Marc L Beningson

Electro - Acoustics in Architechture

Electro-acoustic solutions create the correct acoustic environment.

THE ACOUSTIC CHARACTERISTICS of a space are critical to the correct perception of any performance in that space. Traditionally, physical acoustic solutions have been used to create the correct acoustic environment for a given program. More recently, electro-acoustic solutions have been developed to create required acoustic criteria in situations where innovative architecture, historic preservation, multiple use, or other factors limit or prevent more traditional physical acoustic solutions. In the next few pages, the reader will find a synopsis of what Electronic Architecture is, as developed and practiced by Jaffe Acoustics, and descriptions of seven different electronic systems used for acoustic design problem solving.

PHYSICAL/ELECTRONIC

Perception of sound in a performing arts facility is dependent upon the relationship of the acoustic environment to the program being presented. Qualities that listeners describe as warmth, intimacy, and fullness are the result of specific acoustic criteria of both source and listening areas of a concert hall or theater. The acoustician can translate these qualitative experiences into quantitative room characteristics relating to the time arrival and intensity of early reflections and the amplitude and duration of reverberation. It is the role of the acoustician to create the correct acoustic environment for the intended program(s) of a performing arts facility, using a variety of design solutions.

Traditionally, acoustic design solutions have been of a physical nature, dealing mainly with the placement and treatment of boundary surfaces. While not in any way a replacement for properly executed physical acoustic designs, electronic solutions can be devised to provide the same acoustic characteristics, especially in situations where physical acoustic solutions are impossible, impractical, or undesirable.

Simply stated, Electronic Architecture is the application of electro-acoustic systems to meet the necessary acoustic criteria of a space in place of, or in conjunction with, physical architectural surfaces.

THEORY

It is well known that reverberation time is an important factor in the acoustic design of any performing arts facility. The distribution and intensity of early reflections is at least as important as reverberation time. The sound received by the ear in the first 30 milliseconds following the arrival of the direct sound contains information that is critical to the perception of definition or articulation of speed and music. The ratio of direct to early reflected sound, and the ratio of direct to reverberant sound are key factors in determining the quality of sound in a space.

Our experience indicates that these architectural components can be enhanced or even replaced by electronic components. The use of electronic design solutions is referred to as Electronic Architecture because the system affects sound in a space in exactly the same way as physical architecture.

The direct sound field is not amplified, reinforced, enhanced, or affected in any way. A design solution encompassing electronic architecture cannot be described as a sound reinforcement system. Only the reflective and reverberant fields are controlled through electronic architectural design. Because the system operates at low levels, loudspeakers are never identified as discrete sources, and experienced listeners cannot discern between comparable physical and electronic architectural acoustic environments.

INNOVATIVE AND UNUSUAL ARCHITECTURE

Throughout the world, there are hundreds of concert halls and theaters. The vast majority of them have configurations that do not vary significantly from one another. Even so, most architects prefer to add a personal statement to their designs. Acoustical requirements place a severe limitation on the architect's creativity if only physical design solutions are considered.

The use of electronic architecture allows the basic hall configuration to deviate from the norm. Architectural surfaces such as the theater walls and ceilings, underbalcony ceilings and soffits, and the proscenium throat-walls can be placed in less than ideal acoustical positions. The volume of the hall can vary, and within limits, the propor-

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tions of the hall can deviate from the usual. Importantly, a more intimate atmosphere can be created without sacrificing acoustical performance. The limitations placed upon an architect's design in order to meet acoustic criteria are reduced, because the criteria can be satisfied electronically. Electronic Architecture offers the architect more freedom to develop creative performing environments.

The Outdoor Music Pavilion is a North American phenomenon which is rapidly spreading. The Pavilion provides an informal, comfortable setting for concerts of all types. Frequently, such facilities are summer homes for major symphony orchestras, but the casual atmosphere and number of seats attract "middle of the road" and rock acts as well. The combination of fixed seating under a shed-roof and an open-lawn area accommodates audiences from four thousand to well over fifteen thousand, without the facility seeming empty or overcrowded.

With wide-fan shaped seating, a high roof, and no side or rear walls, a music pavilion is an unusual piece of architecture presenting many difficulties in terms of physical acoustic designs. While concert enclosures and forestage canopies can provide early reflections to seating areas closer to the stage, the size and shape of the seating area does not permit the distribution of natural reflections in sufficient quantity or amplitude to the entire audience. Due to their size, it is difficult for an orchestra to generate enough sound pressure to energize the air volume in a typical pavilion. With electronic architecture, an orchestra can perform without reinforcement to an audience of five thousand people under the shed roof cover. The volume under such a roof might be 1.5 to 2.0 million cubic feet, two to three times that of the Boston Symphony Hall.

EXISTING STRUCTURES AND HISTORIC RENOVATIONS

Physical modifications to an existing structure to improve the acoustics environment of a space may be impractical or impossible. Lifting a balcony, raising a roof, or moving walls are all extraordinarily expensive undertakings whose budget implications could easily eliminate the feasibility of proceeding with a project. Electronic architecture provides the ability to create the appropriate acoustic environment without the expensive alterations of building structure.

Historical renovations are an important application for electronic architecture because the historic character of the architecture of the theater is the motivating factor for the renovation. This environment would be destroyed through the architectural modifications required by traditional physical acoustic design solutions. Because the acoustic qualities of a renovated theater are of prime concern to the user, a delicate balance between historical and acoustical requirements must be maintained. With the acceptance of electronics in the concert hall environment, both acoustic and historical requirements are met, thereby giving special historical spaces "a new lease on life."

ASSISTED RESONANCE (AR) ACOUSTIC—INVESTIGATION RESEARCH ORGANIZATION

Assisted resonance (AR) was developed by P. H. Parkin and K. Morgan of the Building Research Station. The year 1964 saw the start of a four-year research and development program to install a system in the Royal Festival Hall to correct the short-fall in low frequency reverberation. The reverberation time was measured at some 1.5 seconds, a little on the low side for symphonic presentations. The AR system was a practical alternative to radical physical changes to the room.

An AR system consists of a large number of microphone-amplifier-loudspeaker channels with each channel being, as far as practically possible, frequency independent of the others. This frequency independence is achieved by the use of high Q acoustic filters (Helmholtz resonators). A block diagram of the basic system channel is illustrated in *Figure 1*. Each microphone is placed at a frequency-specific pressure anti-node, and its associated loudspeaker is placed at a corresponding frequency-maxima (peak). The two are then joined by an amplifier and phase shift network, and the phase is adjusted so the signal is in a "phase-locked-loop." The system employed in the Royal Festival Hall uses 168 of these channels and achieves an increase in reverberation as shown in the graph of *Figure 2*. Parkin also recorded an increase in sound pressure level in the reverberent field with the system on and this amounted to some 1.9 dB in the 115 Hz octave band.

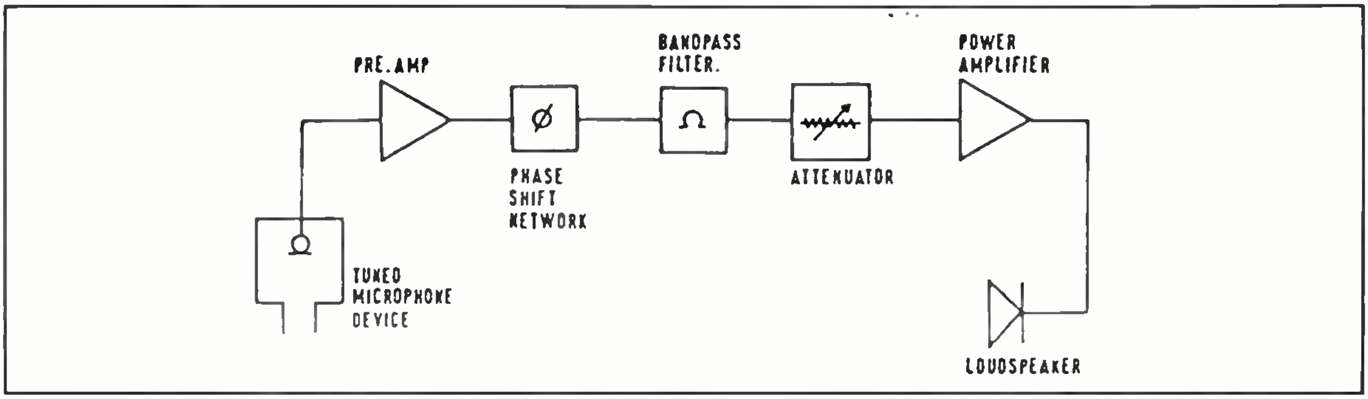

Figure 1. Block diagram of the basic system channel.

The number of channels used is based on work carried out by Schroeder and Kuttruff who demonstrated using a statistical method that the transmission response between any two points in a space had peaks which may be expected to occur, on average, at a frequency interval n(f) given by: n(f) 3.91/RT.

For the Royal Festival hall this implied a frequency spacing of around 3 Hz and hence to cover the frequency range 58 Hz to 700 Hz which would require over 200 channels.

In 1969 the Acoustic Investigation Research Organization (AIRO) was granted a license to exploit the assisted resonance concept and between 1969 and 1983 some ten systems have been installed.

There have been a number of developments in the Assisted

Resonance System since the Royal Festival system. AIRO reduced the number of channels and increased the frequency range over which the system was to operate. A recent typical system employs 90 channels and covers the frequency range 63 to 1300 Hz. The channel spacing is not allocated on the basis of constant frequency, but instead the spacing is typically four percent at low frequencies and two percent at the highest. This is based on the premise that the ear's discrimination is related more closely to a logarithmic rather than linear frequency interval.

Obviously, the technology employed has been updated. AIRO now uses 50 Watt MOSFET power amplifiers instead of the 5 Watt tube amplifiers of the original system, and instead of fixed attenuators they use a microcomputer to change the gain. The microcomputer offers the feature

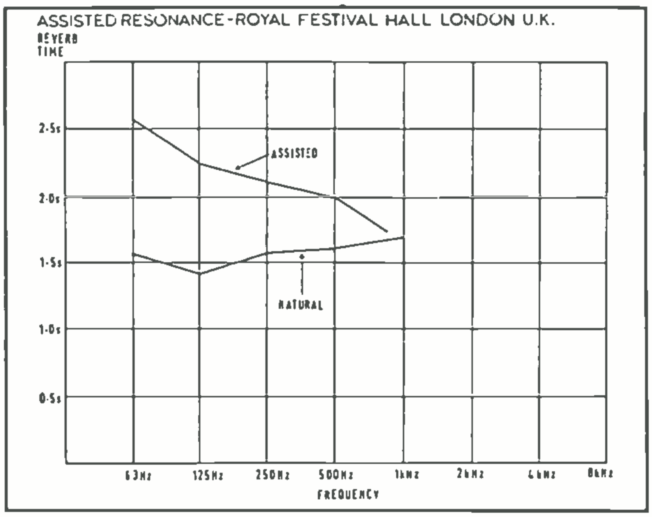

Figure 2. Graph showing increased reverberation in the Royal Festival Hall.

of instantaneous changes of every channel, with, for example, "presets" of opera, symphony, or speech. The latest system installed was in Eugene, Oregon (1981), in accordance with the specifications of our firm. It is a multipurpose hall that hosts symphony, Broadway shows, and rock concerts. The reverb times for these presentations are obviously conflicting, and *Figure 3* shows the AR system's range.

The AR system, as installed at Royal Festival Hall, was the first application of Electronic Architecture. When first installed, no one was told of the intrusion of electronics into the hall. However, it was when musicians and the music critics began favorably commenting on the hall's improved acoustics that, the system was announced and subsequently expanded. It was the immediate success of the AR system that paved the way for the acceptance by musical communities of Electronic Architecture. Multi-Channel Reverberation System (MCR), N. V. Philips, Electro-Acoustrics Division.

This system was developed by Professor N. V. Franssen of Philips Electroacoustics Division, Netherlands, in 1968. This system, as its name suggests and in common with Assisted Resonance, consists of a large number of channels (between fifty and 100), the exact number being dependent on the hall and the reverberation lift required. However, the channels are not frequency-selective, and are, therefore, frequency independent. Franssen's original intent was to design a sound reinforcement system that was source/listener-position independent. However, the number of channels required made this approach cost prohibitive. Philips, therefore, applied the system to reverberation enhancement techniques.

Philip's MCR, however, is not to be confused with their Ambiophony system which predates MCR. In the Ambiophony system the sound near the source was picked up by microphones, delayed by a magenetic tape waterfall type delay unit, and then added by means of distributed loudspeakers to the diffuse sound in the auditorium. This system, which used the Philips EL6911 tape delay unit, was installed in many theaters including Studio 4 in the BBC Television Center, and the Teatro alla Scala in Milan, where it is still in use.

The typical MCR channel is shown in *Figure 4*. Equalization is applied to correct for the random-directive sensitivity of the microphone, loudspeaker, and the transfer function between them. The principle behind this system is simple and compact. In the diffuse field, sound energy density and reverberation time are directly related, so that if the diffuse sound is amplified there will be a corresponding increase in reverberation time. Basically then, the MCR system is a sound reinforcement system that amplifies the diffuse or reverbererant field, as opposed to conventional reinforcement systems that amplify the direct field only.

Unlike Assisted Resonance, where the microphones are placed at frequency-specific pressure antinodes, the positions of the MCR microphones and loudspeakers are predetermined statistically and each channel amplifies the entire spectrum. However, each element must be in the reverberant field with respect to any other element. In practice it is found that for each channel about 0.8% is added to the energy of the sound field, but only 0.6% to the reverberation time. Increasing the reverberation time by

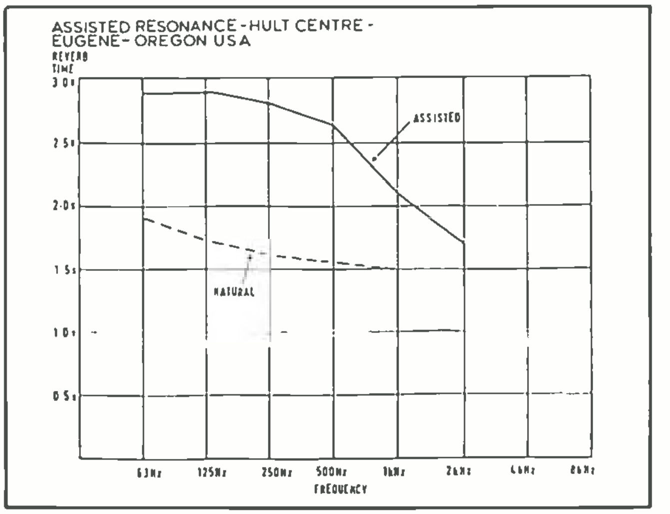

Figure 3. Reverberation times at Hult Center, Eugene, OR.

half, thus, requires over 80 channels. While it is advantageous to be able to precisely define the positions of transducers for very small spaces, it could be difficult or impossible to find sufficient positions that both satisfy the reverberant field criteria and provide the required reverberation lift.

Like Assisted Resonance, the MCR system's reverberation is dependent directly upon system gain. Both systems operate at only -5 dB to -10 dB below feedback, and as such there is only a small margin of error. The theoretical limit for raising the original diffuse-field level is 12 dB. However, coloration sets in just above 5 dB of gain and system instabilities are encountered beyond 6 dB of gain, where

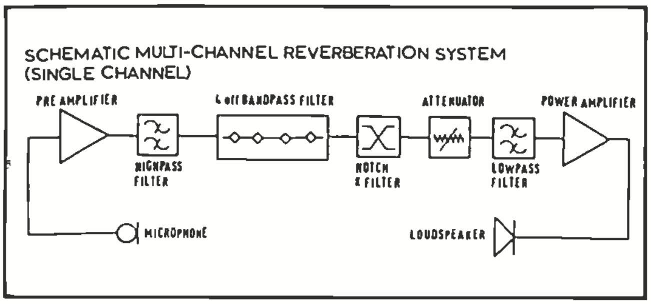

Figure 4. Simplified block diagram of basic reverberation system.

there is a doubling of the reverberation time. The MCR system has a continuous checking system that inspects the electronic gain to detect the onset of problems. It does not, however, check the total loop gain since this would involve continuous acoustic measurements. There are also two detection and measuring microphones which are placed between the sound source and the system microphones. These microphones provide advance warning of levels outside the system's capability (110 dB SPL) such that overload and distortion will not result.

To date, five MCR systems have been installed, the most recent is in Limehouse Studio 1, London, where it is intended to provide an acoustic climate suitable for orchestral presentations in an otherwise acoustically dead space. Similarly, the Hans Rosbud Studio Sudwesfunk broadcasting organization in Baden-Baden (Federal Republic of West Germany) has been provided with a 70-channel MCR system. The first auditorium to be provided with an MCR system was the one in Philips POC Congress Centre, Eindhoven, (1981). The POC system consists of 90 channels, so that the reverberation time can be increased in steps from 1.1 seconds to about 1.7 seconds. An MCR installation has also been fitted at the Claude Debussy Theatre of the Palais des Festivals et des Congres, Cannes (France). The 66 channels can be used to increase the mean reverberation time from 1.45 seconds to 2.0 seconds. The Saalbau, a multi-purpose hall at the Weinstrasse, in Neustadt Netherlands, is the most recent MCR installation. It has 79 channels, and through the mid-range it raises the reverberation time from 1.25 seconds to 2.0 seconds.

REVERBERATION CHAMBERS AND ACTIVE ACOUSTICS—Bolt, Beranek, & Newman; John W. Ditamore; Paul S. Veneklasen.

Prior to the advent of electronic delay and reverberation devices, external chambers were used as the source of additional reverberation to be added to halls. In a system of this type, microphones fed loudspeakers in an isolated reverberation chamber located elsewhere in the facility. Additional microphones were used to pick up the reverberent sound and feed it to loudspeakers distributed through the facility.

In 1965, David Klepper (now with KMK) and Russell Johnson (now with Artec) worked in conjunction with John Ditamore, an independent theater consultant on the faculty of Purdue University. They designed and specified an electronic reverberation/surround system for the Miller Auditorium, University of Western Michigan, Kalamazoo. The system used conventional microphoning and mixing techniques, with the console feeding a power amplifier driving an Acoustic Research loudspeaker in a reverberation chamber, well isolated from the auditorium.

The reverberation chamber had an adjustable drape to vary the reverberation time from about one to three seconds at mid-frequencies, depending on the extent of the drape exposed from its pocket. The signal in the reverberation chamber, which was completely non-parallel, was picked up by an omnidirectional condenser microphone, fed through a tape-loop delay unit (built from an Ampex 350), and delivered through amplifiers to a number of Altec 604 coaxial loudspeakers above a panel-array ceiling and behind sound-transparent walls. This system worked well for orchestral performance, and is still in use, although some modern digital equipment has been added.

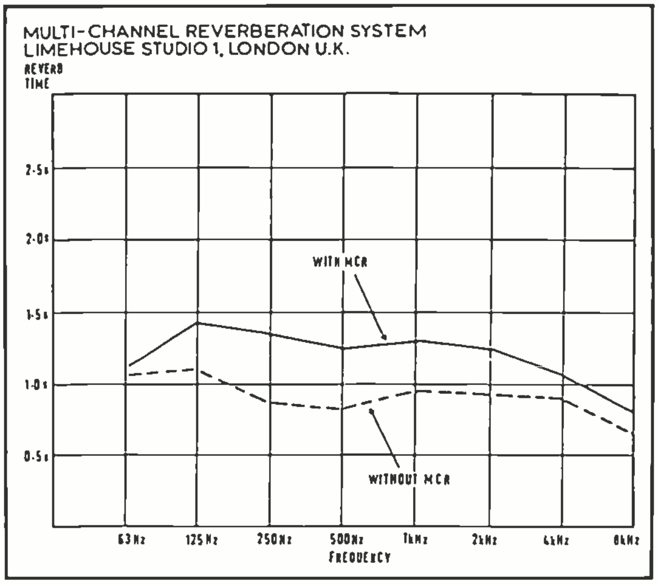

Figure 5. MCR system graph at Limehouse Studio 1 in London.

Paul S. Veneklasen filed for a patent on a "Method for Synthesizing Auditorium Sound" in May of 1967, was granted U.S. Patent Number 3,535,453 in October, 1970, which is shown in *Figure 6*. This system utilizes a reverberation chamber and a delay tube to provide both the reflection patterns and reverberation of a large auditorium in a smaller room. The system was conceived for use with either a natural or amplified source. The system was described to have a more natural room sound, hence the use of the word 'synthesized,' rather than 'artificial' reverberation provided by tape delay systems. The Veneklasen system was installed at the Classic Beauty Collection, San Sylmar Museum, Sylmar, California, to enhance the acoustics of an auditorium where a large Wurlitzer theater pipe organ is played regularly.

Veneklasen's Auditorium Synthesis method was also used by his firm as a research tool. The progression of direct, envelopmental, and reverberant sound were precisely controllable. One of the most important facts first demonstrated was that, as important as are time delays and directions, the relative levels of the three key components of auditorium sound are most important. They also found that, the preferred levels vary with taste and program material, and in particular, the ratio of reverberant versus direct sound is more important than the reverb time itself and controls the clarity.

In 1974, John Ditamore served as theater consultant to Rudder Auditorium at Texas A & M University in College Station, Texas, and designed a sound reinforcing system

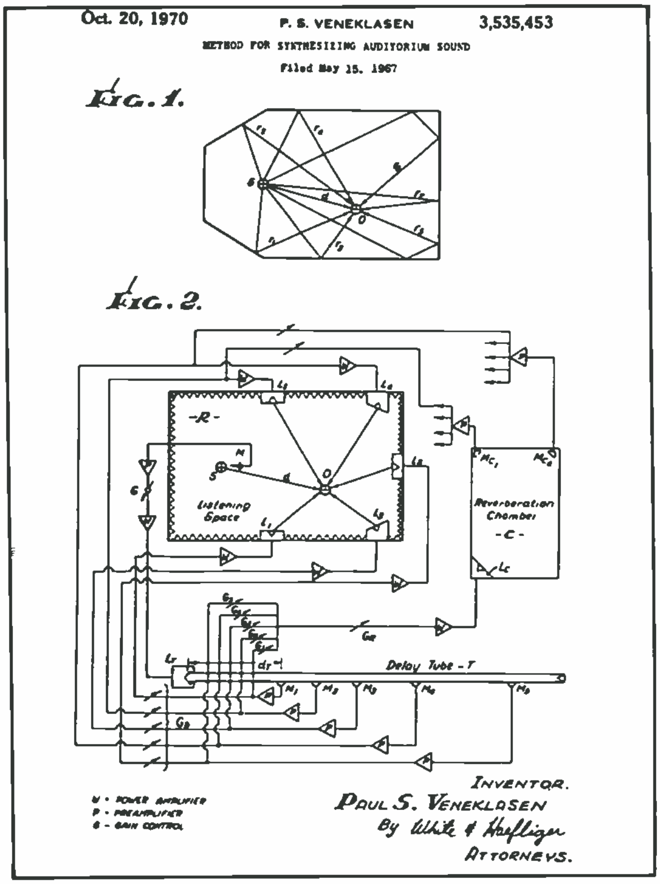

Figure 6. Paul S. Veneklasen's method for synthesizing auditorium sound.

including 'active acoustis.' In a manner similar to the University of Western Michigan system, an external reverberation chamber was used to provide additional reverberant sound through loudspeakers located throughout the ceiling, sidewalls, and balcony soffits. The levels of both the direct sound from proscenium speakers and the reverberant sound were independently adjustable. The basic reverberation time at mid-frequency, without the active acoustics system, was 1.4 seconds. This was increased to 1.8 second with the system in use.

REVERBERATION ENHANCEMENT WITH ELECTRONIC DEVICES—Bolt, Beranek & Newman; J. Jacek Figwer; Theodore J. Schultz; David L. Klepper; Towne, Richards & Chaudiere, Inc.

In the late 1960s, Bolt Beranek & Newman served as acoustical consultants on a project to improve the acoustics of Kresge Auditorium, a 1238-seat multi-purpose auditorium on the Massachusetts Institute of Technology campus. In conjunction with a series of suspended plaster sound reflecting panels designed to counteract the undesireable acoustic qualities of the room's dome-shaped ceiling, a number of experiments in electronically assisted reverberation were conducted in 1967-1969. The result was a system designed by Jacek Figwer, using a Kuhl's plate as the reverberation source and two rows of four loudspeakers installed above the reflector panels. The front row speakers point upward and the sound is reflected from the ceiling. The rear speakers point downward. Signal delay is used to provide the correct arrival time of the reverberant sound following the direct sound. The two system microphones are hung from the reflector panels over the orchestra. "In the technical minded community of M.I.T., the intrusion of electronics into the world of music did not seem to create any adverse reactions," according to Dr. Figwer. The block diagram for the system, and the resulting lift in reverberation is shown in *Figure 7*.

In 1976 to 1977, Figwer designed an underbalcony system in conjunction with Ted Schultz, physical acoustics consultant for Bolt, Beranek, & Newman, Inc., on a project involving the Orpheum Theatre in Vancounver, British Columbia. The concept was to obtain reverberation from the upper portion of the hall itself, which was not lacking in reverberation, and introduce this natural reverberation into the deep, low overhang underbalcony area through loudspeakers in the balcony soffit. No additional delay was required due to the geometry involved. The intent was to keep the installation a secret, but word leaked out, resulting in skepticism on the part of the conductor and musicians. However, Schultz reports that after initial tuning and adjustments, the musical community was delighted with the system's ability to remove the balcony.

In 1984 at Klepper Marshall King Associates, Ltd., David Klepper designed a simple, but comprehensive,

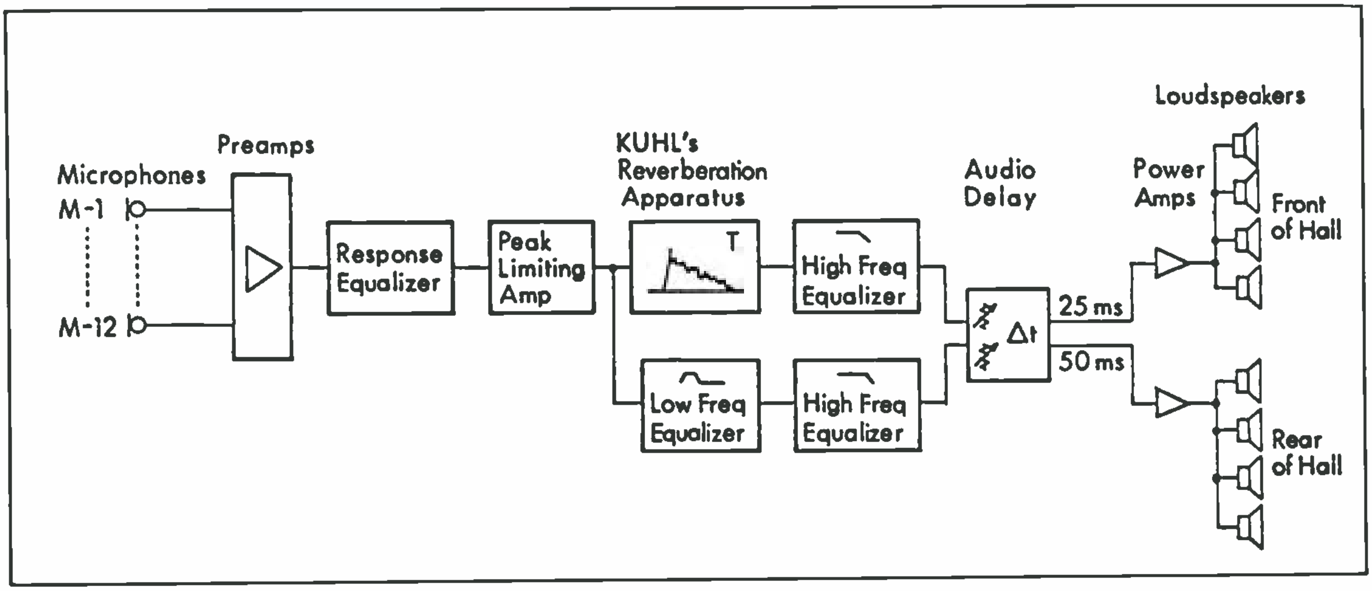

Figure 7. Block diagram for the Kresge Auditorium reverberation system.

sound reinforcement system for the University of Hartford's Lincoln Theatre, in West Hartford, Connecticut. The system re-used existing JBL loudspeaker clusters, which can provide reinforcement by themselves, or serve as precedence loudspeakers in conjunction with a distributed system of Electro-Voice PRO-12 loudspeakers, partly on delay. The Music School's Lexicon 224 reverberation unit has been used with the system to add liveness to chamber music performances and will be programmed for orchestral concerts in the future.

Electronic Reflected Energy System (ERES)—Jaffe Acoustics, Inc.; Technical Acoustics, Inc. When an Electronic Forestage Canopy (EFC) was installed at the Oakland Paramount Theatre in Oakland, California, in 1973, the involvement of Jaffe Acoustics in the field of Electronic Architecture began. Historical renovaton did not permit the installation of forestage reflector panels, required for providing critical early reflections in the theatre. In conjunction with the natural excitement of physical volumes acoustically coupled with a hall—such as acoustic 'moats,' stagehouses and organ chambers—to extend and enhance reverberation in a hall, Jaffe Acoustics developed a system to electronically energize these coupled volumes—the Reverberant Field Energizer (RFE). This system was first used in 1977 at Laurie Auditorium, San Antonio, Texas, and was granted U.W. Patent #4,061,876 in December, 1977. In the following years, these systems evolved into the Electronic Reflected Energy System, or ERES.

ERES uses loudspeakers distributed throughout a hall to enhance or provide natural reflection patterns for the proper perception of sound in the hall. While other electronic architecture systems deal primarily with reverberation, ERES provides presence, running liveness, reverberation, and warmth in a concert hall, theater, or multi-purpose performing arts facility. Any or all of the four channels may be used individually or simultaneously, depending on the acoustic requirements of the hall itself and particularly the intended program of the space. ERES can be used to correct acoustic deficiencies in an existing hall, however, a number of multi-purpose theaters have been constructed with ERES included as an integral part of the acoustic design of the facility. The four basic channels of ERES are shown in *Figure 8* .

The first two channels are provided through the use of digital delay devices and strategically located distributed groups of two- and four-inch loudspeakers. Delay times are set to provide or augment the envelope of early field reflection patterns for a specific audience area. Each transducer requires 10-20 Watts of amplifier power. The second two channels are provided through the use of a custom, multi-tap digital reverberation device and distributed eight-inch coaxial and twelve-inch loudspeakers. The custom reverberator provides a diffuse package of late arriving reflections, gradually decaying but pseudo-randomly varying in amplitude and time spacing, which combines with the natural reverberation decay of the room. The reverberation time, the level of the reverberant field, or both, may be increased. Each transducer requires 20-50 Watts of amplifier power.

Sound pick-up is in the late field of the sound source, by microphones implanted in overhead reflector panels. Although a number of microphones are provided for different programs (symphony, symphony pops with soloists, chamber, chorus), generally only one microphone is used for a particular function. One or more notch filters are provided to remove primary feedback frequencies if necessary. Technical Acoustics Inc., a wholly-owned subsidiary of the Bozak Corporation, New Britain, Connecticut, currently manufactures a line of products for Acoustic Field Management Systems using ERES and other technology under license from Jaffe Acoustics for applications in performing arts and religious facilities, as well as corporate boardrooms and conference rooms.

AMBIENCE ENHANCEMENT BY TOWNE, RICHARDS, AND CHAUDIERE, INC.

Towne, Richards, and Chaudiere's involvement with Electronic Architecture, or as we call it, Ambience Enhancement, has been in the area of broad-band enhancement of reverberation, in conjunction with the facility's sound reinforcement system.

This approach has been the result of typical projects with budget limitations and multi-use program requirements. It is not always possible to have sufficient volume for music programs (hence, inadequate reverberation), and speech-related programs are best with relatively little reverberation. This conflict (speech vs. music) can be resolved for much less money using Ambience Enhancement as compared to adjusting reverberation by architectural means.

Our first experience was at the Capitol Theater restoration in Yakima, Washington. This Pantages theater originally opened in 1920, functioned for a time as a movie theater and was restored as a community multi-purpose performing arts facility in the late 1970s. Our calculations indicated the hall would be on the dry side for classical concert use and since a good house sound reinforcement was needed, we looked into the possibility of adding some reverberation.

The sound system was designed as a combination point source/delayed distributed, primarily since the seating under the deep balcony could not see the cluster centered over the proscenium. A Quad Eight CPR-16 digital reverb unit was fed from one of the outputs of the sound system console and fed to the four delay zones as well as directly to speakers in the domed ceiling of the theater. The reverb unit was operated as a single-channel device.

The opening concert with Jan Peerce and the Yakima Symphony was positively enhanced by judicious use of the system. It was determined that any attempt at "more is better" could be disastrous, particularly in view of the inherent coloration of the CPR-16.

The next two installations used a similar approach, but with the Lexicon 224. These systems, one at the McMinnville, Oregon, Community Center, a multi-purpose facility generated out of an old National Guard Armory building, and the other at South Kitsap High School Auditorium, a 700 seater in Port Orchard, Washington, were a definite improvement over the Capitol Theater system, but were still basically a single channel system.

The next installation, in a multi-purpose room at the new Jewish Community Center on Mercer Island, Washington, incorporated two basic improvements. In all of the previous installations, the distributed speakers were all ceiling mounted and exposed. In the Jewish Community Center, there were both ceiling and side wall speakers, totally concealed, which were wired on alternate circuits to the left and right incoherent outputs of the 224 reverb unit.

In the previous installations, the sound system operator had access to all the reverb unit controls. At the JCC, the 224 control head was preset and put in the equipment rack.

The sound system controls and a single reverb control were mounted on a panel at the back of the hall. The effect was the best yet.

The latest system is presently being installed in a multi-purpose auditorium on Kodiak Island in Alaska. The hall is very similar to the South Kitsap High School Auditorium, but the system will use the Lexicon PCM-60 which is less expensive than the 224, and will have only ceiling distributed speakers, but will be wired on alternate "left/right" circuits.

Characteristic	Frequency Spectrum	Time Arrival
Presence	250 - 6000Hz	0 - 20 msec
Liveness	250 - 2000Hz	300 - 2500 msec
Reverberation	20 - 1500Hz	300 - 3000 msec
Warmth	20 - 250Hz	60 - 300 msec

Figure 8. Four basic channels of ERES.

Two other systems, one at another Pantages Theater restoration and the other for a new State University Theater building, were carried through design but not implemented to date, due to budget constraints. All of the systems can apply the reverb to the reinforcement mix and/or dedicated "ambience" mics. The latter can be PZM's mounted on the orchestra shell overheads. Where "idiot proof" user operation is a requirement, preset parameters with a simple "dry to wet" control can be used effectively.

Our limited experience shows that properly implemented, broad-band ambience enhancement can provide a positive effect that would not be possible without it. We see an increasing potential market in community and institutional multi-purpose performing facilities. Where competent resident operators are available, the wide range of selectable parameters in state-of-the-art reverberation devices can be used to good advantage for special effects, and/or varying program requirements.

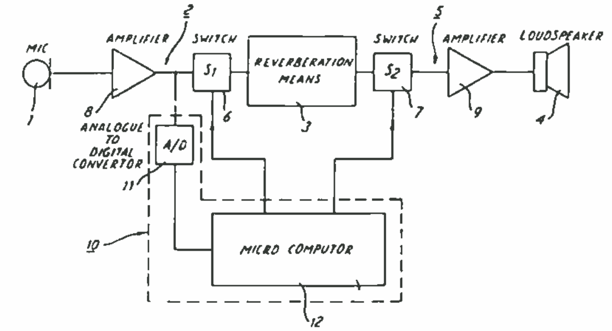

Figure 9. Simplified block diagram of the basic RODS system.

REVERBERATION ON DEMAND SYSTEM (RODS)—ACOUSTIC MANAGEMENT SYSTEMS, LTD.

RODS is the most recent development in the area of electronic architecture and was developed by Peter Barnett, formerly with AIRO (the developers/suppliers of the AR system). This system is designed to integrate with ERES and provides only the reverberation content. The diagram of *Figure 9* shows a simplified block diagram of the basic system. The essence of the system is as follows: Switches Sl and S2 are controlled by a microprocessor. The state of the switches is dependent upon the sound field; when the field is either steady or rising, Sl is closed and S2 is open. When the sound field starts to fall, Sl opens and S2 closes, releasing the stored reverberation into the space. Since Sl and S2 cannot be closed at the same time, the problem of coloration due to recirculation is much reduced. Clearly this is a much simplified account, since Sl and S2 are not, in fact, switches, rather they are digitally-controlled attenuators.

Because the reverberation level in one frequency band could be falling while another is rising, there is a need to increase the number of frequency dependent channels. The expanded block diagram of *Figure 10* shows a comprehensive system. The system operates on the same principle as the basic system, but each channel operates independently in a fixed frequency bandwidth. In addition, delay units and input and output transducers have been added to ensure that the reverberation is delivered in a natural fashion.

EPILOGUE

The viability of electronics in imitation of architectural acoustics has been shown as an adjunct to basic architectural and noise-reduction acoustic design techniques. An outline of the seven basic types of elctronic architecture techniques established a perspective on the technology. It was also shown that the use of electronic architecture gives the architect and/or owner unprecidented freedom for expression in architectural statement and flexiblity, while providing true multi-purpose spaces with the appropriate good multi-purpose acoustics. Likewise, these techniques allow for complete and precise control of the acoustics by/for the composer/musician enhancing and extending the limits for both performers and listeners alike. The increasing interest in performance-space electroacoustics, and its economic and functional attractiveness, is manifest in applications from small boardrooms to large multi-purpose halls. Perhaps, the next horizon are real home hi-fi ambience systems!

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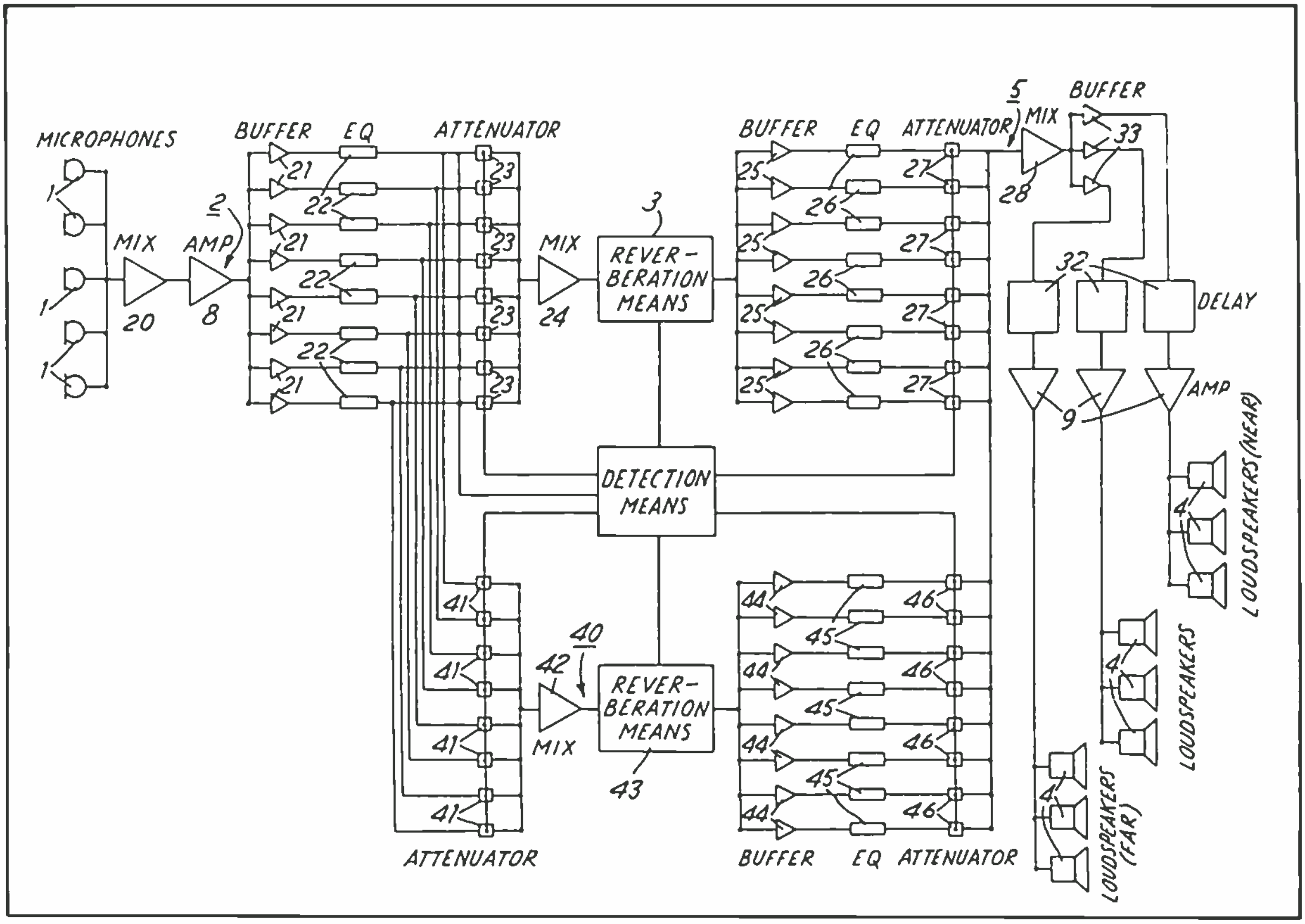

Figure 10. Expanded block diagram showing a comprehensive system.

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Marc L. Beningson

Electronic Architecture Applications

Learn the ins and outs of architectural acoustics.

Room acoustics, characteristic of almost any room or hall, can be duplicated in three dimensional space through electronic analogies of surfaces, material types, and physical volumes, as developed and practiced by Jaffe Acoustics, Inc.

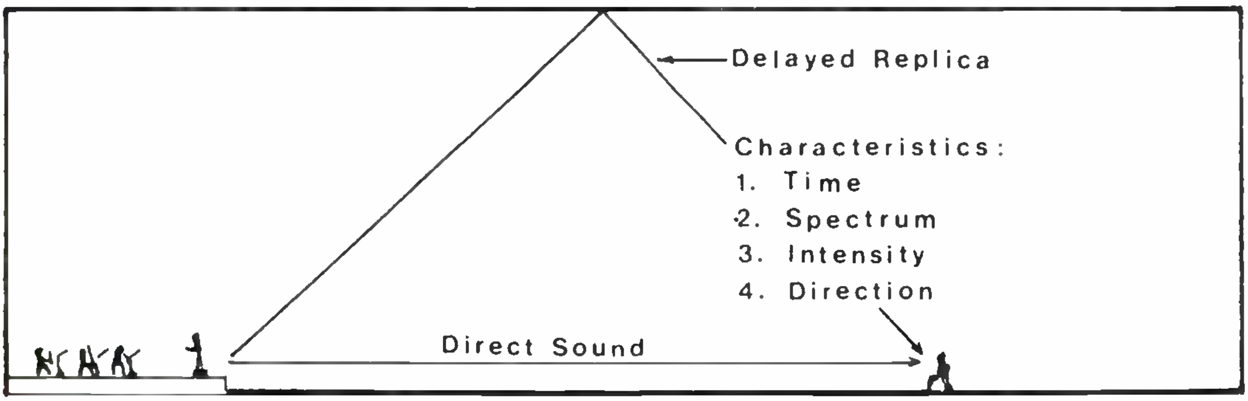
ACOUSTICS

Any sound in three dimensional space has four characteristics: direction, intensity, frequency composition, and time of arrival (which can be remembered by the acronym DIFT). Each of the many sonic events which collectively make up architectural acoustics is so characterized.

The direct sound, early reflections, late-field, and reverberant-field all make important contributions to musical sound, not only for the listener but for the musicians as well. Direct sound provides localization and a foundation to be enhanced by acoustic interaction.

Early reflections, normally from a concert shell and side walls, enhance volume, timbre, and articulation. They also provide a sense of liquidity, breadth, and immersion. Late reflections, from more distant surfaces and from multiple bounces, are important in maintaining the warmth and impact of bass instruments. This is also true of the reverberant-field, in addition to its prolonging and enriching effect.

Listeners appreciate the enhancement that good acoustics give to a performance. It is less well known that musicians also require good acoustics. They must hear their own sounds and be able to hear each other as an ensemble. The "friendliness" of a responsive space and its acoustic cues bring about an inspired performance. When good acoustical cues are absent limits are put on the performance even before it begins, including the impossibility of presenting certain types of music at all.



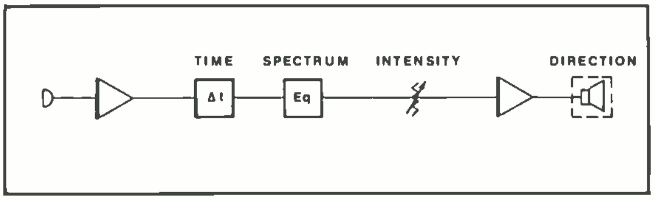
Events which collectively make up architectural acoustics.

Marc L. Beningson is an acoustical consultant of Jaffe Acoustics of Norwalk, CT.

THE ELECTRONIC REFLECTED ENERGY CONCEPT(ERAS)

It is possible to provide all of the components of natural acoustics through the careful application of audio technology, augmenting deficient natural acoustics or providing the complete ambience in a "dead" space. An electronic analogy of walls, canopies, ceilings, and physical volumes can be created, which responds to a sound source as would physical structures.

A basic ERES channel consists of a microphone, mic-

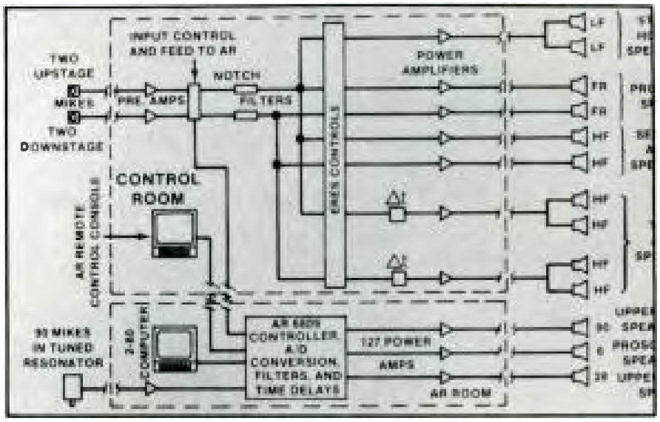


Basic channel for reflected energy' system.

rophone preamplifier, frequency shaping network, signal delay, power amplifier, and loudspeaker. The location of the loudspeaker provides the "D" in "DIFT"; the other three characteristics are controlled in the electronic path.

Unlike a recording or sound reinforcement audio chain, which typically condenses a multiple of input transducers into one or two output channels, an ERES begins with very few input transducers (usually a single carefully placed microphone) and expands through independent signal processing channels into a multitude of independently placed and adjusted output transducers, numbering in the hundreds in large installations. Appropriate location and signal processing enables these channels to imitate the behavior of architectural reflections in a concert hall, church, or other desired space. ERES, like the Philips MCR system, does not amplify the direct field, which contains unblended, amplitude-only information; ERES amplifies the diffuse sound which is a true representation of the intensity or total power and is fully blended. This aspect of which sound-field that is being amplified is what differentiates ERES from conventional sound systems.

The effect of a larger physical volume is provided by a special reverberator containing a large digital memory, through which signal passes only once (no electrical recirculation). The reverberator releases a dense string of replicas of the original sound, appropriately tapered and randomized in amplitude, time and phase, through a number of incoherent output channels. Between releases the room's early and late reflective fields are always developed, giving the decay a uniform character and avoiding coloration. The custom reverberator was designed by our firm and was first used for the NBC television programs "Live from Studio 8H," featuring the New York Philhar-



Block diagram of system at Silva Hall.

monic Orchestra. (*Editor's note: this application will be discussed in greater detail in Wade Bray's article which will appear next month*).

ARCHITECTURAL FREEDOM

A classic example of a facility incorporating innovative architecture are the Silva and Soreng Halls in the Eugene, Oregon, Performing Arts Center. *Figure 1* shows an orchestra level plan of the two halls, and *Figure 2* shows a section of Silva's 2200 seat multi-purpose hall. In order to accomodate a wide variety of loudspeaker systems, the proscenium arch is sound transparent. Reflective panels located behind the transparent proscenium at critical areas and an orchestral shell provide substantial early reflections.

The acoustics of this hall would not be satisfactory for symphonic programs without the use of electronic architecture. In Silva Hall, the natural acoustics are supplemented by ERES, which supplies the early reflection package that is not sufficiently provided by the architecture. In addition, an Assited Resonance System extends

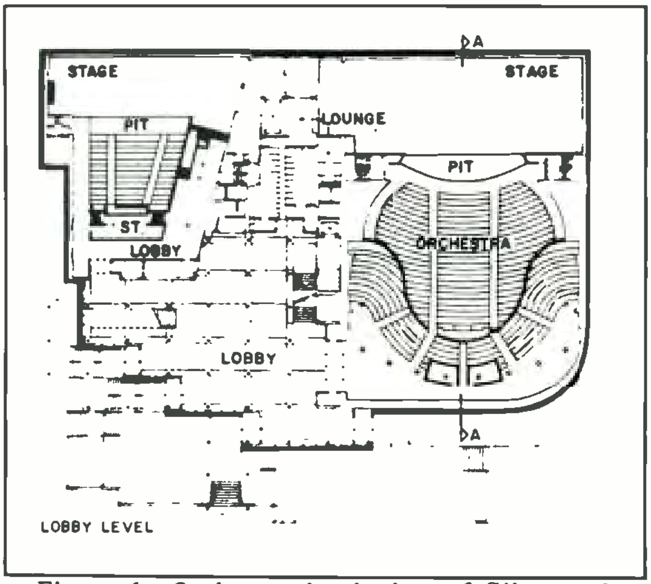


Figure 1. Orchestra level plan of Silva and Soreng Halls.

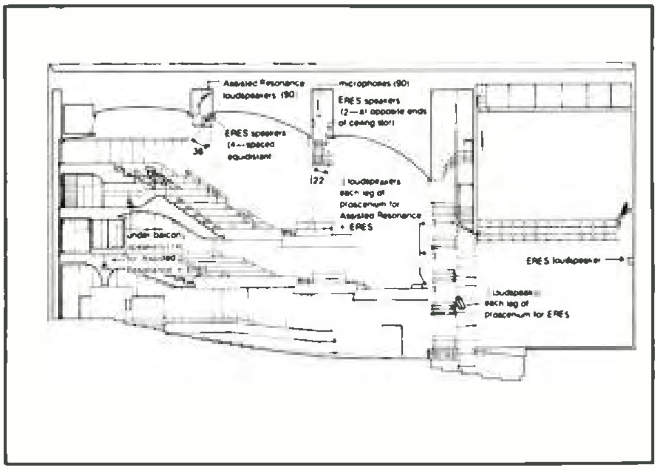
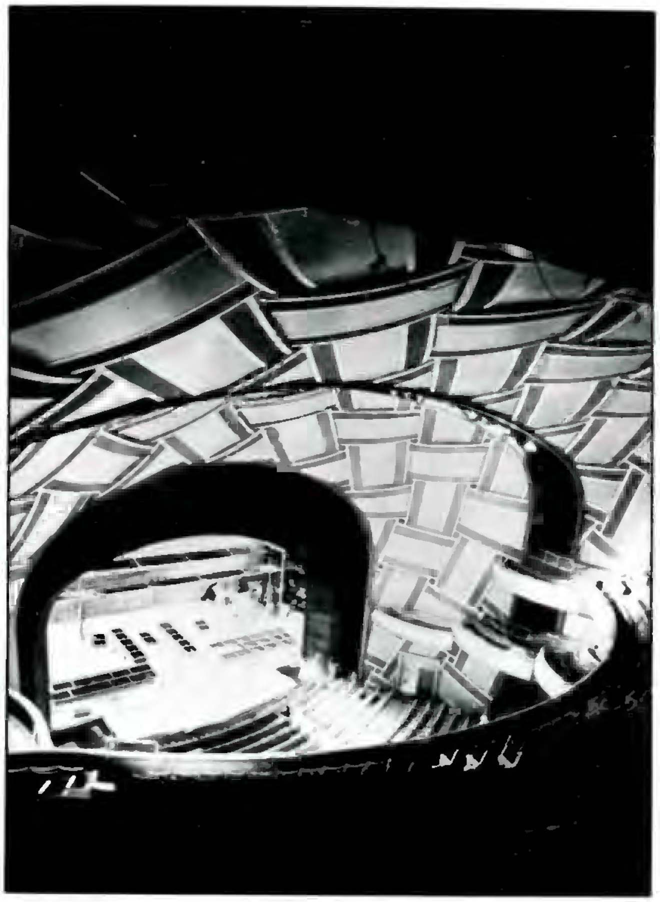


Figure 2. Section of Silva Hall's 200 seat hall.



View from Balcony of Silva Hall.

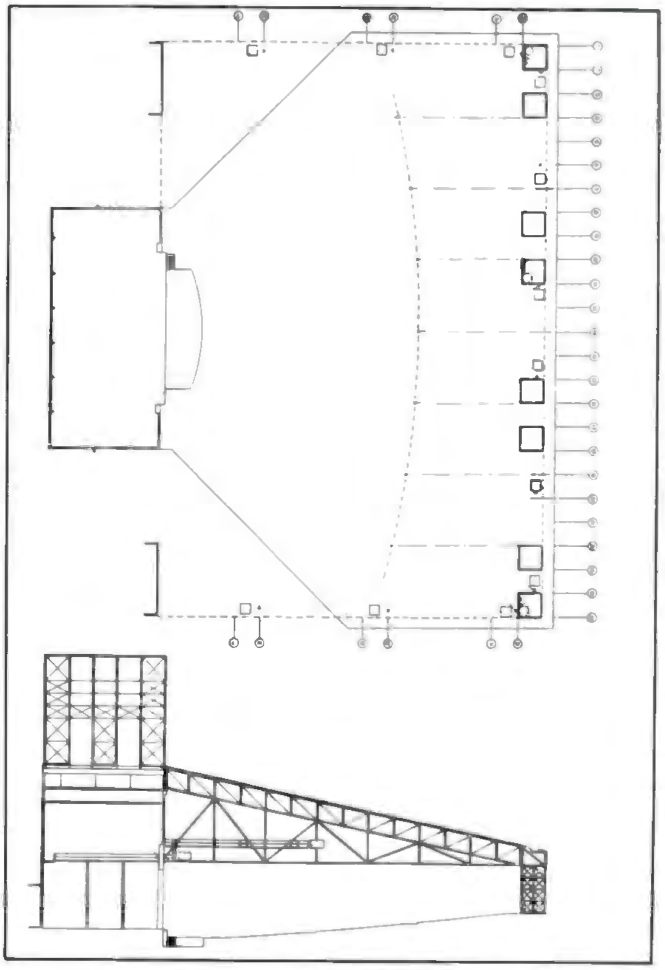


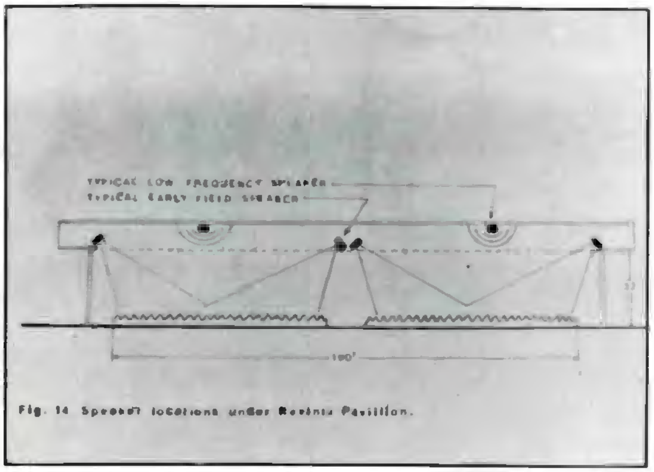
Figure 3. Plan and section of Riverbend.

the reverberation time as required, for unamplified musical programs. Assisted Resonance was originally developed by Peter Parkin, and designed by Jaffe Acoustics as part of the overall plan for Silva Hall. (*Editor's note: The principles of the AR system are covered in detail in* "Electro-Acoustics in Architecture" *in this issue.*)

By varying the settings of the systems, multi-purpose acoustics becomes a reality. Patched absorption above the acoustically transparent basket-weave ceiling increases diffusion and reduces the natural reverberation times, allowing Silva to handle amplified programs more easily. When ERES and the AR are turned on, there is more presence, warmth and fullness for symphony and other musical programs. Settings between these two extremes allow many other different programs to be accommodated. Here, electronic architecture has provided the architect with the ability to design a hall that makes a particular statement by reducing the need to conform to generally accepted architectural acoustic rules.

HALLS WITH NO WALLS

Ravinia Festival Park, summer home of the Chicago Symphony Orchestra, and Riverbend Music Pavilion, summer home of the Cincinnati Symphony Orchestra, are two examples of outdoor music pavilions with no side or rear walls. *Figure X* shows a plan and section of River-



Drawing of Ravinia.

Shed at Ravinia.

Ravinia Shed

View from balcony of Laurie Auditorium.

bend. At Riverbend, an audience of over 5,000 is seated in front of a standard proscenium stage. Ravinia seats 3,000 in front of a stage platform which is in the same acoustic space as the audience. Ravinia has a somewhat capped roof, while Riverbend's walls are almost completely open. Both have patched absorption under their shed roofs to increase diffusion and reduce the reverberation for amplified programs, and ERES re-creates and further increases early reflections and reverberation for concerts and symphony pops productions.

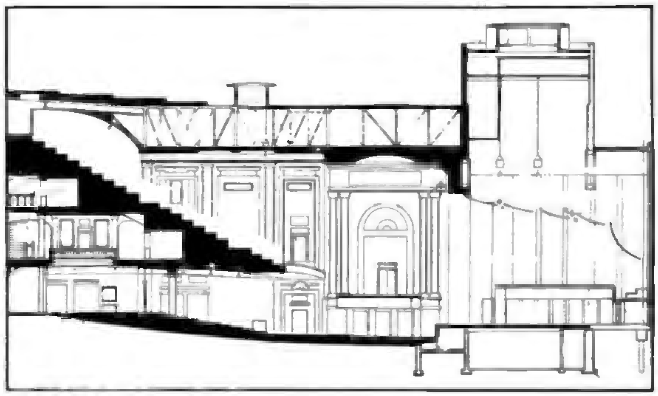
The lawn at Ravinia Festival Park, Chicago, Illinois, is an interesting example of unusual architecture—there is none. Here physical acoustics cannot be utilized, because there is no structure of any kind. The direct sound must be reinforced on the lawn. No symphony orchestra could provide enough sound pressure level for ten thousand people spread over ten acres to be heard effectively. But, in addition to the pole-mounted column speakers needed to reinforce the direct field, delayed omni-directional speaker arrays on each pole provide lateral and rear reflections for the lawn audience. Low-frequency speakers on long delays provide a sense of reverberation in what is essentially a free-field environment. The acoustics of a fine concert hall are created by electronic architecture in a situation where there is absolutely no possibility of using a physical acoustic solution.

Laurie Auditorium at Trinity University in San Antonio, Texas, is an example of an existing facility whose original design intent did not accomodate the acoustic requirements of a new program. Built as a collegiate lecture hall, Laurie Auditorium has a wide fan-shaped seating area and a low physical volume. The acoustics of the space were appropriate for speech and lecture. But when the San Antonio Symphony began performing in the auditorium, it was immediately apparent that the acoustics were inappropriate for the presentation of orchestral music. A simple ERES was installed and later expanded to a full system. In conjunction with onstage reflectors, ERES provides early reflections which would otherwise arrive too late because of the wide side walls.

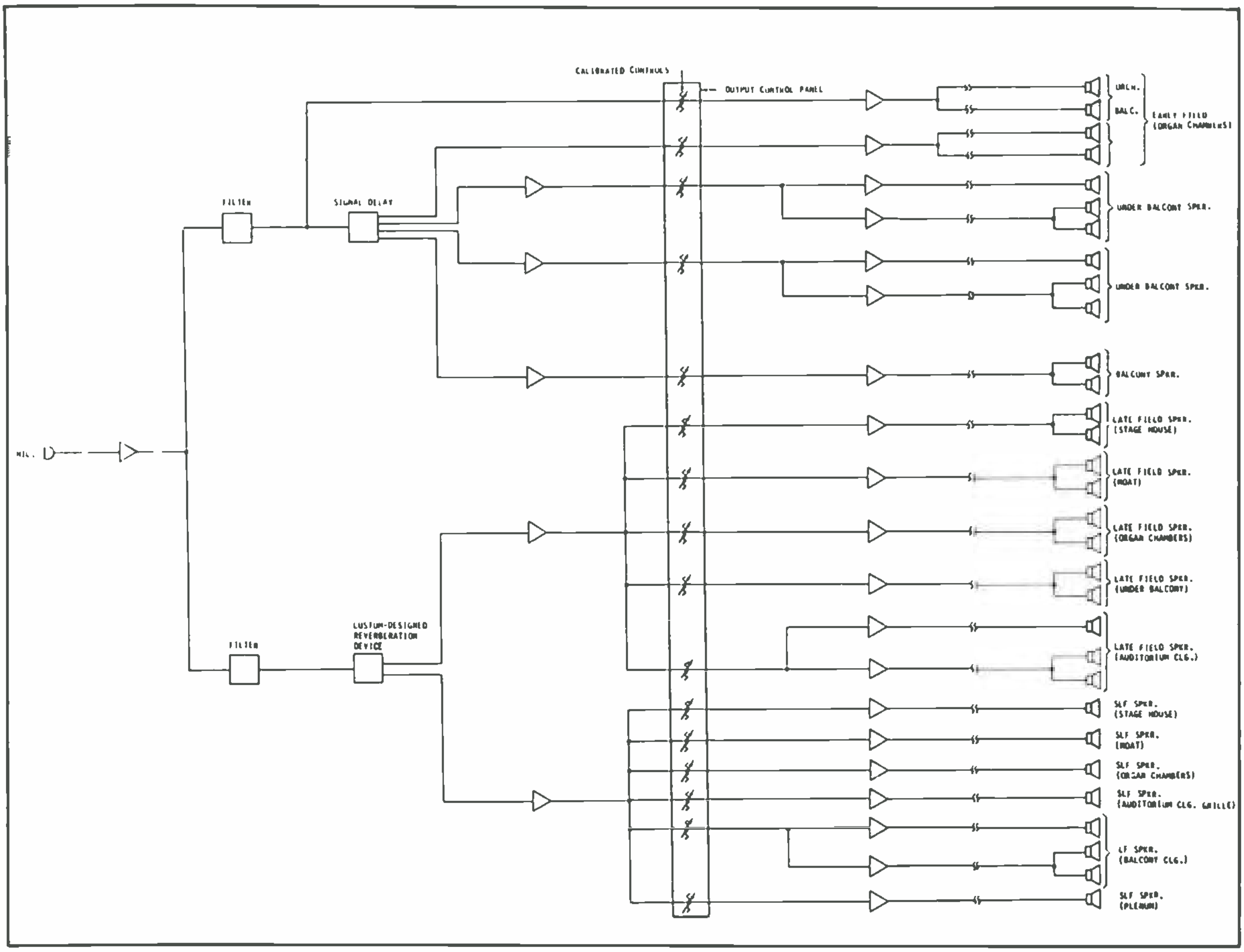
The reverberant-field, which was severely lacking in the space due to the low physical volume per unit area of audience seating, is supplied almost completely by ERES. Thus, without altering the structure in any way, the acoustic requirements of a new and different program were effectively and inexpensively met. Addittionally, because the structure was not altered, the original program has not been excluded from the space. With ERES off, Laurie Auditorium is the same lecture hall it was before. With ERES on, it becomes a viable concert hall. In this case, a physical solution providing the same flexibility would be complex and cost prohibitive.

The Circle Theatre, which is the new permanent home of the Indianapolis Symphony Orchestra, is currently the flagship of a number of facilities utilizing ERES technology of electronic architecture to meet the correct acoustic criteria for symphonic performance. Originally, a vaudeville house and movie theater, the Circle has a low physical volume per person, and deep but low-ceiling underbalcony

Stage at Circle Theatre.



Section of Circle Theatre.



ERES system at Circle Theatre.

area typical of this type of theater. With narrow sidewalls and a renovated stagehouse, including a Jaffe Acoustics designed reflector system (concert shell), the natural early-field was excellent; thus, only a minimal early-field system was required to augment presence and running liveness in the underbalcony and low-ceiling upper mezzanine. The late-field system was designed to provide the additional reverberation required for the symphony. A number of coupled physical volumes were energized, including the stagehouse over the reflectors, the organ chambers, and an acoustic-moat constructed from the old orchestra pit. SLF field speakers, located in the same spaces, provided additional warmth for the low-frequency instruments. Several warmth speakers were also located in the underseat return air plenum which coupled to the hall through over one-hundred "mushrooms."

Electronic architecture, in the form of ERES, was able to transform the Circle Theater from a movie palace into a concert hall. The symphony could not have used the space within the guidelines of historic preservation without electronic architecture. With the acceptance of electronics in the concert hall environment, both acoustic and historical requirements were met, thereby, giving a special space such as the Circle Theater a new lease on life.

The ERES installation at the Circle continues to be well received as the Symphony begins its second sold-out season in its new home. Musicians, concert goers, and critics have been pleased with the Symphony's sound in the theater.

ERES has also been used successfully in other facilities for symphonic production including Whitney Hall, Kentucky Center for the Arts, Louisville, Kentucky; Salle Wilfred Pelletier, Place des Arts, Montreal; NBC Studio 8H, New York City; and Kansas City Music Hall, Kansas City, Missouri; among others. Upcoming projects utilizing ERES include a 2,100-seat, multi-purpose hall at the Anchorage, Alaska Performing Arts Center, designed by architects Hardy Holzman Pfeiffer Associates, the architects of the Eugene facility, and a 1,200-seat, multi-purpose theater in Columbus, Ohio.

CONCLUSION

Electronic Architecture is not a replacement for physical acoustics. Other aspects of acoustic design such as sound isolation, elimination of echoes, HVAC noise control and the reduction of excessive reverberation, must rely on physical acoustic solutions. At present, electronic architecture is most effective when used in conjunction with good physical acoustic design practice. However, after twelve years of development and application, ERES has proven itself a sophisticated and cost effective tool in the design of all types of performing spaces. ■

Electro-Acoustic Techniques In The Boardroom

Richard Feld

Good acoustics prompts efficient communication.

Editor's note: This article is based upon "A New Concept in Boardroom Sound" that appeared in the January, 1986, issue of Sound & Communications.

GOOD ACOUSTICS IS NOT WHAT one generally associates with corporate boardrooms. But in today's computerized information age when meetings take place almost robotically, good acoustics affords the possibility of efficient communication within the conference room itself. Good boardroom acoustics also greatly enhances the quality of transmitted audio for teleconferencing. When a sound contractor is called upon to "do something about the sound" in a corporate boardroom, the last thing on their minds is modifying their posh decor or tearing out their solid Brazilian rosewood walls, both of which happen to reduce the reflections necessary for increasing speech intelligibility. A lot of us have been faced with these situations, and unfortunately conventional sound system designs are often marginal at best. When TekCom Corporation was recently called upon to improve the speech intelligibility in one such boardroom, we decided to install an electro-acoustic "enhancement" system. The story begins here with some basics on electro-acoustic techniques in boardroom applications and concludes with some highlights of the installation at the Health Services Center, in Princeton, NJ.

SOME BASICS

Poor conference room acoustics can degrade the working environment to such a degree that productivity decreases—something with which no company can live with. Human stress can be attributed to several basic common acoustical problems, prevalent in many conference and board rooms today. When one must project their voice loudly, to overcome the distances encountered in long boardroom tables, physical and psychological stress is provoked. Likewise, physical and psychological stress is provoked when one must strain throughout a meeting to hear properly. Also, secondary problems may arise due to individuals who habitually speak at low levels, or even more frequently, for many senior board members who have some degree of hearing difficulty. The studies on speech intelligibility date back to the early days of telephone with much work done in the early 1900s by Cambell, French & Steinberg, Fletcher, and Knudsen. Their work provided us with a wealth of information and has served as a foundation for work in the field of speech intelligibility. Later, Beranek conducted research concerning speech communication and his methods became the "benchmark"

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Ceiling showing installation at Health Services Center in Princeton, NJ.

for the assessment of the percentage of articulation of consonants used as a basis of a measure of speech intelligibility. Lochner and Burger developed the concept of signal-to-noise-ratio (S/N) discriminating between "early" energy deemed useful and "late" energy which masked the signal.

The intelligibilty of speech is easily rated subjectively—either one can understand words spoken in a room or the words result in cacophony. Reliable objective analysis, however, was not possible until the work of Houtgast and Steeneken, who developed the Modulation Transfer Function (MTF). With MTF measurements one can, for the first time, objectively measure the intelligibility in any room or sound system/room(s) and assign a single meaningful MTF number, which corresponds to subjective assessment. Based on the work of Houtgast and Steeneken, Bruel & Kjaer have developed a dedicated system that simplifies the measurement of MTF, their process is called Rapid Speech Transmission Index or, RASTI. With these tools at our disposal, it is now possible to objectively measure, with great accuracy, exactly what degree of intelligibilty may be expected, and thus, assign target values to be provided for. Once these values are established, it is the object of the designer to determine methods of providing the necessary articulation, signal-to-noise ratio, and optimum MTF.

THE HARDWARE

Based on the technologies Jaffe developed for con-

Speaker and mic on ceiling at Health Services Center.

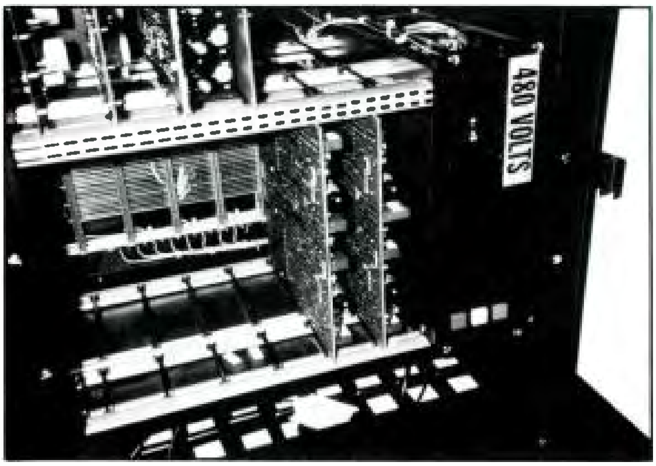
cert hall ERES, they developed a "Boardroom Sound Reinforcement System," and were granted patent #3,992,586 in 1976. Jaffe's boardroom system is based upon modules which consist of two loudspeakers operating in anti-phase, such that there is a "cancellation-zone" in between the loudspeakers, where a microphone is then placed. The loudspeakers in a module do not reproduce any sound pickup from its microphone; the loudspeakers only reproduce signals from microphones in the other modules. This technique allows for a stable system since the microphone is not in the direct field of the loudspeakers. Thus, there is a sufficient amount of gain-before-feedback due to the geometrical relationship of the talker/microphone/loudspeaker/listener. Additionally, the reverberation times in these types of rooms is usually on the dry side, especially in the vicinity of the acoustical ceiling. This helps even more by ensuring that there is not much in the way of reverberant energy to be amplified. The only physical requirement is that a maximum noise level of NC25 should be measured in the room. That is what might be called the "physical-alignment" part of the system.

Now, for the electronic side of the story. Everybody knows that when the distance from a source is doubled, its SPL drops by 6 dB—that is, the inverse-square law. So the electronics in the mainframe are set-up to compensate for the 6 dB drop-off by increasing the gain at a rate of 6 dB as the distance from the source is doubled. This is, of course, field-adjustable to compensate for any reverberant energy that may contribute to the level. Signal delay is also incorporated to take advantage of the well known "Haas-effect" or "auditory fusion-zone." This simulates the "early-field" reflections one would normally hear a lot more efficiently (no absorption or diffraction from architectural materials). Because of the incremental delay introduced to the signal the source is never "colored" by the loudspeaker. In addition to the gain afforded by the "cancellation-zone" microphone placement, narrow-band notch-filtering is also employed for extra system stability.

Jaffe's first specified boardroom installation was the General Electric Corporate Headquarters in Fairfield, Connecticut. After the highly successful installation at GE, the boardrooms of prestigious corporations soon followed suit, they included Federated Stores, IBM, Natomas Company, Utah International Corporation, and Mitsubishi Corporation in New York. Because of the need for this technology to be brought to its full potential in the marketplace, Technical Acoustics Incorporated, a wholly owned subsidiary of Bozak, Inc., was formed. TAI licenses the technology from Jaffe, manufactures "ready-to-install" Boardroom Systems, and directly supports those interested in specifying or installing the "Jaffe Boardroom System" with complete design specifications on a project-by-project basis. TAI currently manufactures a mainframe that houses individual cards that perform the various I/O, mixing/matrixing, filtering, delay, and amplification functions. They also manufacture two different configurations of the ceiling loudspeaker/microphone module. The notch-filter cards that are included with the system feature two sets of four filters each. Each card has dip switches so that the notch-filters may be assigned to any part of the circuit, or disabled if necessary (for example, AV playback). Other options that the mainframe can accommodate include AV inputs, recording outputs, teleconferencing interface, link-ups of multiple spaces, hard-of-hearing loops, and translation system interface. Recently, GE renovated their board room and decided to update the original Jaffe Boardroom System. This time, instead of a custom-wired installation, a TAI mainframe and modules were installed which incorporated teleconferencing features. A true testimonial when a client orders the same system after ten years of use!

"HOT-CEILING"

A further development of the Boardroom System is



Box with cover off at Health Services Center.

Boardroom Installation at Federated Stores

Boardroom Installation at Natomas Co.

what TAI calls the "Conference-Ceiling." The Conference-Ceiling evolved around the necessity to provide a system for boardrooms with irregular layouts. For example a large square table. This system differs in that the modules use only one loudspeaker, and are installed such that they are geometrically and electronically balanced in pairs. A Conference-Ceiling system was the type of system installed at the Center for Health Affairs in Princeton, NJ. Their boardroom presented some unique features, starting with the large square-shaped boardroom table with twenty-six seats, and ending with the three rows of "audience" seating that must be capable of two-way communication. For this project the capability was added to mute the audience microphones during formal presentations and then open them for full duplex-communication when desired.

The boardroom's solid-wood walls, concrete floor with thin carpeting, and oversized table presented several problem areas. These hard surfaces in this rectangular shaped room yield several room modes at 200 Hz and 440 Hz. When the system was being designed it was clear that these modes would be both excited and amplified by the system. Therefore, a White 3900 series narrow-band passive equalization was specified. The 3900 system consists of 600 ohm filters that have a Q of 50; i.e., below 500 Hz they are 10 Hz wide. The filter-set covers the frequency range of 50 Hz to 2.5 kHz, with a 5 Hz spacing at the low end changing to a 13 Hz spacing in the upper range. This adds up to 195 filters. The filters are brought to the job site in three flight-cases, weighing in at approximately 175 pounds.

The narrow-band system enabled us to de-energize the system at several predicted room modes, suppress individual sinusoidal feedback frequencies, and eliminate proximity modes. Because of the very high Q bandwidth of the filters, very little information was lost in the equalization process, yielding a high-fidelity, high-intelligibility, sound system. All totalled, fifteen filters were used, and the tuning took several hours. Since the filters are passive the equalization is totally quiet—using active electronics would result in a noise generator.

From an ergonomic point of view, the Jaffe/TAI board room systems offer a unique alternative to the massive array of microphones and the associated hardware of "conventional" systems. The Jaffe/TAI systems offer the consultant or contractor the opportunity to show a client a system that is totally invisible, not only visually but operationally as well. Jaffe/TAI's Boardroom Systems have proven themselves as an effective approach in providing a "perfect" acoustic environment for corporate executives to work in. Articulation of consonants is maintained at a high level, while eliminating the need and stress/inhibition of talking into a microphone. There are ergonomic advantages for the consultant and contractor as well. A typical corporate person who wishes to "do something about the sound" in his boardroom may have his requirements easily fulfilled by the architecture of one system. The specifier of the project may now design the system from

Boardroom Installation at Utah International Corp.

various plug-in components within a mainframe system—no more custom engineered relay schemes, etc. The actual installation is also easy as it entails only installing ceiling modules and wiring them to a factory-wired mainframe. There is no pre-installation fabrication of the system required by the installer. Any system may be installed, tweaked, and tuned in a matter of a couple of days.

The bottom line is that in most cases the TAI Board-Room System is a more economical approach than using conventional microphones, signal processing, and amplifiers. In the long-run, it saves the customer money, while at the same time giving him a "slick" installation, and may be your best sales tool. ■