individually, and with respect to its place within the entire chain. This is necessary to ensure efficiency and compatibility. If one part of the signal chain does not operate properly, the entire audio transmission path is rendered useless.

A top-level system block diagram of the sound system is shown in Fig. 4-8. This diagram outlines the finalized hardware setup in the studio. This system is robust and flexible, presenting extensive recording and mixing capabilities.

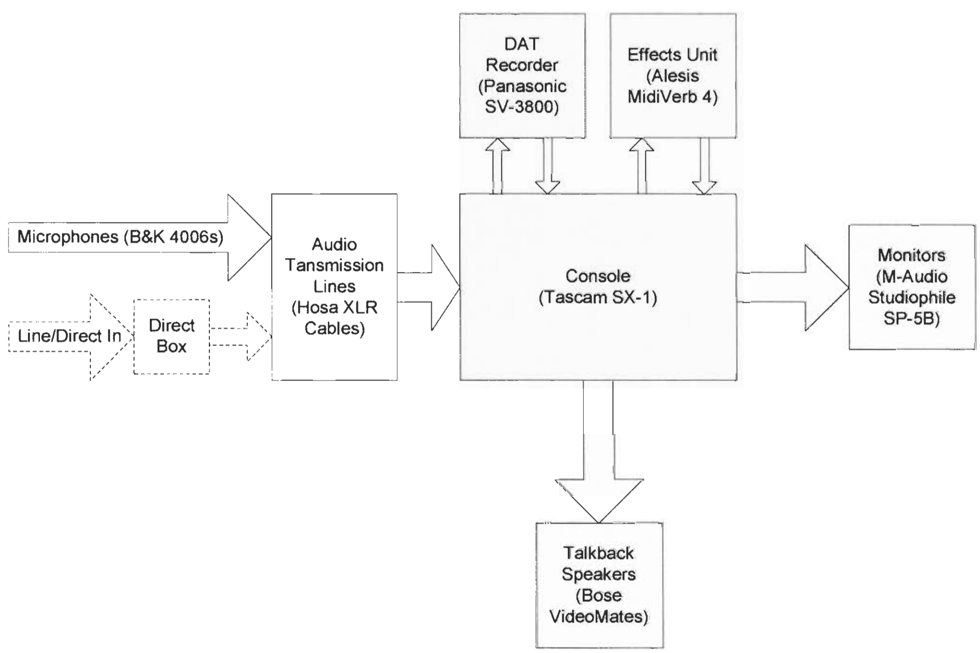



Fig. 4-8 Sound System Block Diagram

### 2.5.1 Microphones

Microphones are the first point in the signal chain. They capture acoustic signals and translate them into electrical signals, which can then be transmitted, altered, monitored and recorded. Some use magnets to perform the acoustic-electric conversion, others use charged metal plates. There are also a variety of microphone "pickup patterns" that dictate how microphone placement effects which acoustic signals are picked up by the microphone, and to what degree.

The focus of this project, however, is not on microphone selection or placement; these topics are covered by Andrews et al. in their IQP. If the reader desires to learn more about this topic, they should refer to that project report. For the purposes of this report, it is only necessary that the reader understand the role of microphones as a means to convert sound waves into electrical signals.

Since the focus of this project is the creation of a live-capture recording facility, microphone considerations will be kept to a stereo pair, positioned some distance in front of the ensemble to be recorded. Dan Foley donated two 4006 Model Bruel & Kjaer microphones to the WPI Music Division for use in this project, which are an industry standard for stereo, live-capture studio recordings. They have a very even frequency response from 20 Hz to 20 kHz, low self-noise, and a wide dynamic range. A picture of one of these microphones is shown in Fig. 2-38. Its frequency response is shown in Fig. 2-39.

Fig. 2-38 Bruel & Kjaer 4006 Omnidirectional Condenser Microphones[20]

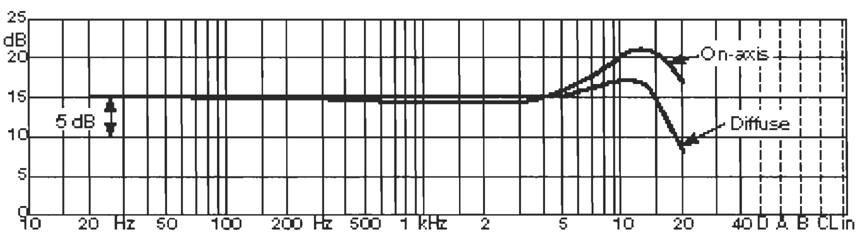



Fig. 2-39 B & K 4006 Frequency Response[21]

## 2.5.2 Audio Transmission

Audio transmission systems are the means by which audio signals are routed, processed, and assigned to the desired monitor and recording output channels (Eargle 112). The first element in any audio transmission system is the collection of cables that transmit electrical audio signals from their sources to the recording console. This console is where most of the signal routing then takes place. In their most basic form, such consoles consist of a set of volume controls or "faders," stereo placement or "panning" controls, some form of sound level metering, and switches for routing signals to various

[20] http://www.dpamicrophones.com/Images/DM00728.jpg
[21] http://www.dpamicrophones.com/Images/DM00350.GIF

places – such as additional processors, recorders, and monitoring systems. A diagram of a typical system is shown is shown in Fig. 2-40.

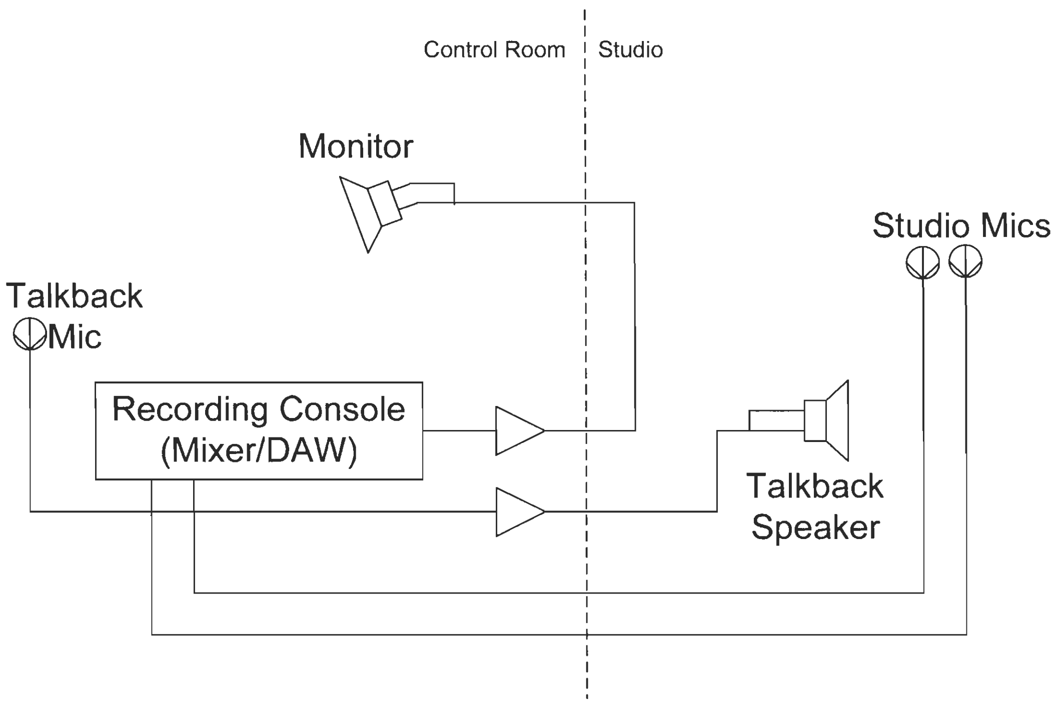



Fig. 2-40 Audio Transmission System[22]

The team used standard XLR and TS audio cables to transmit signals between the Recording Environment (where the microphones and talkback speakers are located), and the Control Room (where the console and monitors are located). Images of each of these cable types are shown in Figs. 2-41 and 2-42, respectively. XLR cables are balanced, and less susceptible to noise. This makes them better suited for carrying signals with low levels, such as those coming from microphones. TS cables are cheaper and more straightforward than XLR cables, but are unbalanced and thus more susceptible to noise. The team used XLR cables to transmit signals from the microphones to the console, and TS cables to transmit signals from the console to the talkback speakers.

[22] Eargle 138

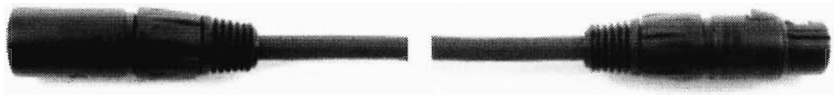


Fig. 2-41 XLR Microphone Cable[23]

Fig. 2-42 TS Audio Cable[24]

In the case of this project, the console consists of a Tascam SX-1 LE Plus DAW (Digital Audio Workstation). The SX-1 has extensive recording and mixing capabilities, including 16 microphone inputs, 16 motorized and automatable faders, and a 16-track hard disk recorder with 24 bit resolution. It also has a built-in talkback signal routing system. For visual feedback, it has a built-in dot-matrix display, and a VGA monitor output. In addition to the controls in its mixing section, there are keyboard and mouse inputs for use with the external VGA screen. An artist's rendering of the SX-1 is shown in Fig. 2-43.

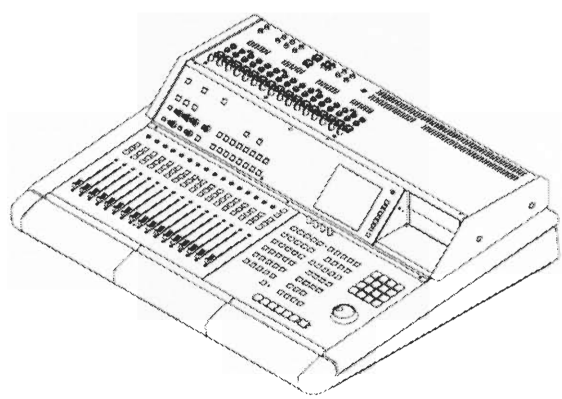


Fig. 2-43 Tascam SX-1 LE Plus[25]

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[23] http://www.hosatech.com/hosa/images/image_cmk_microphone.gif
[24] http://www.hosatech.com/hosa/images/CPP-100.gif
[25] TASCAM SX-1 Digital Production Environment Quick Start Guide

In addition to all of the above-mentioned features, the SX-1 has reverberation, compression and equalization effects included as a part of its mixing system. These features, when combined with the 16-track mixer, allow for monitoring of processed signals without committing any changes to disk. Also, the multiple tracks allow for adding tracks to already existing recordings, without changing the pre-existing mix. These facts make the SX-1 a powerful multi-tracking console. For the purposes of this project, though 16 microphone lines will be run from the Recording Environment to the Control Room and the talkback capabilities of the SX-1 will be used, no further exploitation of these multi-tracking facilities will be performed. That is left as an exercise for future IQPs. Because this team is solely concerned with live-capture, only stereo recording capabilities are needed.

Two Bose VideoMate speakers, donated by Dan Foley, serve as talkback speakers in Spaulding. They are hooked up to the talkback output of the console, and allow the recording technician in the Control Room to talk to the musicians in the Recording Environment. One of these speakers is shown in Fig. 2-44. As mentioned before, the talkback feature is conveniently built into the Tascam SX-1 DAW, and can be operated with the touch of a button. Fitted brackets, which can also be seen in Fig. 2-44, were purchased by the team directly from the Bose Corporation and used to mount the speakers. The brackets are pleasing to the eye and conveniently allow for angular adjustment.

The microphone cables, DAW, and talkback speakers constitute the audio transmission system. Monitoring and Monitor speakers will be covered in the following section.

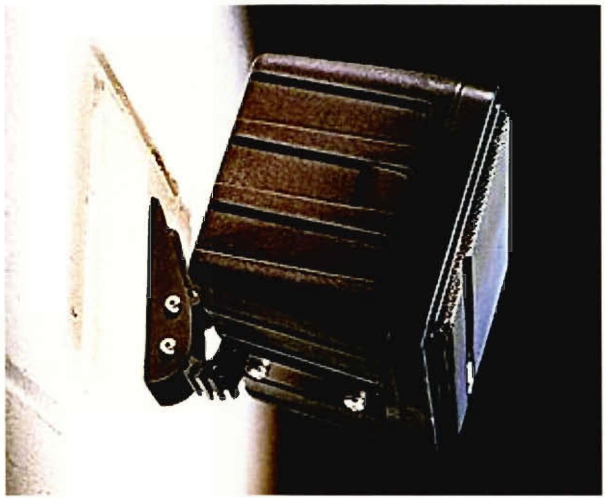

Fig. 2-44 VideoMate Talkback Speaker[26]

### 2.5.3 Monitoring and Monitor Speakers

Monitoring is listening to performances captured by microphones in real-time, or listening to prerecorded performances being played back. Both of these have their applications in any studio environment. At the console, the recording engineer should be able to monitor performances while they are being recorded, and also monitor the playback of those recordings while mixing. Accuracy is the key element of any monitoring system, so that what the engineer is hearing is as close to reality as possible.

Near-field monitoring has become a standard in most professional recording studios of today. Near-field simply means that the monitor speakers are placed very close to the listening position (usually within 1 meter). Additionally, these speakers should form an equilateral triangle with each other and the listening position. This setup minimizes the effect of room acoustics on what the listener hears, and provides him or her with a very accurate stereo image. Near-field monitoring also allows better perception of lower frequencies from much smaller and less expensive speakers, because

[26] http://www.bose.co.uk/images_global/home_audio/pal_sm_1.jpg

low frequencies are the first to drop off as distance from the speaker is increased. Placing the listener closer to a speaker, then, naturally decreases this low-frequency drop-off.

Because of the obvious benefits, this project team decided to use near-field monitors in the Control Room. Dan Foley donated two M-Audio Studiophile SP-5B speakers for this purpose. These speakers are powered, which removes the need for a separate amplifier, and have a relatively flat frequency response from 33 Hz to 20 kHz. An artist's rendering of the SP-5B is shown in Fig. 2-45.

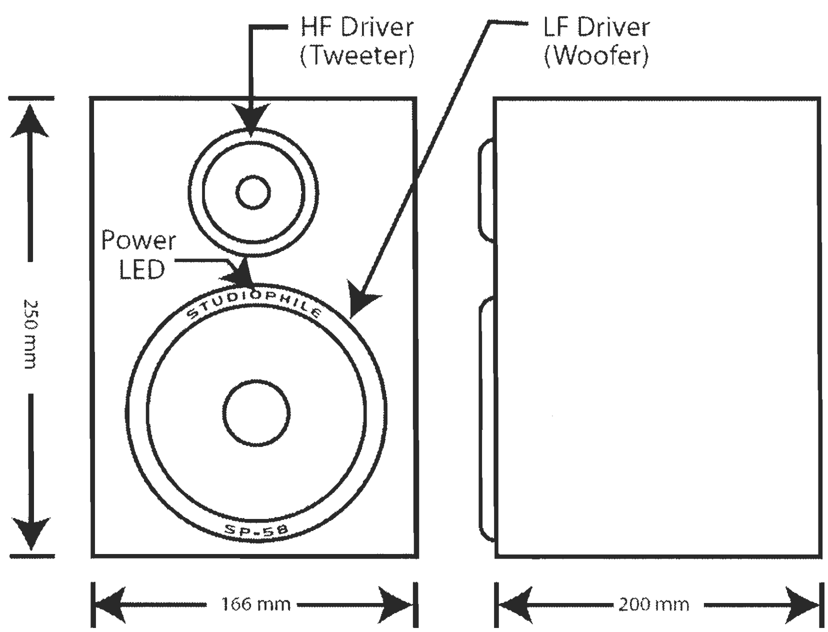


Fig. 2-45 M-Audio Studiophile SP-5B[27]

These speakers were mounted on Samson MS100 adjustable studio monitor stands, which the team purchased from the retailer Sweetwater. These stands are shown in Fig. 2-46. They allowed for optimal placement of the monitors with respect to the listening position, permitting the team to form the appropriate equilateral triangle and to roughly line up the low-frequency drivers with the listener's ears.

[27] Studiophile SP-5B User's Manual

Fig. 2-46 Samson MS100 Monitor Stands[28]

## 2.5.4 Signal Processing and Recording

Most of the signal processing and recording will be done on the Tascam SX-1 LE Plus DAW. Its capabilities in these realms have already been outlined. However, Dan Foley donated an Alesis MidiVerb 4 effects processor, which will allow for additional signal processing external to the SX-1. (The MidiVerb 4 has 32 different effects algorithms, including reverb, chorus, flange, delay, and pitch effects.) Also, Prof. Bianchi donated a DAT recorder for which he no longer had any use, which will allow for additional digital recording external to the SX-1. These two pieces of equipment are shown in Figs. 2-47 and 2-48, respectively.

[28] http://www.sweetwater.com/images/items/MS100-large.jpg


Fig. 2-47 Alesis MidiVerb 4

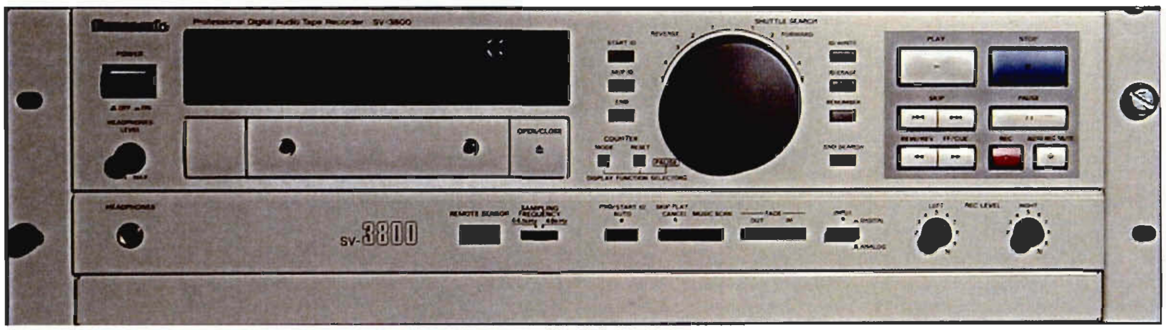


Fig. 2-48 Panasonic SV-3800 DAT Recorder

The MidiVerb effects processor will prove quite useful if the studio is ever expanded for multi-tracking purposes, and the DAT will be useful for archiving stereo mixes of material recorded on the SX-1.

# 3. Methodology

After structurally, functionally, acoustically, and aesthetically analyzing the Recording Environment and Control Room, the team was ready to design and construct the recording facility. Extensive research on acoustics, audio, and recording technology had been undertaken, and this knowledge base set a firm intellectual foundation upon which to make decisions regarding the actual construction phase of this project.

The team chose to implement various acoustic treatments that were both effective and cost efficient. Our research seemed to indicate that there were nearly endless options for treating the spaces, but many of them didn't meet the strict requirements and limitations of the project. The main areas of focus in the Recording Environment were: to increase the acoustic absorption coefficient on the front wall of Spaulding Hall, absorb low "problem" frequencies in the corners, and reduce issues with floor to ceiling reflections. In the Control Room, a live-end / dead-end configuration was sought, with consideration for diffusive characteristics.

First the team organized and cleared the Control Room, removed old treatments from Spaulding Hall, and created a route for cabling between the two spaces. Then the treatments selected for the Recording Environment and Control Room were purchased and installed. Finally, the hardware was set up, connected, and tested.

## 3.1 Known Issues in Spaulding Recital Hall

The characteristics of Spaulding Recital Hall, both architectural and otherwise, make it less than ideal for recording purposes. Before any data collection or analysis was performed as a part of this project, a number of issues were readily identifiable. These issues obviously contribute to unwanted resonances, poor sound isolation, an unacceptable noise floor, electrical interference, and acoustics perceived as generally "unpleasant" to even a casual listener. These non-ideal conditions result from the fact that Spaulding was not originally intended to be used as a performance facility, let alone one meant for critical listening or recording.

### 3.1.1 Room Layout

The principal drawback to Spaulding remains its rectangular shape. Parallel surfaces are generally avoided during the structural design phase of most recording environments; this is a direct result of the undesirable acoustic characteristics of a complex sound field within small, enclosed, symmetric spaces. When designing the shape of a room meant for recording, a rectangle is the worst possible selection because the three sets of axial modes coincide with exaggerated spacings (Ballou 53). The colorations resulting from modal resonances also become more pronounced as room volume decreases. This makes a smaller, rectangular room such as Spaulding especially prone to standing waves in the lower frequencies, in addition to undesirable frequency response and uneven decay rates across frequency bands. All of these problems stem from the basic, structural layout of the room.

Another readily identifiable issue with Spaulding is the construction of its walls, in particular, the south wall. This wall is flush with the exterior of Alden Hall, and overlooks a busy city street. Additionally, it contains three large, bay windows. The poor sound insulation of this wall contributes significantly to the overall noise floor in the room and introduces frequent, unacceptable transients. Though the remaining three walls are interior surfaces, they similarly do not provide suitable isolation from noise originating elsewhere in Alden Hall.

The placement of Spaulding within Alden Hall also proves to be less than ideal. It is located in an area that is characterized by heavy foot traffic, and it is surrounded by rooms used for classes, rehearsals, and performances. These conditions, coupled with the poor sound insulation provided by the walls and doors of Spaulding, provide many opportunities for sound pollution during recording.

The room adjacent to Spaulding which was to be used as a Control Room is better suited to its intended purpose. Its placement within Alden Hall provides better isolation from sound sources elsewhere inside the building, even from sources originating in Spaulding. Its relatively large size for a control room provides welcome flexibility, but also presents a greater challenge in treating the space to provide for an optimal listening position. However, it also suffers from rectangular dimensions and two walls flush with the exterior of Alden Hall. Another issue is that there is no line of sight between the Control Room and Spaulding; the rooms are separated by two double doors and a hallway.

### 3.1.2 Construction Materials

The walls of Spaulding Recital Hall are composed primarily of hardboard panels. Many of these panels have decorative, raised surfaces with a cavity behind them. The hardwood itself is highly reflective, thus presenting a significant potential for contributing to trouble modes in the room. At the same time, the raised panels present opportunities for unwanted resonances and unforeseen, diaphragmatic absorption characteristics. See Fig. 3-1.

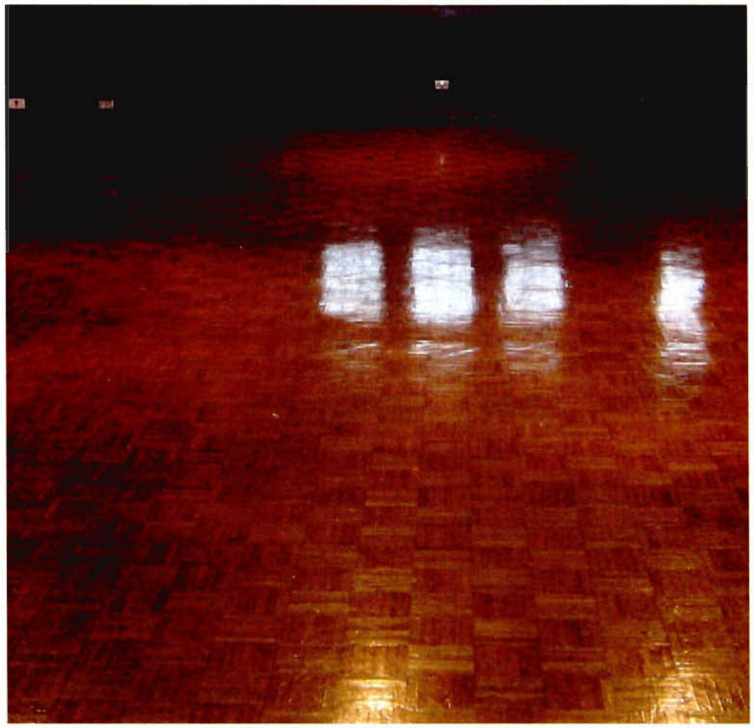

Fig. 3-1 Hardboard Panel Walls

Fig. 3-2 Hardwood Floor

The floors of Spaulding, much like the walls, are made of hard and reflective materials. The hardwood floors of Spaulding are parallel to the drywall ceiling, thus precipitating issues with the floor-to-ceiling axial modes. See Fig. 3-2.

When Spaulding was converted into a performance and rehearsal facility in the 1970s, several acoustical flats were constructed and placed on the north wall. These flats appear to be intended for absorptive purposes, but have a negligible effect on the acoustics of the room to the point of being useless. These outdated and ineffectual treatments are shown in Fig. 3-3.

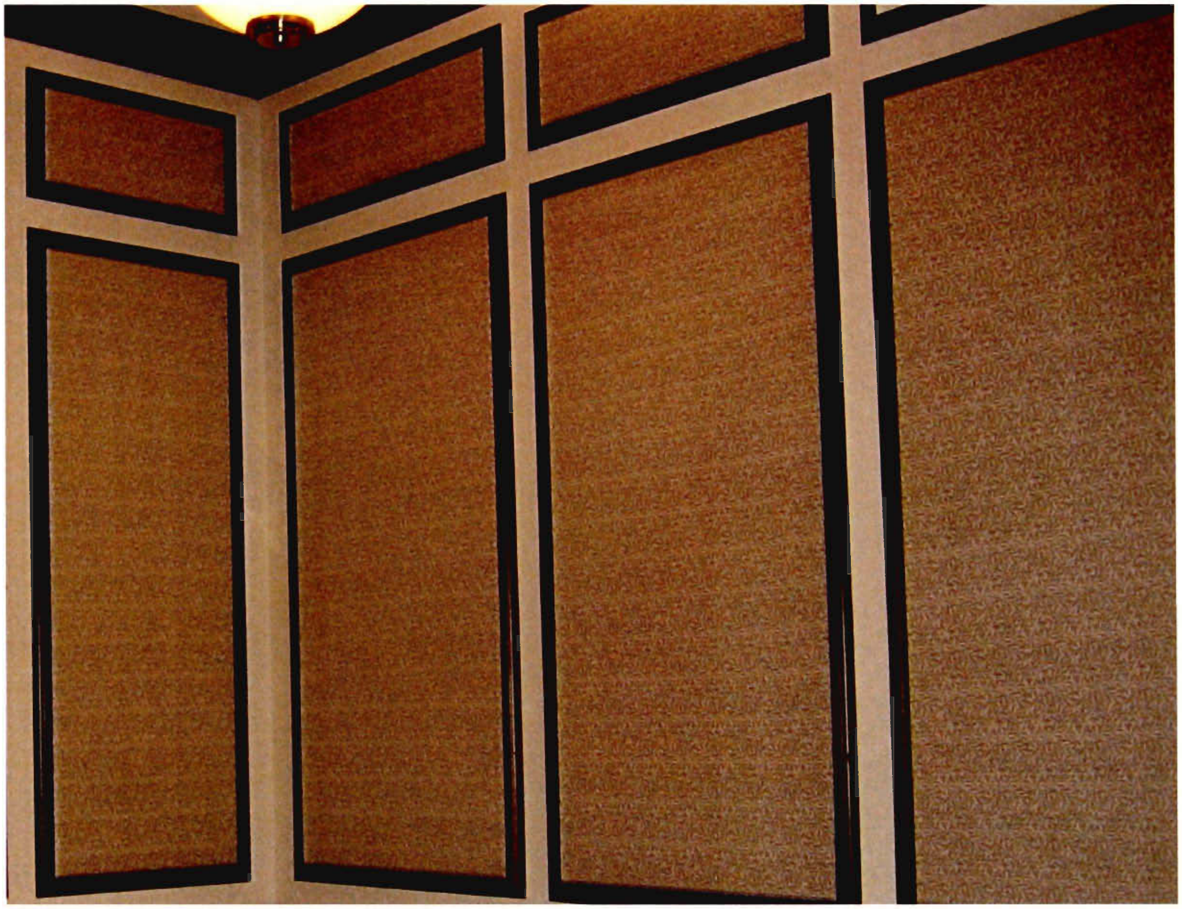

Fig. 3-3 Acoustical Flats

### 3.1.3 Doors and Windows

Roughly 20% of the wall surface area in Spaulding is occupied by windows. These windows face into a storage area, outside (towards West Street), and down a main hallway. Though the window facing the storage area may present some undesirable resonances, its overall effect on the acoustics of the room is insignificant. Of greater concern are the poor sound insulation characteristics of the windows facing outside and down the main hallway. All of these windows are single-paned, and none are acoustically isolated from the walls they are mounted on. The windows facing outside and facing the Control Room are shown in Figs. 3-4 and 3-5, respectively. A summary of window placement in Spaulding is shown in Fig. 3-6.

Fig. 3-4 Windows Facing West Street

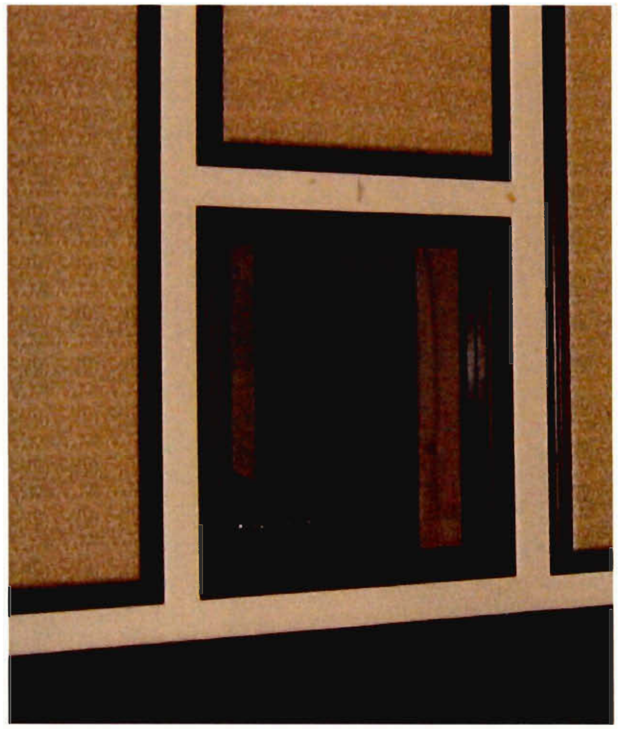

Fig. 3-5 Window into Storage Room

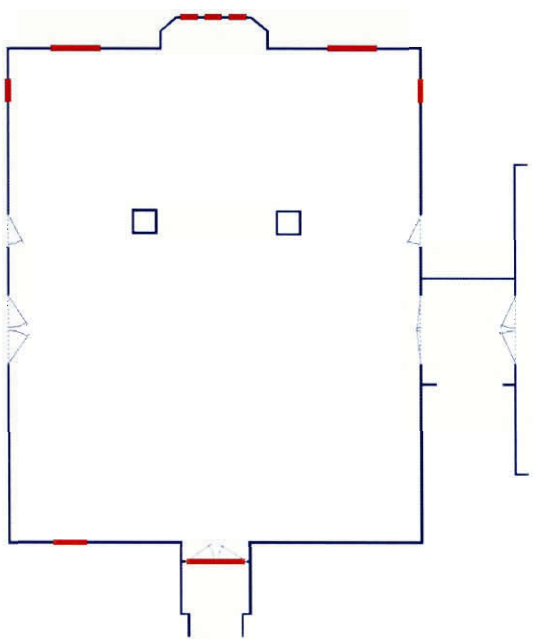

Fig. 3-6 Single-Paned Glass in Spaulding

There are three sets of double doors in Spaulding. The doors on the east and west walls are wooden and hollow-framed. These features, combined with a poor fit in their frames, provide minimal isolation from sound outside the room. The doors on the north wall, which join Spaulding to a main hallway, have all the same problems as the aforementioned doors. They are also covered in a set of windows, as mentioned above. These especially problematic doors are shown in Fig. 3-7. For more information on properly treated doors and windows, refer to sections 2.4.1 and 2.2.2.

Fig. 3-7 Glass Entrance Doors

### 3.1.4 HVAC (Heating, Ventilation and Air Conditioning)

The HVAC system installed in Alden Hall was designed to provide maximum airflow at minimum cost, and is very noisy as a result. Most of the noise floor present in Spaulding hall is due to the HVAC system, either directly or indirectly. The machinery moving the air through the ducts is considerably noisy, as is the vibration of the ducts themselves. This mechanical noise, coupled with noise caused by air turbulence in the ducts and at the vents, presents a significant problem. There are several vents of similar construction in Spaulding, one of which is shown in Fig. 3-8. The generalized placement of vents is shown in Fig. 3-9.

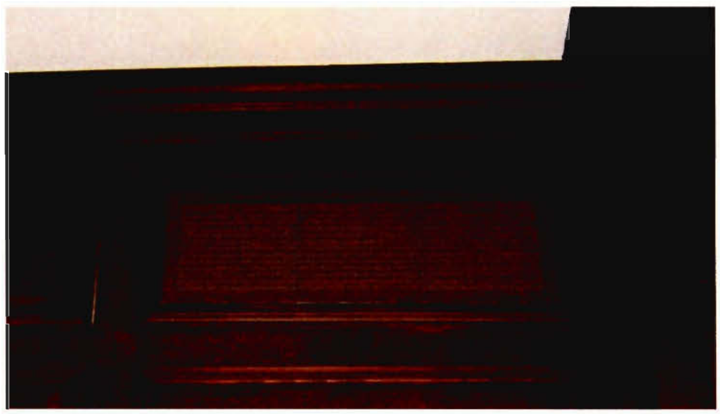

Fig. 3-8 Ventilation Duct

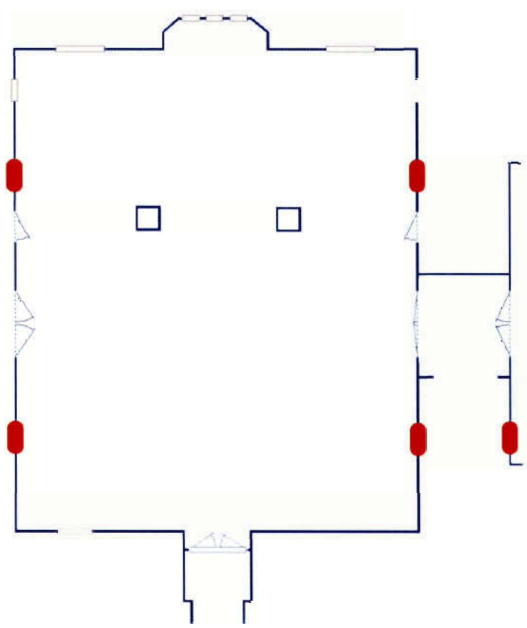

Fig. 3-9 Placement of Vents in Spaulding

After visiting Berklee College, it became obvious that professional studios take great care in eliminating noise from their HVAC systems. It is important to note that these professional spaces have treated HVAC systems integrated during construction. In Alden Hall, such a system would have to be retrofitted. This would require substantial time from professionals in this area, and therefore could not be accomplished within the small budget and timeframe the IQP team had for their project.

### 3.1.5 Lighting

The lighting installed in Spaulding is robust, versatile, and optimized for aesthetic considerations pertaining to live performance. A dimming and selector system can be used to highlight individuals performing, as well as illuminate music stands. However, the halogen track lighting is very noisy and the dimmer is a considerable source of electrical noise and interference. The system was definitely not optimal for recording studio use. The problematic track lighting is shown in Fig. 3-10.

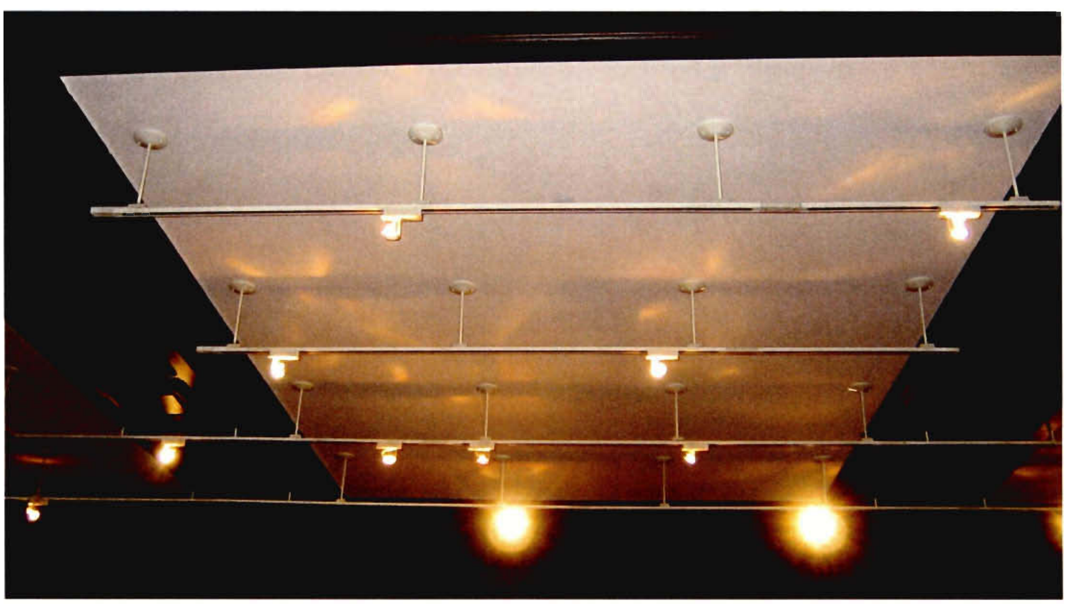

Fig. 3-10 Lighting System

## 3.2 Selection of Preferred Acoustical Solutions

After first considering a number of standard alternatives, this project team selected those that would best suit the specific needs of Spaulding Recital Hall. This was done through careful consideration of the project's constraints. The team had to complete all treatment within seven weeks, could not exceed their working budget, and could not make any significant structural changes to Spaulding or the Control Room; these limitations, coupled with the team's extensive literature and field research, are what ultimately determined which alternatives would be used.

Though none of the explicit, ideal alternatives discussed in the preceding section could be implemented fully, a foundation was laid that will allow future project teams to continue working on the WPI spaces. The acoustic foam and diffusor panels that the team decided to use in their implementation can easily be added to and expanded upon. If necessary, more audio connections can be run between Spaulding and the Control Room. There is also plenty of flexibility for expanding the hardware and software currently used by the studio.

### 3.2.1 Exclusions

Unfortunately, no improvements to the sound insulation characteristics of the room were feasible; neither were any improvements to the HVAC or lighting systems. Based upon acoustical research and recommendations proposed by a previous IQP team, affecting any audible difference would have required considerable changes to the structure of Spaulding and some surrounding areas in Alden. The team was left to outline these changes in the **Future Improvements** section of this report, without implementing them.

In addition to the above-mentioned exclusions, neither were any adjustable acoustical treatments included in the implementation of this project. Such solutions sacrifice economy for a flexibility that, at this time, is not a priority. Though the ability to adjust the acoustics of Spaulding for different performance applications is certainly desirable, there were major acoustical issues that had to first be addressed with permanent treatments. Thus, prioritization relegated any adjustable solutions to the **Future Improvements** section of this report.

However, it is important to note that a great deal of time was spent considering a set of drapes as the primary treatment to be installed. An example of such draperies is shown in Fig. 3-11.

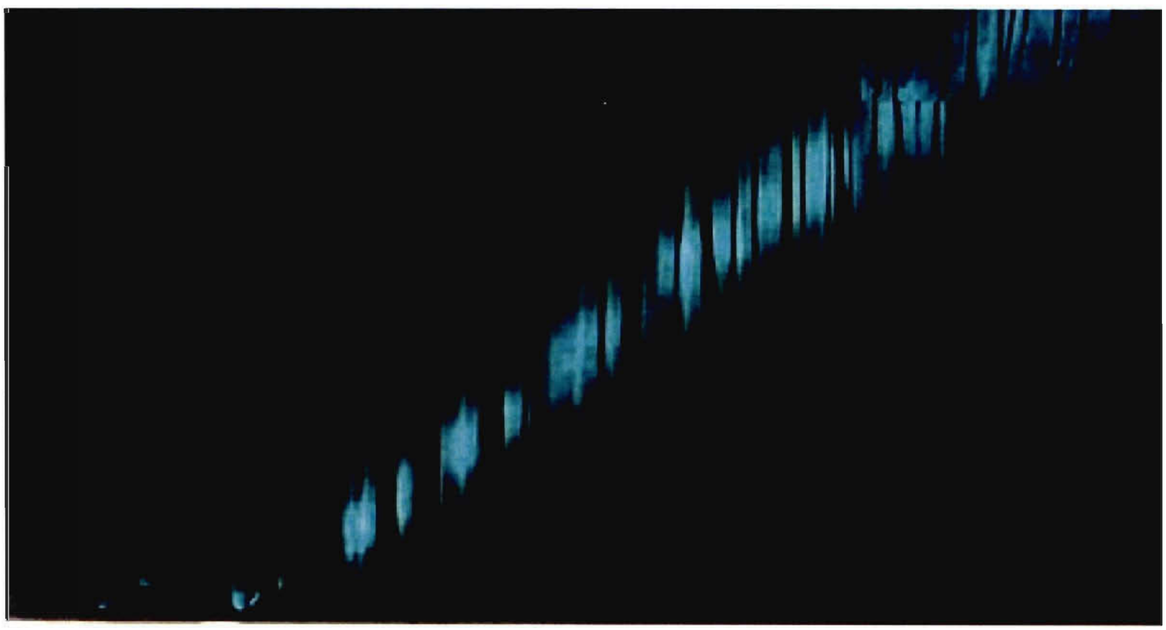

Fig. 3-11 Acoustic Draperies[29]

After researching all the available drapery options, it became clear that such a solution was not feasible for a number of reasons. The thick material used for acoustic

[29] http://www.theatrequip.com.au/images/rtown.JPG

draperies is expensive and has to be custom-ordered, and the turnaround time for orders is impractically slow. Also, the drapes require an equally expensive set of rails to be mounted on (see Fig. 3-12). These rails would as well have to be custom-ordered, and their installation would be laborious and overly time-consuming. In all likeliness, professional union labor would have been necessary, and this would have quickly driven up the price of installation.

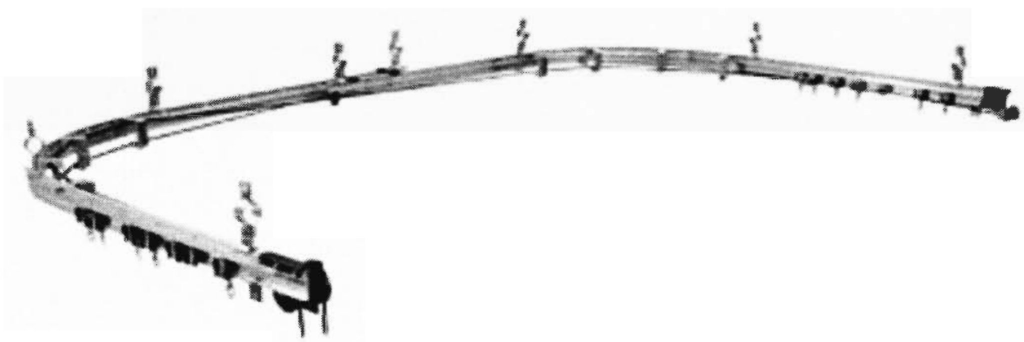

Fig. 3-12 Curtain Rail System[30]

A number of companies manufacture large curtains, but only a few do so with the intent for acoustical treatment. Many of these large curtains are produced for stage applications. Stage curtains are very suitable for use as an acoustic treatment, as they posses the thick, absorbent characteristics which were desired, are available in large sizes, and often are available with a track system. Unfortunately, the shear size of the curtains needed makes them costly. An ideal fabric such as velour ranges from $10 to $30 per square yard. The amount of material needed to treat the front area of Spaulding Hall is 75 yards, taking into account a 12 foot curtain height, 25 feet of linear distance per side of Spaulding, and a 50% increase for proper pleating when hung (150% of the horizontal length to achieve ideal acoustic characteristics). This would put the cheapest

[30] http://sewwhatinc.com/Track/Images/model140TN.jpg

curtains in the $3000 range, not including a track system or installation costs. The project budget could not accommodate this expensive avenue of acoustic treatment, despite its ideal characteristics. Even if the budget would have allowed for the purchase of this type of treatment, the production time of these curtain treatments (which can exceed one month), plus added installation time, would greatly surpass the time constraints for the installation of the studio.

### 3.2.2 Non-Adjustable Acoustic Treatments

The first suggestion Andrews et al. made to improve the acoustical characteristics of Spaulding was to change the absorption coefficients of the hall's existing acoustic panels, so as to increase absorption in the 500Hz and 250Hz octave bands (Andrews et al. 89). As stated above, this project team first considered using curtains with carefully spaced folds to accomplish this. After that alternative was ruled out, the use of Auralex acoustical foam was decided upon as a viable solution. Absorption coefficients of the basic Auralex foam products are shown in Table 3-1.

| | 125Hz | 250Hz | 500Hz | 1KHz | 2KHz | 4KHz | NRC |
|---|---|---|---|---|---|---|---|
| 1" Studiofoam | .10 | .13 | .30 | .68 | .94 | 1.00 | .50 |
| 2" Studiofoam | .11 | .30 | .91 | 1.05 | .99 | 1.00 | .80 |
| 3" Studiofoam | .23 | .49 | 1.06 | 1.04 | .96 | 1.05 | .90 |
| 4" Studiofoam | .31 | .85 | 1.25 | 1.14 | 1.06 | 1.09 | 1.10 |

Table 3-1 Noise Reduction & Sound Transmission Coefficients of Auralex Foam Products

Andrews et al. state: "Based on the information concerning the hall's early decay times and reverberation times, in addition to the results of the resonance testing, it was felt that Spaulding Recital Hall suffered from a lack of absorbency in the 250Hz and 500Hz octave bands." The 4" Studiofoam is an obvious choice for treating Spaulding, due to its absorption coefficients of 0.85 and 1.25 in the 250Hz and 500Hz octave bands, respectively. This high level of absorption at such low frequencies is quite unusual for an audio treatment as compact as a single layer of foam, and presents its major advantage over glass fiber and insulation. This project team decided to use the 4" Studiofoam because it was such an effective and economical solution, and it fit perfectly with the design requirements dictated by Andrews et al. A picture of this foam is shown in Fig. 3-13. Though structural alterations could not be performed as part of this particular project, the studio foam panels could easily be incorporated into even more efficient diaphragmatic absorbers as outlined in **Non-Adjustable Acoustics Alternatives**, by constructing minimal additions to the preexisting frames in Spaulding (See Fig. 2-31). These changes are left for future project teams to implement. As is, the excellent absorption characteristics of the 4" Studiofoam are sufficient reason to initially preclude the use of diaphragms for additional low-frequency absorption.

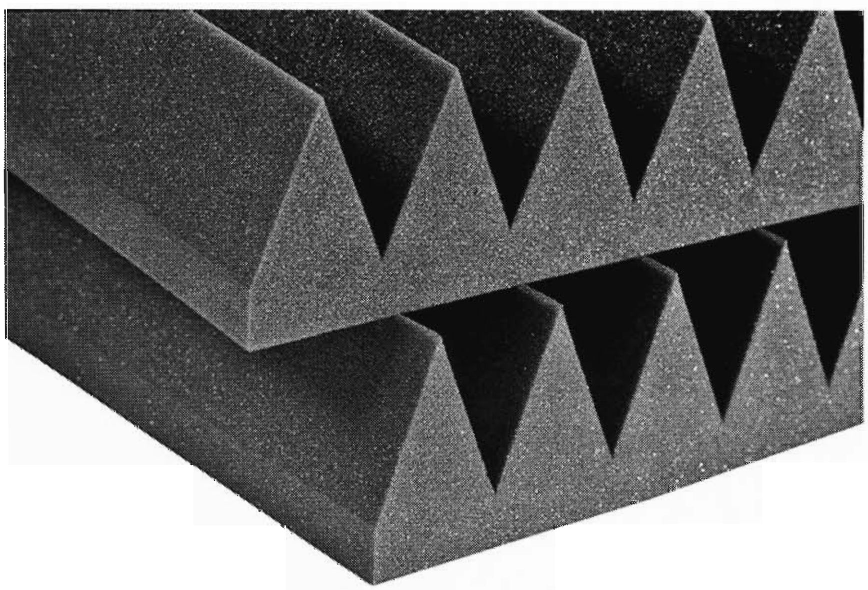

Fig. 3-13 Auralex 4" Studiofoam[31]

[31] http://www.sweetwater.com/images/items/Studiofoam4-large.jpg

In addition to replacing the old acoustic panels, this team decided to treat the corners of Spaulding with Auralex Cornerfills. This decision was made based on the effectiveness of the 4" foam in treating the particular, undesirable acoustical characteristics of the room, and on the fact that room modes terminate in corners. A picture of a Cornerfill is shown in Fig. 3-14. Such treatments economically approximate the effects of treatments such as those shown in Fig. 2-32.

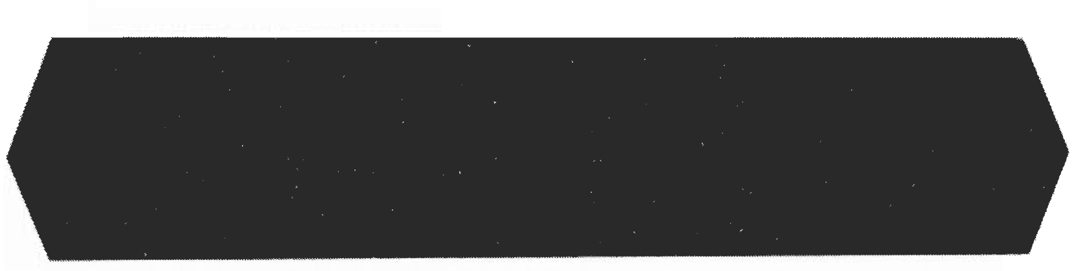

Fig. 3-14 Auralex 4" Cornerfill[32]

Though neither the Studiofoam panels nor the Cornerfills were adjustable, this fact is of little consequence. Both treatments more than make up for their inflexibility with their economy. Furthermore, their installation addresses problems in Spaulding that are present in both recording and performance applications.

### 3.2.3 Diffusive Treatments

In addition to installing the absorptive treatments outlined in the above section, the team decided to install diffusive treatments on the ceiling of Spaulding. As stated in the **Known Issues** section of the report, the ceiling and floor of Spaulding are both mostly flat and highly reflective. By placing diffusive materials on the ceiling, standing waves between the ceiling and floor can be significantly reduced, without removing sound energy from the room. Research indicates that this is advantageous for a space that

[32] http://www.sweetwater.com/images/items/CornerFill4-large.jpg

is intended for both recording and performance purposes. A picture of the diffusive treatments used – Auralex DST-R panels – is shown in Fig. 3-15.

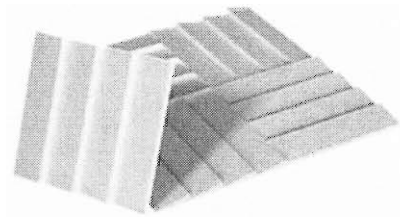

Fig. 3-15 Auralex DST-R Diffusive Panels[33]

Auralex DST-R diffusors are 1' square, and only 1" think. Easy installation was an important factor in their selection, because the team would be attaching them to the ceiling without making any structural changes. They are lightweight and easy to install, and can be arranged in a variety of patterns to create a designer look. Their aesthetic appeal is also an advantage, because Spaulding must still be pleasing to the eye to be an appropriate performance space.

### 3.3 Project Preparation

Before any changes were made to the audio closet, the Control Room, or Spaulding, the spaces first had to be prepared. This preparation consisted of cleaning out the audio closet and the Control Room, and removing the old acoustic treatments from Spaulding. The first task this project team undertook was cleaning out the audio closet. It was originally planned that the audio closet would be the control room, before WPI music faculty graciously donated the space on the West side of Spaulding. However, the audio closet has since proved to be a useful and secure storage space for project-related

[33] http://www.sweetwater.com/images/items/DSTR.jpg

materials. Through the WPI music faculty, an ID card activated security system was installed to protect the valuable items stored in this room.

Pictures of this space, before and after its cleaning, are shown in Figs. 3-16 and 3-17, respectively.

Fig. 3-16 Audio Closet Before Cleaning

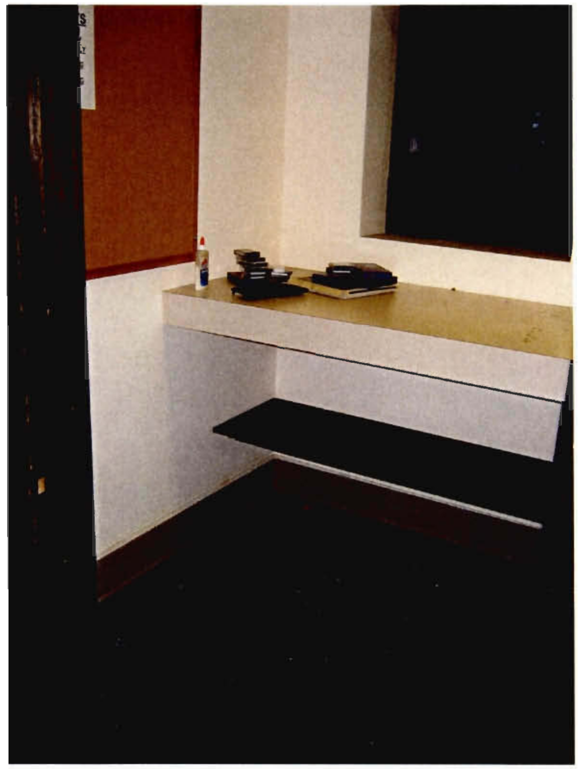

Fig. 3-17 Audio Closet After Cleaning

A great deal of the equipment stored in the audio closet was broken, severely outdated, or useless. There was also a lot of trash and misplaced materials. All of this was sorted through, and whatever was not absolutely necessary to keep was disposed of. (It is important to note that the DAT recorder, speaker pair, and all working audio cables were not disposed of.) A picture of all the discarded equipment and material is shown in Fig. 3-18.


Fig. 3-18 Discarded Contents of Audio Closet

After the audio closet was cleaned out, the team focused on the newly donated Control Room on the West side of Spaulding. This room was full of clutter, much like the audio closet had been. The North and South views of this room, before cleaning, are shown in Figs. 3-19 and 3-20. For pictures of this space after it was cleaned, refer to **Integration of Sound System into the Environment**. All of the equipment in the Control Room that was not part of this project was returned to the appropriate professors, for storage in other places. All of the furniture was removed except for a piano, a harpsichord (that had to remain due to space constraints in Alden Hall), and a table on which the mixing and monitoring equipment would be placed. Also, a couch was moved into the room and placed against the West wall. This was done because of the couch's absorptive characteristics, and the need to accommodate more than one seated person in the Control Room at a time (a technique observed at the team's visit to the Berklee studios).

Fig. 3-19 North Wall of Control Room

Fig. 3-20 South Wall of Control Room

By the time that the audio closet and Control Room were entirely cleaned out, the team was ready to start acoustically treating the Recording Environment. However, the previously installed sound-absorption panels in Spaulding first had to be removed (refer to Fig. 3-3 for a picture of these panels before removal). The panels were either attached with Velcro or glue. The ones with Velcro were easy to remove, but those that had been glued onto the wall presented the team with much more difficulty. The removal of one of these panels is depicted in Fig. 3-21. Any intact panels were kept in storage.

Fig. 3-21 Glued Panel Removal

Once all the rooms had been cleaned and the old acoustic treatments were removed, the team was ready to begin installing their solutions.

## 3.4 Integration of Acoustical Solutions into the Environment

After preferred alternatives were selected, the team considered how to best integrate them into the existing environment. Any old treatments had to be removed, and the new ones had to be prepared and installed. This process took place during January and February 2005, while preparations started as early as November 2004.

### 3.4.1 Installation of Acoustic Foam

The Auralex 4" Studiofoam came in boxes of six 2' by 4' panels. Samuel Brown is shown unpacking the boxes in Fig. 3-22. The team ordered three boxes, totaling 144ft$^2$. This was enough material to cover the three panels on the North wall of Spaulding, and to also treat some of the Control Room. Each panel was cut into one 2' by 3' piece and one 2' by 1' piece, so that the preexisting 3' by 7' panel frames in Spaulding could be used. These cut segments of foam are shown in Fig. 3-23. Each frame then contained three 2' by 3' segments, and the remaining 1' by 3' area was covered using fractions of the 2' by 1' segments. One of the frames, before the final 1' by 3' area was filled in, can be seen in Fig. 3-24.

Fig. 3-22 Unpacking Auralex Studiofoam

Fig. 3-23 Cut Segments of Foam

Fig. 3-24 Partially Completed Treatment

Fig. 3-25 Applying Foamtak to Foam Panel

Mike Drnek is shown applying Foamtak adhesive to one of the foam panels in Fig. 3-25; this adhesive was put on both the foam and the wall before pressing the former to the latter. In this way, the new treatments were attached to the wall, within the existing frames. The Cornerfills were installed in a similar manner, in each of the four main corners of Spaulding. One of the treated corners can bee seen in Fig. 3-26.

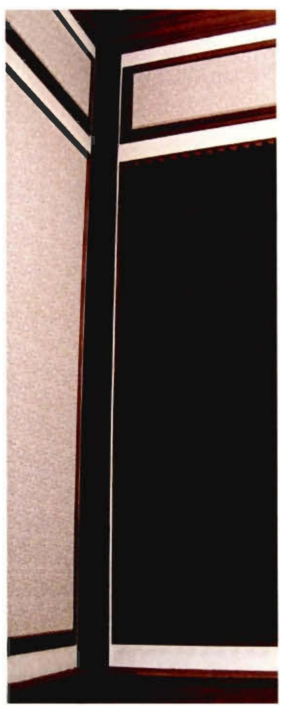

Fig. 3-26 Acoustically Treated Corner

### 3.4.2 Installation of Diffusor Panels

After the Auralex 4" Studiofoam had been installed, the team set to work on the DST-R Diffusive Panels. These 1' square panels came in a box of 36, and required Tubetak adhesive for application to the ceiling. This form of adhesive, which is shown in Fig. 3-27, is hardier than the slightly more convenient Foamtak.

Fig. 3-27 Tubetak Adhesive

A 15' ladder was borrowed from WPI's Lens and Lights Club, and the team set to work attaching the diffusor panels to the ceiling of Spaulding. The positioning of the ladder and placement of the diffusors are shown in Figs. 3-28 and 3-29. Optimally, the entire ceiling would be covered with such panels. This was not possible to do within this project's budget. However, placement of the 3' by 12' section of panels was chosen carefully, based on the work of Andrews et al. and suggestions from professors in the

WPI music division; both indicated the presence of undesirable floor-to-ceiling standing waves in that specific area.

Fig. 3-28 Installation of Diffusor Panels

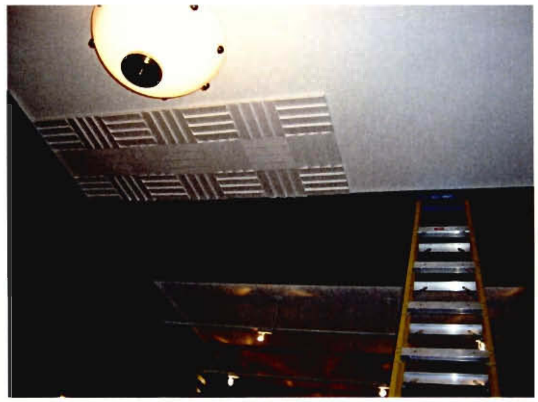

Fig. 3-29 Diffusor Panel Placement Detail

### 3.4.3 Treatment of the Control Room

After Spaulding had been acoustically treated, there was enough Studiofoam remaining to partially treat the Control Room. The team decided to use the standard "live-end, dead-end" methodology, which has the listening end of the Control Room extremely absorptive and the opposite end very reflective and diffuse. This allows for room acoustics that uniformly color the output of studio monitors and minimize early reflections, thus providing an accurate listening environment.

The team acquired three room-partitioning separators from WPI Residential Services that had good absorptive qualities, and placed these as initial treatments in front of the listening position. This set-up is shown in Fig. 3-30. Some foam left over from the treatments in Spaulding was then mounted on these separators, positioned so it would be behind each monitor. Though this is not a complete treatment of the listening end of the Control Room, it is a fair approximation of ideal conditions, especially with near-field monitors (which minimize the acoustic effects of the room on playback).

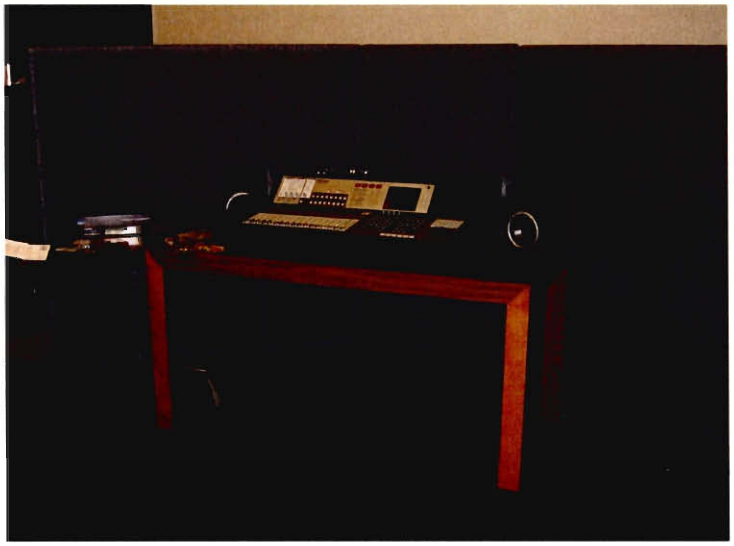

Fig. 3-30 Initial Treatment of Listening Position With Room Separators

The rear end of the Control Room was not treated with diffusors – as it would be in ideal conditions – but its irregular and reflective surface provides adequate acoustic properties for the time being. Suggested additional treatments to both the Control Room and Spaulding Recital Hall are outlined in the conclusion of this report.

## 3.5 Integration of Sound System into the Environment

As described previously, the Recording Studio designed by the team is comprised of two separate spaces. Spaulding Recital Hall is primarily used for performance and audio signal capture, while the Control Room is used to monitor, save, and edit the captured audio signals. For the two spaces to operate together, the team established a permanent, concealed, quality connection between the Control Room and the Recording Environment. After this was accomplished, the appropriate hardware was installed.

### 3.5.1 Cabling and Connections

To fully utilize the sixteen channel capability of the Tascam Digital Audio Workstation located in the Control Room, the team installed sixteen premium quality HOSA XLR cables. These cables were run from the Control Room, through the walls and ceiling, to the Recording Environment. The team chose the most discrete and efficient route for the cables, minimizing visibility while ensuring a secure and discrete installation. Each of the sixteen cables is seventy feet in length. A diagram of the cabling route is shown in Fig. 3-31.

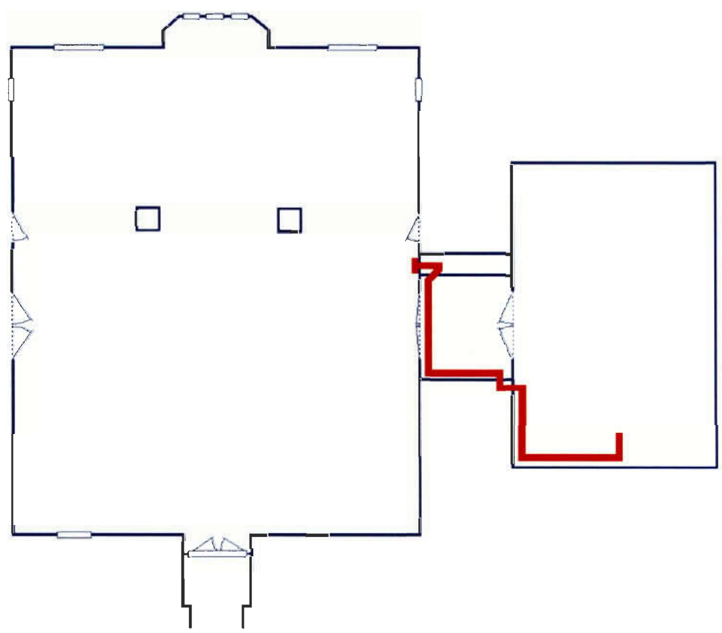

Fig. 3-31 Cabling Route from the Control Room to Spaulding

In addition to the sixteen XLR cables run between the Control Room and the Recording Studio, the team installed an unbalanced audio cable to facilitate the use of the talk back system described in **Sound System Design**. All of these cables were neatly bundled every eight to ten inches, and permanently secured inside the wall and above the ceiling to avoid future interference. The end result is shown in Fig. 3-32.

Fig. 3-32 Bundled Cables Installed Above Ceiling

After receiving permission from Plant Services through Professor Falco, the team used a stud finder to determine suitable locations for cutting through surfaces, and planned carefully to avoid structural and electrical components within the walls. Use of the stud finder is shown in Figs. 3-33 and 3-34. In Fig. 3-35, Samuel Brown is shown cutting through the wall in Spaulding.

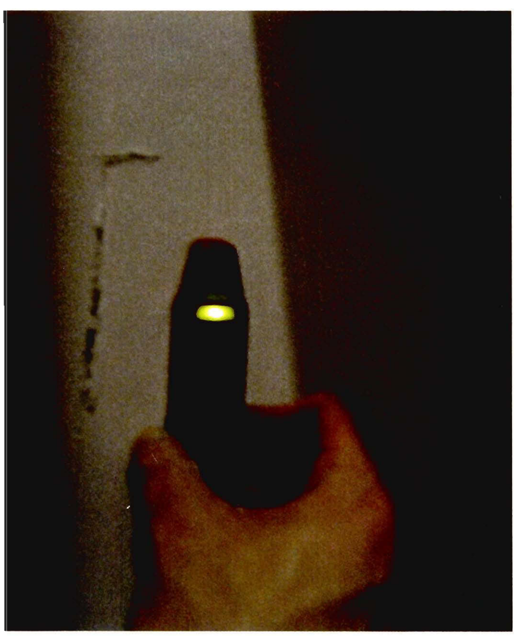

Fig. 3-33 Stud-finder Clear

Fig. 3-34 Stud-finder Detecting Obstruction

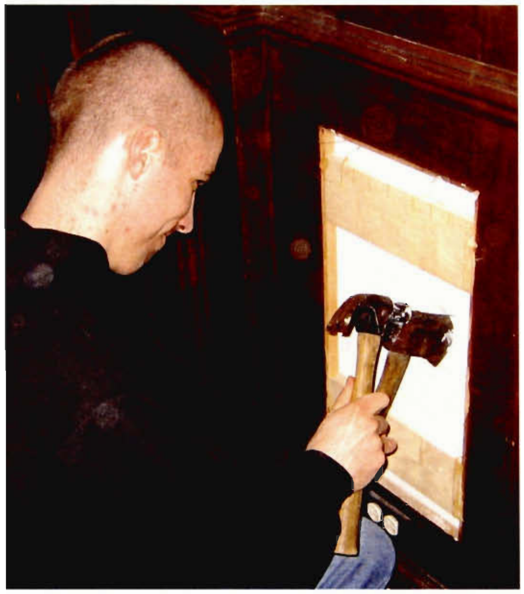

Fig. 3-35 Cutting Through the Wall in Spaulding

The team encountered numerous obstacles in the process of making the cable pathway, including insulation (which was removed from the immediate vicinity of the cables to avoid any future issues). Pictures of the hole in Spaulding's West wall, before and after insulation removal, are shown in Figs. 3-36 and 3-37, respectively.

Fig. 3-36 Hole Before Insulation Removal

Fig. 3-37 Hole After Insulation Removal

The cables enter the Control Room through a neat hole in an existing wooden panel, which is located directly to the right of the DAW. This hole is shown in Fig. 3-38. The cables then disappear behind the acoustic panels, only to reappear as they connect to the DAW. In the Recording Environment, custom wall plates were fabricated to meet the needs of the studio. These wall plates were then mounted to a custom wall panel, which replaced an existing wall panel in Spaulding Hall. This panel is shown in Fig. 3-39. Throughout the entire installation process, the team paid close attention to aesthetic detail.

Fig. 3-38 Control Room Cabling Point of Entry

Fig. 3-39 Custom XLR Plate Wall Panel

The team used over twelve hundred feet of cable, but saved hundreds of dollars by measuring and cutting each of the cables to the desired length. The team also cut costs by finishing the ends of the cables themselves (soldering Male XLR connections to the ends in the Control Room, and soldering the ends in the Recording Environment to the custom wall plates). The prepared, but un-soldered, male ends of the cabling are shown in Fig. 3-40. The soldered ends of the female wall plates are shown in Fig. 3-41.

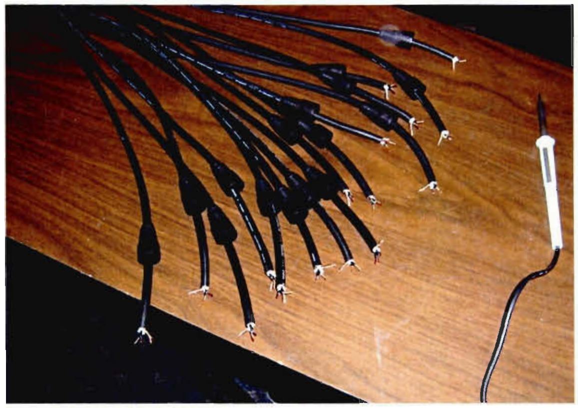

Fig. 3-40 Un-Soldered Male XLR Ends

Fig. 3-41 Soldered Female XLR Ends

Finishing of a male XLR end is shown in detail in Fig. 3-42.

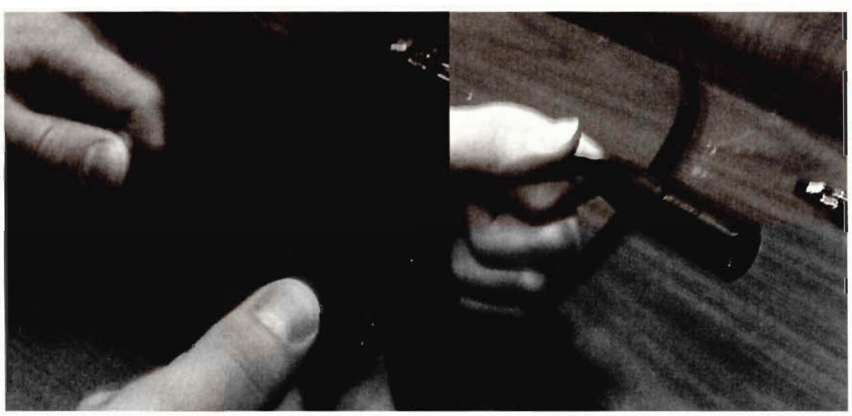

Fig. 3-42 Male XLR Cable Finishing

During the soldering process, the team tested each cable using a standard ohmmeter, to ensure that the connections were tight and that there was no signal shorting. First, the opposite sides of each connection were tested to ensure conductivity. Second, the same sides of different connections were tested to ensure no conductivity. Cable testing is shown in Fig. 3-43.

Fig. 3-43 Testing Cable for Conductivity

After the cables were installed securely, and the individual cables were tested, the team tested each cable with a microphone to ensure a clean signal. When it was determined that the cables were fully installed, the wall plates were secured to the walls, and the team matched each connection in the Recording Environment to the corresponding input in the Control Room.

### 3.5.2 Hardware Installation

In the Control Room, the physical hardware was installed with precise attention to individual function and purpose, while leaving room for future expansion. The Alesis MidiVerb, Digital Audio Tape Recorder (DAT), and Furman power conditioner were mounted in an equipment rack donated by professor Bianchi. This rack was then placed to the left of the Tascam DAW, on the main workstation table. With the equipment rack within easy reach of the technician, an efficient workspace was created. This space is shown in Fig. 3-44.

Fig. 3-44 Equipment Rack and DAW

The main workstation table was positioned facing the northern wall to maximize space, function, and overall flow in the Control Room. For easy access to the cables and equipment, the team left enough space behind the freestanding acoustic panels (which are behind the workstation). The left and right studio monitors were placed on newly purchased Samson MS100 stands, adjusted to be at ear level, and positioned to achieve an equilateral triangle with the technician/listener. One of these monitors is shown in Fig. 3-45.

Fig. 3-45 Installed Left Studio Monitor

In Spaulding, the Bose talk-back speakers were installed on the western wall, above the door leading to the Control Room. A mono signal is transmitted from the Control Room to the active speaker, which houses the amplifier for both speakers. By positioning the talk-back speakers closest to the Control Room, the amount of exposed cabling was minimized while creating a natural feeling method of communication (the musicians hear the technician from the physical direction the technician is in). The team installed the speakers high enough to prevent theft, and angled them slightly downward to direct the sound towards the musicians. This is shown in Fig. 3-46.

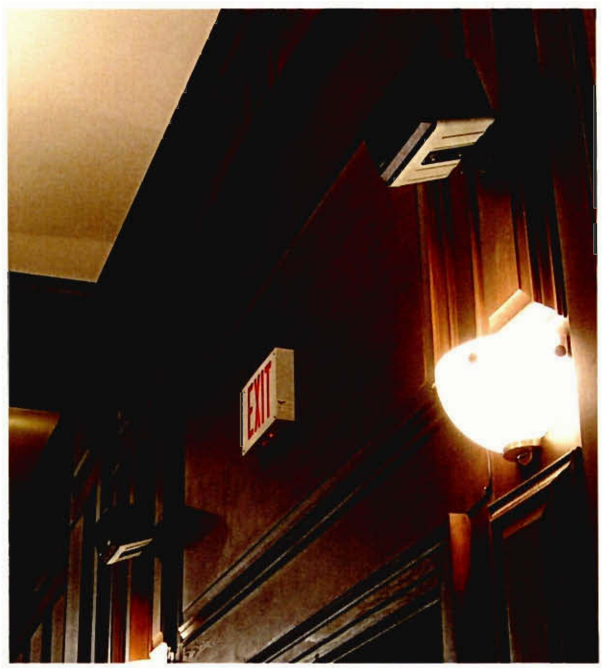


Fig. 3-46 Talkback Speakers in Spaulding Recital Hall

# 4. Conclusion

The purpose of this IQP was to provide the greater WPI community with a controlled, fully equipped, on-campus recording studio. All main objectives were met: the acoustical analysis of the environment, the design and integration of acoustical solutions, and the installation of a live-capture sound system. Provisions for future improvements were also made. This facility was constructed in Spaulding Recital Hall and adjoining rooms, and – at the time of this writing – is already in operation by the WPI Music Division and affiliates.

## 4.1 Accomplishments

The completion of this project has brought with it a number of significant accomplishments. The acoustical characteristics of the Recording Environment (Spaulding Recital Hall) have been noticeably improved, through the use of both absorptive and diffusive treatments. A permanent, two-way audio connection has been installed between Spaulding and an adjoining Control Room. This Control Room has been equipped with state-of the art recording and playback equipment. Together, these two rooms form a fully functional and fully equipped Recording Studio.

The finalized acoustic treatments of Spaulding can be seen in Figs. 4-1 and 4-2. As these figures show, the treatments are aesthetically pleasing and are physically well-suited for the environment. The appearance of any treatments was always an important factor, because Spaulding is still to be used as a performance space. The project team was able to strike an effective balance between visual and functional considerations.

Fig. 4-1 Acoustical Treatments in Spaulding

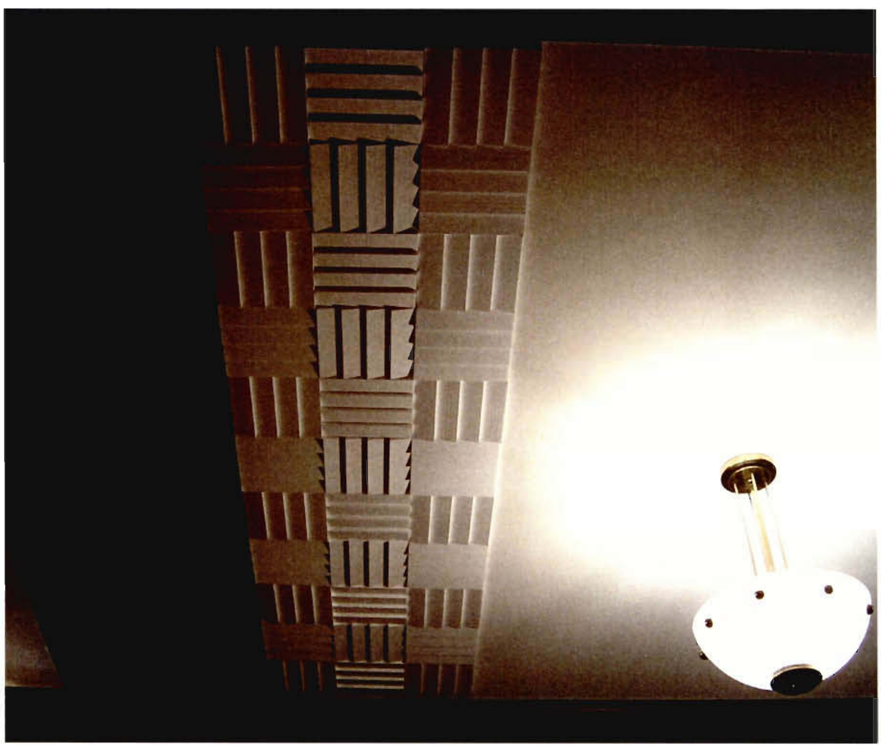

Fig. 4-2 Diffusive Treatments in Spaulding

Fig. 4-3 shows the talkback speakers and their neatly mounted cabling.


Fig. 4-3 Talkback Speakers

Figs. 4-4 and 4-5 show the panels on each end of the audio transmission line between Spaulding and the Control Room. These two panels are aesthetically pleasing as well, without sacrificing their durability or ease of use. All cabling is hidden within the walls, also contributing to the pleasing visual appearance of the studio.

Fig. 4-4 Audio Panel in Spaulding

Fig. 4-5 Audio Panel in Control Room

The finalized listening position in the Control Room is shown in Fig. 4-6. This setup parallels those in modern, top-flight professional recording studios. The equipment is laid out in a logical, easy-to-access fashion, and all sound system functionality is within an arm's reach. The Control Room follows the "live-end, dead-end" paradigm, allowing for excellent monitoring of any audio signals.

Fig. 4-6 Control Room Listening Position

## 4.2 Suggested Future Improvements

As stated before, provisions for future improvements were made throughout the design process. The acoustic treatments made by this project team were a foundation meant to be built upon; there is still much work left to do, in order to make the Recording Environment and Control Room acoustically ideal. Also, though the focus of this project was on live-capture, the studio can easily be expanded for multi-track recording and/or monitoring. Such expansions would entail further structural, acoustic and sound system alterations.

### 4.2.1 Acoustical Improvements

Alden Memorial Hall is used by many music and theatre students during all hours of the day. The building is home to classrooms, rehearsal spaces, offices, and most recently the Recording Studio installed by this team. Sound permeates throughout the building, between rooms and even between floors. In a recording studio environment, it is necessary to have proper sound isolation from surrounding activities. As addressed in section 2 of this report, Spaulding Recital Hall needs to achieve better sound isolation. This can be done by following these measures:

- Replace the doors and door frames with acoustically designed door/frame sets. This would efficiently reduce much of the sound that travels into Spaulding Hall, while also solving the security issue posed by the current doors (some of which can't lock). This is a long term goal, and would require significant construction time and funding.
- Place an additional set of doors to the main entrance of Spaulding Hall. By adding this set of doors, the current doors could remain (saving construction time and cost), and a sound lock would be created that would enhance the sound isolation in Spaulding Hall. (Adding additional doors to the side entrances of Spaulding would be difficult, given their close proximity to other rooms).
- Treat the current doors with compressible rubber tubing or weather stripping. Installed properly, this modification would block the open spaces between the doors and their frames, achieving a much greater seal. This would involve

little modification to the door structure, and could be accomplished in a short period of time with a small monetary commitment.

The Heating, Ventilation and Air Conditioning system used in Spaulding is extremely noisy, and is an uncontrollable nuisance during rehearsals, performances, and recording sessions. Any changes made to the HVAC system need to be approved by Plant Services, and would involve a significant amount of time in addressing these issues. With Plant Services' cooperation, many things can be done to lessen the noise created by the HVAC system. The team suggests:

- Install vibration isolating and noise reducing members to the HVAC system. Specially designed intermediate vent pieces, airfoils, a decoupling platform, and plenum silencers can all reduce the amount of machine/air noise that travels to the Recording Environment, and throughout the entire building. Some of these devices can absorb machine vibrations, eliminating their transmission throughout the HVAC system, while others correct airflow patterns to reduce noise. The members themselves can be very cost efficient, but the labor time and costs make these long term goals.
- Replace the vent grills with more aerodynamic grills. This improvement will reduce the amount of turbulence as the air leaves or enters the vents, thus reducing noise.
- Line the ducts with a broadband absorptive material, to reduce overall noise from the HVAC system.

Following the suggestions of Andrews et al, as well as advice from professionals, the team purchased and mounted absorptive foam to replace the ineffective acoustic treatments currently installed in Spaulding. The team could only afford to replace half of the ineffective treatments, but they identified several ways in which the WPI Music Division could continue to improve the absorption characteristics of Spaulding Hall:

- Install additional absorptive foam on the walls of Spaulding Hall. Using more of the 4" Auralex Studiofoam, the remainder of the ineffective acoustic treatments should be replaced, and selected wall panels on the south half of Spaulding Hall should be removed to allow for the installation of Studiofoam. This treatment is recommended for the immediate future, as it would provide the greatest immediate benefit to the characteristics of the space. The foam is relatively inexpensive, when compared to actual structural changes, and can be installed without the cooperation (and associated time delay) of labor unions.
- Add an absorptive, moveable, freestanding curtain system to Spaulding. This treatment would allow increased sound absorption, while increasing flexibility in the characteristics of the room. This treatment is recommended for the immediate future, as it would add versatility to the room at a very low cost.

Fig. 4-8 shows a proposed layout for further absorptive treatment. The red lines indicate replacements for the rest of the old treatments, blue indicates curtains, and pink indicates acoustic foam replacing selected wall panels.

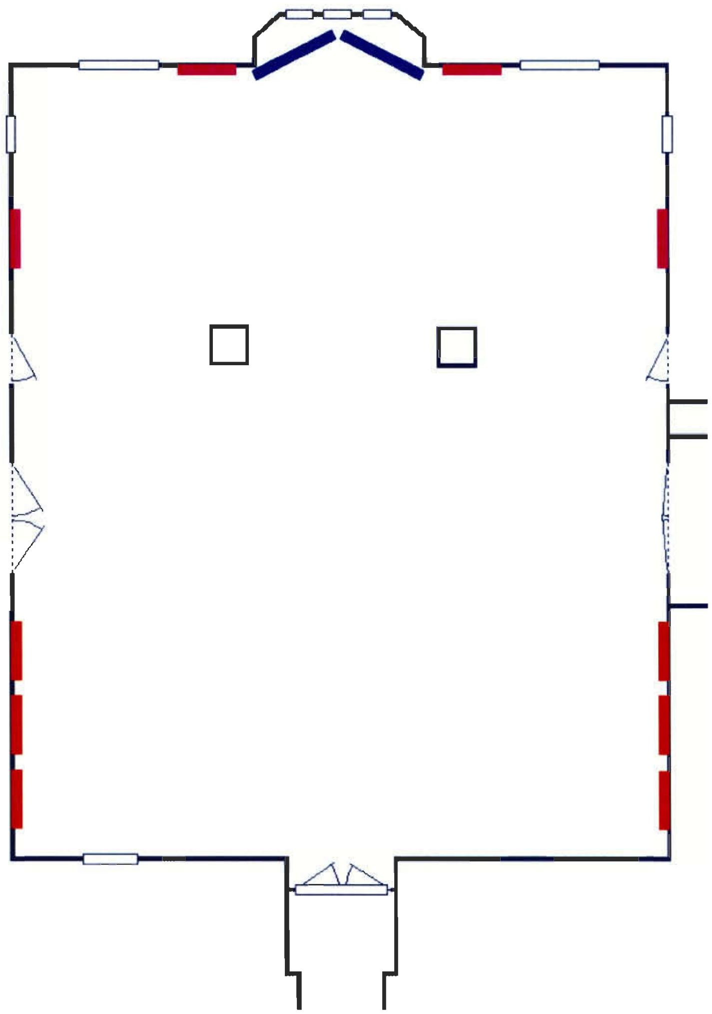

Fig. 4-8 Future Absorptive Treatments

The team started to improve the diffusive characteristics of Spaulding Hall by installing as many diffusive ceiling tiles as was afforded by their budget. The team installed these tiles near the two large structural pillars, where undesirable floor-to-ceiling reflections were observed by Andrews et al.

The purchase and installation of additional diffusive ceiling tiles would be highly beneficial. By increasing the diffusion of the ceiling, sound energy isn't lost but is reflected more ideally throughout the space. This treatment is recommended for the immediate future, as it can be installed with minimal labor and low cost. Fig. 4-9 shows a suggested layout for installation of further diffusive tiles. The color green indicates already installed tiles, while red shows where additional tiles should be placed.

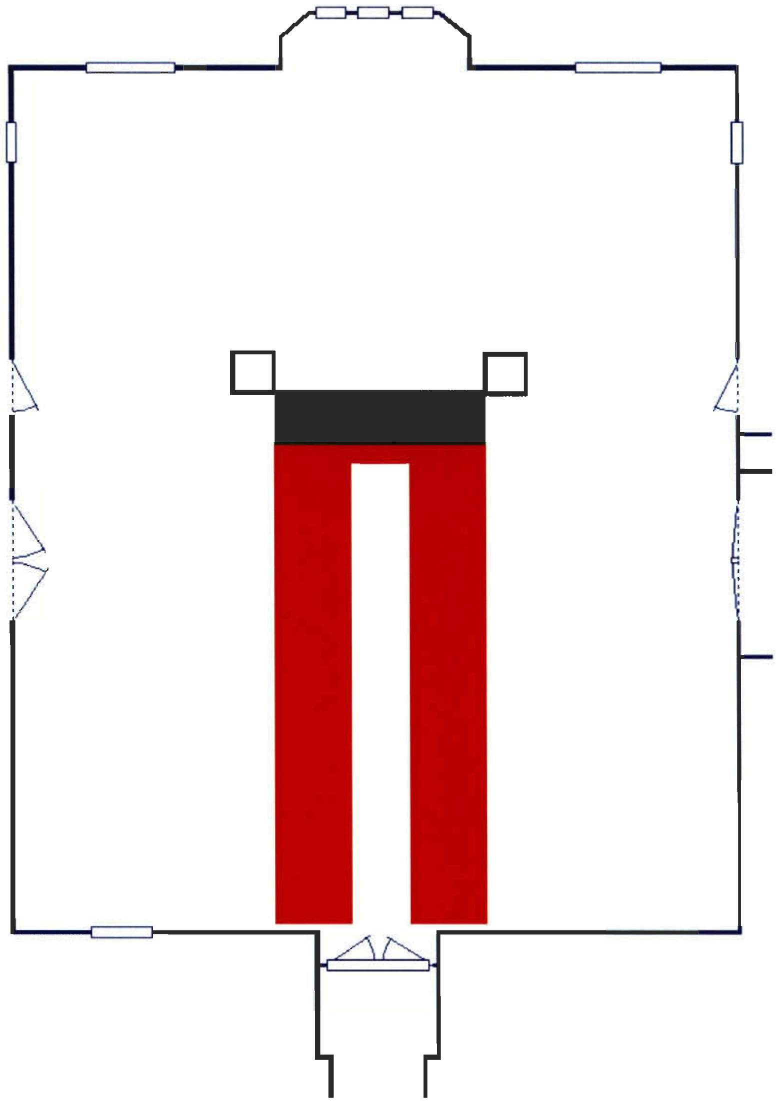

Fig. 4-9 Future Diffusive Treatments

### 4.2.2 Sound System Improvements

The robust and expandable nature of the Tascam SX-1 DAW, which is at the heart of the sound system, holds potential for significant improvements to the currently installed system. However, establishing a visual link between the Control Room and the

Recording Environment would take precedence over any other hardware additions or alterations. The best way to do this would be to hook up an LCD monitor to the VGA output of the SX-1, then also connect a multiplexed digital video feed (from the studio) to the same monitor. This would increase the ease of using the SX-1, by increasing the size and improving the functionality of its Graphical User Interface. It would also increase the intuitiveness of the recording process; visual cues between the Recording Environment and Control Room significantly enhance any recording experience.

As stated previously, there is the potential to expand the current studio to accommodate multi-track recording (as opposed to stereo live-capture). The first step towards implementing this particular form of expansion would be to provide headphone lines and/or cue mixes along the current audio transmission lines. This would require sending multiple stereo mixes to the Recording Environment from the Control Room, and would lead to a large increase in the amount of cabling between the two rooms. It would also further complicate the recording and monitoring processes. However, multi-track recording leads to much increased flexibility and audio fidelity, so it would be a worthwhile investment. It is also important to note that 16 XLR cables – rather than a simple, stereo transmission line – have already been run between the Control Room and Recording Environment. This will facilitate the transition to multi-tracking.

The addition of isolation booths, or some form of room partitioning, would greatly enhance the quality of multi-track recording. This structural change, though potentially costly, would be the logical continuance of the expansions outlined in the above paragraph. An isolation booth or partitioned area could be constructed in the free space to the rear of the Control Room. Also, the hallway between Spaulding and the

Control Room could provide an excellent space for constructing recording booths. Since this hall is used only for access to these two rooms, its permanent partitioning would not cause the WPI Music Division any inconvenience. Alternatively, heavy drapes or portable acoustic flats (see section 2.4.5) could be used to dynamically partition any number of the previously mentioned areas. This last option is more feasible as a short-term solution.

Just as adding multiple tracks to the recording process is worthwhile, so is adding multiple tracks to the monitoring process. As consumer-grade surround sound systems are becoming more and more affordable, so is the popularity of this playback format. Adding surround monitoring capabilities to the Control Room would be a very worthwhile supplement to the current facilities. Also, the wall directly in front of the listening position provides an ideal space for projecting video. Installation of a video projector, combined with surround playback/mixing capabilities, would add a whole new dimension to the studio.

Lastly, digitization of the audio transmission lines may be an intelligent step to take at some point in the future. As more and more audio processes become digitized, the point in the signal chain at which analog-to-digital conversion takes place is moving ever closer to the microphone. The integrity and reliability of digital transmission will likely cause it to replace its analog counterparts, so the XLR and TS cables currently installed in this studio should eventually be replaced with fiber cabling. However, this transition should only be made after the new technology has been well established within the industry.

## 4.3 Summary of Conclusions

Like many other branches of study, acoustics is both a science and an art. WPI strives to produce well-rounded engineers, and the studio constructed by this project team presents the school with yet another opportunity to integrate the technical and objective with the artistic and subjective. In this way, the IQP outlined in this report has benefited both the WPI Music Division and the WPI community as a whole. It has also provided facilities and laid a foundation for many more projects to come. The completion of this project is the beginning of an exciting new chapter in the WPI Music Division history…and beyond.

## Works Cited

Andrews, Michael J., et al. "Acoustical Analysis of Spaulding Recital Hall." Unpublished essay, 5 May 1994.

Auralex Acoustics Product Guide. Electronic. 1997.

Ballou, Glen, ed. Handbook for Sound Engineers. 2nd ed. Boston, MA: Focal Press, 1998.

Berklee Recording Studios. 5 May 2005 < http://classes.berklee.edu/mpe/studios/>.

Crocker, Malcolm J., ed. Handbook of Acoustics. New York, NY: John Wiley & Sons, Inc., 1998.

Dailey, Mark. "Multitrack Recording: From the Signal Chain to Tracking." WPI Music Division. Alden Memorial, Worcester Polytechnic Institute. 10 Nov. 2004.

DPA Microphones. 8 Apr. 2005 <http://www.dpamicrophones.com/>.

Eargle, John. Handbook of Recording Engineering. New York, NY: Van Nostrand Reinhold Company, Inc., 1986.

Everest, F. Alton. The Master Handbook of Acoustics. 4th ed. New York, NY: McGraw-Hill, Inc., 2001.

Hall, Donald E. Basic Acoustics. Ed. Lisa Berger and Ellen MacElree. New York, NY: Harper & Row Publishers, Inc., 1987.

Hosa Technology, Inc. 8 Apr. 2005 <http://www.hosatech.com/>.

Mechanics Hall. 15 Apr. 2005 <http://www.mechanicshall.org/>.

Studiophile SP-5B User's Manual. M-Audio. M-Audio.com. 8 Apr. 2005 <http://www.m-audio.com/images/en/manuals/SP-5B_Manual.pdf>.

Sweetwater Music Technology Direct. Sweetwater. 8 Apr. 2005 <http://www.sweetwater.com/>.

TASCAM SX-1 Digital Production Environment Quick Start Guide. Taiwan: TEAC Corporation. Tascam.com. Tascam USA. 8 Apr. 2005 <http://www.tascam.com/Products/SX-1LE/quickstart.pdf>.

# Appendix A: Budget

SHANNON FUND

| | | | | | | |
|---|---|---|---|---|---|---|
| | Auralex 4" Foam | 3 | 219.97 | 659.91 | 150 | 809.91 |
| | Rack Rider | 1 | 49.97 | 49.97 | 12.6 | 62.57 |
| | Wall Plates | 4 | 20.75 | 83 | 6 | 89 |
| | Foam Spray | 2 | 19.95 | 39.9 | 0 | 39.9 |
| 2/15/2005 | Samson Stands ms100d1 (pair) | 1 | 69.97 | 69.97 | 0 | 69.97 |
| 2/3/2005 | HOSA 1ft XLR Cable Spool | 1000 | 0.2 | 200 | 93.17 | 293.17 |
| 2/3/2005 | Neutrik XLR Male Connectors | 20 | 2 | 40 | 0 | 40 |
| | XLR 100 | 2 | 48.97 | 97.94 | 18.39 | 116.33 |
| | Foam Corner Lengths | 28 | 5.19 | 145.32 | | 145.32 |
| 2/14/2005 | Ceiling Diffuser Tiles | 1 | 99 | 99 | | 99 |
| | | | | | TOTAL | $1,765 |

STUDENT COSTS

| | | | | |
|---|---|---|---|---|
| 2/14/2005 | THE HOME DEPOT | | | $41.93 |
| | cable ties | 9.72 | | |
| | flange | 0.01 | | |
| | screws | 2.98 | | |
| | mounting tie | 1.27 | | |
| | Wire cutter/stripper | 12.98 | | |
| | stud finder | 9.5 | | |
| | exacto blade | 3.47 | | |
| 2/14/2005 | RadioShack | | | $17.40 |
| | speaker cable - 75ft | | 8.59 | |
| | 10oz solder | | 3.99 | |
| | 1.5oz solder | | 3.99 | |
| 2/17/2005 | THE HOME DEPOT | | | $49.23 |
| | 1/4 2X4 MDF | | 3.88 | |
| | Spray Paint | | 5.57 | |
| | Tape Measure | | 12.96 | |
| | 15ft Power Cord | | 11.25 | |
| | Screws | | 4.49 | |
| | Cable Ties | | 4.89 | |
| | Mounting Cable Ties | | 2.54 | |
| 2/27/2005 | THE HOME DEPOT | | | 70.76 |
| | large circular drill bit | | 7.47 | |
| | small circular drill bit | | 4.98 | |
| | 13/64 drill bit | | 2.17 | |
| | AC cord | | 7.17 | |
| | Wood glue | | 2.47 | |
| | Drill | | 39.97 | |
| | Dry wall screw bases | | 3.16 | |
| 2/27/2005 | Union Music | | | $21.90 |
| | Rack Mount Screws | | 6.46 | |
| | HOSA Cables | | 14.4 | |
| 3/2/2005 | THE HOME DEPOT | | | $10.22 |
| | 5/16 drill bit | | 3.79 | |
| | 7 piece drill bits | | 4.97 | |
| | finishing nails | | 0.97 | |
| 3/19/2005 | Radio Shack | | | $2.71 |
| | Cable Mounting Clips | | 2.58 | |
| | | | TOTAL | $214 |