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INSIDE OUT – TIME VARIANT ELECTRONIC ACOUSTIC ENHANCEMENT PROVIDES THE MISSING LINK FOR ACOUSTIC MUSIC OUTDOORS

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ABSTRACT

No matter how good the acoustic ensemble, moving them from the concert hall to an outdoor stage dramatically changes the listening experience for both the musicians, and those in attendance – usually, not for the better. For the musicians, the loss of reflected and reverberant energy alters communication between members of the ensemble. The physiology of playing the instrument changes as well – without support from reflected and reverberant energy, musicians must compensate. Thus while the outdoor performance experience of may be deemed “good” for both those playing as well those listening, it is not the experience that either desire. This paper describes how time variant electro-acoustic enhancement has been successfully used to dramatically improve the acoustical musical experience for outdoor performance.

1. INTRODUCTION

It has taken some time, but after 30 years, modern time variant electronic architecture has moved from a measure of last resort to a viable means of improving the listening experience in a wide variety of venues and applications. One of the most unique and demanding uses of this technology is in outdoor venues. This paper will describe the numerous challenges involved in the implementing these systems successfully. Installations to be discussed include Crystal Palace - UK, Morbisch Seefesspiele – Austria, Vienna Fest – Austria, Mathausan – Austria, Turandot at the Forbidden City-China, Millennium Park – Chicago IL, and the Sun Valley Pavilion- Sun Valley, Idaho.

No matter how good the acoustic ensemble, moving them from the concert hall to an outdoor stage dramatically changes the listening experience for both the musician as well as those in attendance – usually, not for the better. For the musicians, the loss of reflected and reverberant energy alters communication between members of the ensemble. The physiology of playing the instrument changes as well – without the support from reflected and reverberant energy, musicians must compensate. In most cases, this literally equates to more effort. Thus while the outdoor performance experience of may be deemed "good" for both those playing as well as those listening, it is not the experience that either musicians or the listeners desire.

2. ACOUSTIC MUSIC IN ENCLOSED VOLUMES

Enclosed volumes designed to support acoustic music typically provide a significant amount of reflected and reverberant sound to both the listeners as well as the musicians. The manner in which this energy is developed is dependent on the size, geometry, and the composition of the surface treatments of the volume. The architectural elements of the volume have linked relationships that were first documented scientifically by Wallace Clement Sabine's experiments in the late 19th century, and subsequent work on the acoustics of Boston Symphony Hall. The level and duration of reflected sound changes as these architectural elements are manipulated. If a volume has uniform surface absorption, increasing the size will increase the reverberation time, and the reverberation level will decrease. Likewise, reducing the size will increase the level of the reverberation, and reduce the reverberation time. The geometry of a volume is crucial to the sonic characteristics perceived in the space. Boson Symphony Hall, Gross Concertgebow, and Gross Musicvereinshall are all shoebox shaped halls of about the same size. The sound quality in these halls is rated very highly. This implies that the properties of the reflected and reverberant energy produced in these spaces, as interrogated by human neurology, produce a musical experience is deemed to be "good" for both the musicians and patrons alike. We can use these spaces as a benchmark for good musical sound quality derived from architectural acoustics. Beranek[i] notes the following averaged parameters:

	Boston	Amsterdam	Vienna	Average
RT	1.94	2.00	2.00	1.98
EDT	2.40	2.60	3.00	2.67
Bass Ratio	1.03	1.08	1.11	1.07
ITG	15 msec	12 msec	21 msec	16.00
V Sq. Ft	662000	663000	530000	618333
Length	128	86	132	115
Width	75	91	65	77
Height	61	56	57	58
seats	2625	2037	1680	2114

Table 1 Averaged Data from Renown Shoebox Halls

At first glance, one could make a guess that if these properties were reproduced outdoors, that the indoor listening experience in a good hall would translate to the outdoor environment. There are several other critical factors, however, that are not accounted for in this data that have a significant impact on perceived sound quality.

First, it is important to note that most of the important parameters developed for quantifying acoustical conditions, including RT60, EDT, RR, and C40 and C80 ignore the direct sound. The ratio of direct sound to reflected and reverberant sound, and our ability to localize the sound source distinctly, is one of the most important factors in perceived sonic quality. The critical distance (where the direct sound and reverberant field have equal magnitude) in Boston Symphony Hall is approximately 21 feet. This means that most of the seats in the venue have a negative direct to reverberant ratio. Under these conditions the Initial Time Gap (ITG) between the arrival of the direct sound and the reflected and reverberant sound is very important to the ability to localize the sound source. When we cannot aurally localize the sound source, the sensation of acoustic intimacy and involvement with the music is undermined[ii]. Boston Symphony Hall, Concertgebouw, and Musikvereinssaal have architectural elements that reflect sound back toward the stage. These reflections help to reinforce the direct sound, particularly at the rear of the hall where the direct sound is weakest. Still, it is important to note that in many of the best seats, the D/R is -6dB to -8dB, and we rate this experience as excellent.[iii]

3. HUMAN PREFERENCES FOR ACOUSTIC CHARACTERISTICS IN RECORDED MUSIC

A little more than 100 years has passed since the advent of recorded and reproduced sound, and about 50 years has passed since the advent of magnetic tape recording. Along with magnetic tape recording came close microphone recording techniques that changed the paradigm for recorded music. Multi-track recording enabled the direct to reverberant ratio to be altered on independent sound sources as required. The advent of digital reverberation 30 years ago provided a variety of ambient conditions that could be summoned on demand. As a result, a 20+ year archive of recorded acoustic music exists, with a large portion using digital reverberation as part of the production process. This means that the properties of the music alone have been used to determine the amounts of digital reverberation required to create results that human neurology might interpret as “optimum”. These direct to reverb ratios chosen are largely in agreement with listening tests that David Griesinger performed at while at Lexicon[iv]. Under these conditions, the D/R deemed to be optimum is +4 dB to +6dB. This is NOT what one experiences in a hall. Yet, if we fundamentally desired a different result – the recordings would have been different. For many of us who are not musicians or conductors working daily in halls, the immense volume of recorded media in all forms serves to condition our expectations for sound quality. This is what we have come to expect from live performances as well.

4. OPERATIC PERFORMANCE

Opera is a bit different. The traditional romantic opera house is horseshoe shaped with multiple balconies on vertical tiers that serve to place the patrons closer to the performance. Unlike a concert hall, the orchestra is not the centerpiece – in most instances it is lowered into a pit below stage level. For opera, the sets and singers are the visual focus, and the drama is key to the performance. In Berlin, Barenboim wanted the singers to be clear and articulate with the orchestra rich and full – a seemingly impossible task. Most of the conductors that we have worked with are very sensitive to the absolute level of the reflected and reverberant energy – even when positioned in the orchestra pit. Most are able to discern a 1dB level change – some even 0.5dB. We have learned through experience that they are listening for a change in perceived acoustic distance from the singers. This change alters the perception of involvement. Richness for the orchestra is secondary to maintaining involvement and aural localization of the principals – even when they are singing in a language that is foreign to the listeners. Achieving desired results involves careful manipulation of the frequency content, magnitude and timing of reflected and reverberant energy throughout the venue. The need to maintain clarity and presence for the principals equates to D/R ratios in the range of vocal formants that are closer to those found on recordings.

It is difficult to make an A/B comparison of the natural acoustics of an excellent hall to an augmented condition in the same venue that has D/R ratios that are indicative of recorded music. This is largely due to the complexities involved in setting up the equipment required on a temporary basis, and making all of the other arrangements required in order to make a valid comparison. For many years, however, we have been using time variant electro-acoustics to improve the listening experience in a variety of enclosed volumes with great success. We have documented many such instances in papers that we have presented at numerous meetings of scientific organizations. In all cases, we have employed both system designs and parameter settings that achieve optimum results based on the nature of the music in these venues. This is an important distinction between architectural treatments that cannot be manipulated quickly for comparison.

5. THE GREAT OUTDOORS

In most instances, the outdoor environment presents many unique challenges that are not faced indoors. Some of these problems are not news to those who regularly operate outdoor sound reinforcement systems. The biggest problem for acoustic music is maintaining impact over a distance that is typically larger what is encountered in most halls. In most outdoor environments, critical distance is meaningless – however the magnitude of the direct sound diminishes with distance. Although sound reinforcement with close microphone techniques is regularly used outdoors, the resultant sound quality for acoustic music is often deemed less than optimal. This is due in no small part to the lack of reflected and reverberant sound that is typically provided by the architecture and surface treatments of an enclosed volume. In all instances that we have encountered thus far, the size of outdoor venues dwarfs a typical concert hall or opera house. All of the outdoor facilities that we have equipped have seating (or standing room) in excess of 3000. This further exacerbates the problem of maintaining the impact of the ensemble. Changing weather conditions – wind, temperature, humidity and precipitation also come into play. The noise floor is dramatically different – and it is different venue to venue. Last but not least all of the venues are unique, as are the designs.

6. SYSTEM ARCHITECTURE

Not all electro-acoustic enhancement systems operate in the same manner. Systems based on the physics of the Philips MCR[v] system employ multiple independent microphone and loudspeaker channels separated by the critical distance of the room with all channels operating just below the onset of acoustic feedback. Any system that is reliant on the acoustical conditions created by architecture in order to operate cannot be utilized outdoors. The gain before feedback advantage associated with time variant electronic architecture[vi] combined with synthetic digital reverberation provide a significant advantage when integrating electro-acoustic enhancement into large outdoor venues.

7. VENUES

7.1. Vienna Fest

Our first encounter with outdoor sound occurred nearly 15 years ago with a request from Adolf Toegel[vii] to install a temporary system for Vienna Fest on the Platz featuring the Vienna Philharmonic Orchestra and the Arnold Schoenberg Choir. Although more than 30,000 are in attendance annually, the scope of the original system was limited to the semi-circular roadway surrounding the Platz, and several positions on the roadway leading to the Art Museum. These speakers were mounted on poles, and were aimed at toward the stage. (See Figure 1) In addition, 24 speakers were mounted over the stage to provide acoustic energy for the choir and orchestra, and four de-correlated clusters were added to the stage FOH system. Sound reinforcement consists of two Midas consoles to accommodate enough independent microphone channels for both the orchestra and choir. A student orchestra rehearses in advance of the concert to enable the engineers to determine rough mixes by section. This is fed to a large LCR array flown over the truss of the temporary staging. The LARES system uses four microphones suspended over the stage, and two of the original LARES Mainframe processors. The results were good, as the distance from the poles to the stage was on the order of eighty feet, and the energy coupled well with the stage system.

From Toegel:

"This was the first time on this location with classical music that we were not critisized for spoiling the music by amplifying it."
Alfred Toegel, Sound Department, Vienna Festival

The system has been subsequently modified to include permanent pole positions and still used for the annual event. (See Figure 2).

7.2. Crystal Palace, UK

The system designed for Crystal Palace in the UK was not intended to improve conditions for the audience – instead it was installed into a unique canopy designed to assist the orchestra by providing reflected and reverberant energy to support the ensemble. Sound reinforcement was incorporated into two towers that provided direct signals to those seated on the lawn. The enhancement system comprised 28 full range speakers mounted flush into the canopy (See Figure 3) – which is a large plainer surface constructed from steel and rotated on an angle that overlooked the stage. (See Figure 4) The stage was suspended over a small lake that extended in front of the stage for some 60 feet or more. Sound from the canopy reflects off of the pond and grazes the hill where the audience is seated (See Figure 5). Thus the audience receives sound that is well blended. As one moved further up the hill, the sound becomes progressively more reinforced, as one might expect. However, for a good portion of the seating area, the sound quality was surprisingly good.

7.3. Morbisch Seefestspiele

Austria has two large outdoor operattas that are situated on lakes. The Bregenz fest located on Lake Constance and boarders Switzerland and Germany. Morbisch Seefestspiele is located on the Lake Neusiedl and boarders Hungary. While Bregenz stages a variety of productions, Morebisch is stages only opera.

These venues are quite unique, and both are well attended. Morbisch has been expanded in recent years to seat 7,500 in a single raked seating area that overlooks the lake (See Figure 6) The stage and seating are separated by a moat, and the orchestra pit is located near the front of the stage below the water line (See Figure 7) The audio systems in Morbish are also unique. The chief engineer for the Vienna Staatsoper, Prof. Wolfgang Fritz, designed the systems in accordance with the system in place at the Staatsoper. These venues were the first to use the TOA ix 9000 digital audio console in the early 1990's. In addition, Morbish employs a Delta Stereophony system for primary sound reinforcement of principals wearing wireless microphones. As many as forty independent loudspeakers are integrated into scenery. Delay and level for each principal is calculated to the loudspeaker array, and adjusted in real time by and dedicated console with belt track faders that enable the operator to follow their movements on stage (See Figure 8). The orchestra is miked by section and another operator creates the mix that is fed to speakers in towers to the left and right of the stage. Ambient microphones augmented by a submix from the orchestra console are fed to one of the LARES Mainframes, while a separate submix from the principals feeds a separate LARES Mainframe. These are treated as two separate systems so that early and late energy can be optimized independently. These signals are then combined and sent to speakers mounted on poles that surround the venue. Poles have both upper speakers that are directed to the middle of the venue, and a lower position that has independent delay and EQ for those seated in closer proximity to the poles. The Delta Stereophony system overcomes typical localization problems that occur when the sound source is not located near the loudspeaker that is producing the direct sound. Thus, the wide stage allows for a wide stereo image from the orchestra. Scenery is often positioned on boats and floated in to place (See Figure 9), and they have on occasion used portable auxiliary systems mounted in these scenes.

We learned about the concept of self masking at this venue. The microphones are in close proximity to the sound sources which are farther away from sources of noise (audience). The overall background noise during performances is surprisingly low. This is because the Marina is located at some distance from the town, and the town is quite small. The venue and the marina are jointly owned, and machinery stops (including motorized boats) at concert time. Thus the ambient output from the system is sufficient to both create the sensation of internal volume as well as mask the background ambience. This is quite noticeable when the system is switched on and off.

7.4. Turandot in the Forbidden City

In 1998, Zubin Mehta and Zhang Yimou (one of China's most internationally acclaimed directors) - joined forces in this staging of Puccini's opera Turandot. Over 1000 participants - 350 alone from Florence - were involved in this production. Eight open-air performances took take place on the square in front of the palace which is today called the Peoples Cultural Palace (See Figure 10). The production was five years in planning that included acquiring the necessary permits. The stage was over 80 meters wide, and sets were constructed that housed LARES speakers. A PBS documentary about the staging of this event was filmed, that mentioned the enhancement system and its purpose.

7.5. Mathausan

In 1999, the Austrian Government staged a memorial concert in Mathausan featured performances by the Vienna Philharmonic Orchestra and Joe Zawinul for an estimated 100,000 attendees. The project planning took more than a year, and engineering a suitable means to provide uniform coverage proved to be a daunting task. The solution was realized through a system of cables installed in the face of the quarry that formed a web over the audience from which loudspeakers could be suspended. The down-firing loudspeakers helped to solve problems from reflections from the quarry walls that had long arrival times by smoothing the ETC. The main reinforcement system was comprised of large L-C-R cluster arrays provided by D&B audio. The LARES system used D&B coaxial speakers suspended between thirty-five and sixty feet overhead. The distance from the quarry walls to the stage ruled out the use of supplemental lateral speakers, or speakers aimed from the rear forward. Per our 1994 Further Developments… paper[viii], the overhead array worked well at providing and enveloping sound field. One caveat is that coaxial loudspeakers do not usually provide power uniformity, and placements were dictated by where cables were positioned.

7.6. Millennium Park

In 1931, the Chicago Band Association offered to form a band to play free concerts in Grant Park provided Chicago's South Park Commissioners built them a band shell. This original venue was built in Grant Park in 1931, during the tenure of Mayor Anton Cermak. The Grant Park Festival was born, however, when the Great Depression put many Americans out of work, including musicians. Labor organizer James C. Petrillo, leader of the Chicago chapter of the Federation of Musicians, saw an opportunity to put unemployed musicians to work in the context of a public works program that had a widespread cultural impact. The festival, then known as the Grant Park Concerts, debuted in 1935. As the nation's only free, municipally-funded, summer long, outdoor classical music festival, the Grant Park Music Festival currently presents more than thirty concerts each summer in Millennium Park and draws an annual audience of more than 300,000.

Prior to the development of Millennium Park, the Grant Park Symphony performed in the Petrillo band shell (See Figure 12) erected in 1977 in Grant Park. One of the curious rules associated with the park prohibits permanent construction of any building on park grounds. Although the Petrillo shell has not moved since it was constructed, it is built as a temporary structure, with many of the idiosyncrasies that are germane to "portable" architecture. The shell provides no protection from inclement weather. It faces toward the lakefront, and storms can create floods onstage. Primary sound reinforcement is provided by an L-R system that is supplemented by permanent pole positions (See Figure 13).

From the 1850s through the late 20th century, the site that is now occupied by Millennium Park was controlled by the Illinois Central Railroad. In Daniel Burnham's 1909 Plan of Chicago he considered the railroad property to be so untouchable that he developed the Grant Park portion of the plan around it (See Figure 14). What is now Millennium Park was first conceived in 1998 with the mission of creating new parkland in Grant Park to transform the unsightly railroad tracks and parking lots that had long dotted the lakefront. Over time, with Mayor Richard M. Daley's vision and Frank Gehry's involvement, the project evolved into the most ambitious public undertaking in Chicago's history (See Figure 15)

Our involvement began when Jonathan Laney, then working for the Talaske Group in Oak Park, IL, asked about the feasibility of demonstrating LARES for the orchestra. Initially, the demonstration was planned for a "closed" rehearsal for the orchestra to enable them to evaluate the system privately. We provided a minimal system with speakers on tripod poles arranged on the periphery of the seating area facing the Petrillo Shell. We began setup at 6:00 AM and had the system operational for the 10:00 AM rehearsal. Evaluation took place during two rehearsal sessions, and we had the system torn down and packed by 6:00 PM that day. Before the equipment was shipped back to our office, I received a call from Jonathan asking if we could do this again. This time, the rehearsal would be occupied. I was a bit concerned about the use of our temporary wiring and minimal equipment compliment, but agreed to do it again. Before the demonstration, I was not privy to the plans in the making for Millennium Park. I was also unaware that the orchestra had invited many of the private donors for the project to the rehearsal to hear the system. As a result of the demonstration, however, the orchestra was insistent that the technology be included in the planning for the new venue.

The initial design for the park included loudspeakers mounted on poles in a manner similar to the lawn area in Grant Park, and what was essentially a larger and permanent version of the Petrillo Shell. This changed with involvement from the Pritzker family who brought Frank Gehry onto the project. Mr. Gehry's firm transformed the poles into the trellis that spans the venue (See Figure 16) This provides support for the loudspeakers and lighting, but more importantly, it provides a visual cue for an overhead canopy. The stage shell was also substantially re-designed. It is essentially an indoor stage enclosure complete with climate control with large glass doors that open to the outdoor environment (See Figure 17). It has enough internal volume to produce reverberation that is sufficient for rehearsals with the doors closed. The shall has two forms of variable acoustics – mechanized draping that reduces reverberation time and level for performances that require a more dry condition, and a dedicated electro-acoustic enhancement system that augments the natural acoustics (See Figure 18). It has a substantial number of motor controlled winches in the canopy that enable almost any kind of stagecraft to be executed (See Figure 19). The stainless steel panels of the shell protrude over the seating area and provide ample weather protection with the doors open.

The nature of the rail yard allowed planning for amenities that typically cannot be considered when considering the addition of a band shell in a park. A multi-story parking structure capable of accommodating those in attendance was built over the rail yard. Public restrooms sufficient to accommodate the numbers in attendance were also constructed into "bunkers" on either side of the park. These bunkers also house dedicated remote machine rooms with independent power isolation and digital interconnection to the main machine room in the pavilion. These remote machine rooms significantly reduce the length of cable runs to the lawn speakers.

Jonathan Laney's design for the main reinforcement system uses L-C-R arrays (See Figure 20) supplemented by distributed rings loudspeakers suspended from the trellis and aimed toward the rear of the venue. (See Figure 21) Direct sound is split into two separate mixes from the Digico D5 console – one for the fixed seating, and one for the lawn (See Figure 22). The LARES system incorporates eight microphones – four over the orchestra and four in the choir loft. LARES processing enables direct, reflected and reverberant energy to be tailored at each loudspeaker position. LARES uses down-firing speakers suspended below the reinforcement speakers (See Figure 23) , as well as speakers and subwoofers that are placed laterally and aimed toward the audience. These reinforcement and LARES systems work to provide a more uniform and consistent listening experience throughout the venue. Unlike the outdoor locations at Morbish, Mathausan, and Sun Valley ID that are far from urban centers, Millennium Park is situated at the heart of Chicago with one of the cities major streets, Michigan Avenue, bounding one side of the entire park. The buildings lining the street are tall, creating a substantial amount of reflected sound that carries into the park. In addition, the venue can accommodate nearly 10,000 people. While those in the fixed seating area are typically more interested in attending a concert, those seated on the lawn are interested in a more casual experience ranging from a picnic with music and a few friends, to those attending at the rear of he venue who may be playing Frisbee, or whose children may be doing this or participating in other activities. This presents a dynamic ambient noise floor that ranges from 40 dBA upwards to 60 dBA. One of the more difficult challenges is maintaining adequate sound level during quiet music passages while preserving both quality of sound and directivity to the stage. The patented speech/music detection circuit in LARES processing helps to keep the increase the level of the ambient field while music is playing. This acts as a noise masking system – with the orchestra as the masking source. Bottom up compression applied in the digital domain is used to increase the level of quiet passages automatically. Since its inception, the systems have received high praise for sound quality. The following is a sampling of musical reviews from the first season's performances:

Chicago Sun-Times - Wynne Delacoma - *"The system has already achieved some of its most important goals........The orchestra sounded vibrant and natural. Its presence as vivid for listeners far back on the lawn as it was for those closer to the stage."*

John von Rhein, Music Critic for The Chicago Tribune reported: *"For the first time, delighted orchestra members can hear each other,"*

Jim Palermo, Grant Park Music Festival Artistic Director praised *"The sound that's produced naturally on the stage, the orchestra is in seventh heaven. They can hear each other. It's a warm, lush sound."*

Rockford Register's Chuck Sweeny - *"I took in a concert by the Grant Park Symphony........I walked to every corner in the lawn. The system works."*

Chicago Tribune's John von Rhein wrote on August 14: *"The Grant Park Orchestra and Chorus presented William Walton's "Belshazzar's Feast," a giddy, brazen oratorio that invariably raises temperatures on both sides of the footlights. Its noisy extravagance gave the new sound system a demanding workout, but one that it passed with flying Technicolors."*

7.7. Sun Valley Pavilion

The Sun Valley Resort in Idaho has supported the Sun Valley Summer Symphony for many years. Until recently, the symphony performed under a portable tent that was erected for several weeks of performances each year. In 2007, construction for a new permanent pavilion began on the ground of the resort. (See Figure 24) The facility has approximately fifteen-hundred fixed seats positioned under a canvas roof that is erected and removed annually (See Figure 25). Enclosed backstage facilities include practice rooms, offices and machine rooms. Lawn seating is provided at the rear of the facility.

The canvas roof provides reflected sound and reverberation for those in the fixed seats – thus no loudspeakers for electro-acoustic enhancement are placed inside the pavilion. Poles on the lawn have independent speakers for sound reinforcement that are aimed away from the pavilion toward the lawn area, and speakers for acoustic enhancement that are aimed towards the pavilion and audience (See Figure 26) The edge of the tent is fairly low to the ground – approximately ten feet. Thus there is a considerable difference in sonic conditions inside the tent, and on the lawn. Inside, the stage and tent couple and there is a buildup of low-mid frequencies that contribute muddiness to the sound. The tent provides substantial reflected energy, but reverberation time is under 1.7 sec. Direct energy from the orchestra does not propagate very far outside the tent. Hence the direct sound perceived at positions close to the tent is primarily sound reinforcement fed from speakers mounted on the outmost steel ring supporting the tent (See Figure 27). This provides forward localization, while the speakers on poles reinforce this signal. Enhancement signals arrive from the sides and rear of the listener, providing substantial envelopment. In the future, we plan to install down-firing enhancement speakers under the center reinforcement speaker locations to minimize differences in perceived uniformity pole to pole. The direct reinforcement for the lawn system uses microphones in close proximity to the instruments. Thus the sound is cleaner on the lawn than what is experienced inside the tent. The spatial characteristics of the enhancement system are also larger than what happens in the tent, and this is in keeping with the visual aspects of the lawn seating (See Figure 30). Thus the sound on the lawn is cleaner and more enveloping than the sound in the fixed seats, and there is a natural transition that occurs between the tent and lawn.

This is the first venue that I have encountered that has two separate operators, one who oversees the sound in the tent, and the other who provides the mix for the lawn. (See Figures 28 & 29) The advent of digital audio consoles has made this possible. The lawn mix is adjusted using a computer that runs a program supplied by the console manufacturer which allows manipulation of the console controls. Hence, each mix can be manipulated independently in real time.

8. CONCLUSIONS

Time variant electronic acoustic enhancement has made a significant improvement in the listening experience in a variety of outdoor venues. Each of these venues has posed unique challenges in both the design and successful implementation of these systems. We find the following to be generally true:

1. Acoustic enhancement outdoors requires substantially more acoustic power than a similar system indoors. This is primarily due to the lack of surfaces that would otherwise reflect energy from the loudspeakers.

2. Energy from the enhancement system must be broadband. This means that:
   - a. Subwoofers are usually required
   - b. Loudspeakers used must remain linear with added power (i.e. – they must not suffer from power compression)

3. Sufficient density necessary to deliver broadband power uniformity must be maintained.
   - a. There is no assistance from nearby surfaces.
   - b. Non-Linear polar response that does not sufficiently overlap device to device creates acoustic "holes" that are noticeably different than listening to the on axis response of a single device.

4. An overhead speaker array combined with a lateral array outdoors is optimum
   - a. When feasible, a down-firing array from poles is preferred to a lateral or in-firing array.
   - b. With a peripheral array aimed at the audience, a taller pole with both an upper and lower pole position is preferred. These must have separate signal paths with independent delay.

5. Microphones must be high quality
   - a. Polar patterns must remain constant through wide changes in temperature and humidity.

6. High quality microphone windscreens are required.
   - a. We can typically watch our microphones move up to two feet off center in Chicago. Under certain circumstances, Rycote shields must be employed.

7. Transducer maintenance is required
   - a. Unlike indoor systems, transducers are exposed to the elements, and must be performance checked periodically.

   b. When microphones and loudspeakers need to be removed and reinstalled to prevent damage from extreme weather, the system must be re-tuned annually.

8. Outdoor systems typically take longer to install and tune
   a. Weather is a significant unknown factor

9. Initial level settings made for both reinforcement and enhancement during rehearsal conditions when the venue is unoccupied have little in common with what is required during occupied conditions.
   a. Thousands of people on a lawn represent a large, distributed, biologically powered masking system that generates random, and sometimes interesting, noise that must be accounted for.

10. When the area is sufficiently large, or sound in the main portion of the venue lacks continuity with other portions of the venue (i.e. bowl vs. lawn seating) having separate operators for each should be considered.

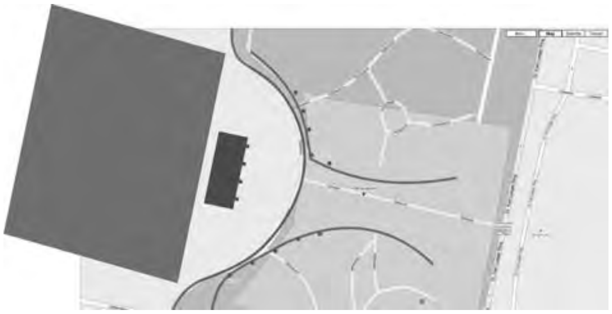

Figure 1 Pole Positions at Vienna Fest

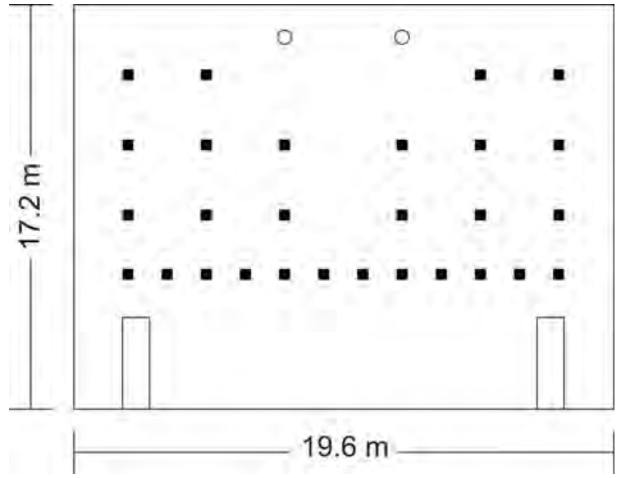

Figure 3 Loudspeaker Locations in Crystal Palace Reflector

Figure 2 Vienna Fest

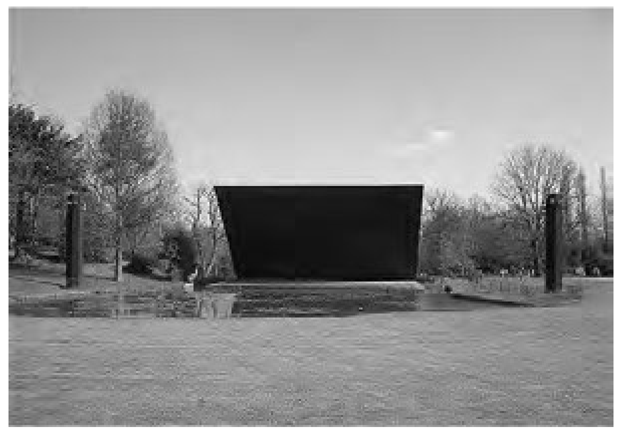

Figure 4 Crystal Palace Stage

Figure 5 Crystal Palace

Figure 7 Morbisch stage

Figure 6 Morbisch seating and poles

Figure 8 Delta Stereophony ontrol

Figure 9 scenery and boats during performance

Figure 10 Turandot at People's Cultural Palace

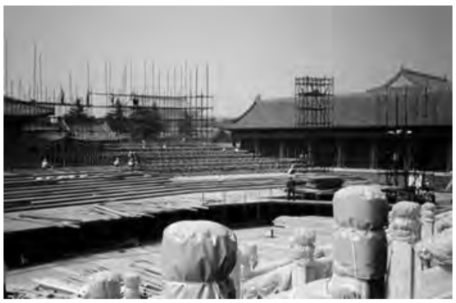

Figure 10-2 Set construction

Figure 11-1 Cables over Mathausan

Figure 11-2 Cables over Mathausan

Figure 12 Petrillo shell, Chicago

Figure 13 Petrillo shell speaker pole

Figure 14 Rail Yard – future site of Millennium Park

Figure 15 Aerial View Millennium Park

Figure 16 Millennium Park Trellis

Figure 17 Pritzker shell doors

Figure 18 Grant Park Orchestra and Chorus

Figure 19 Enhancement Speaker Locations

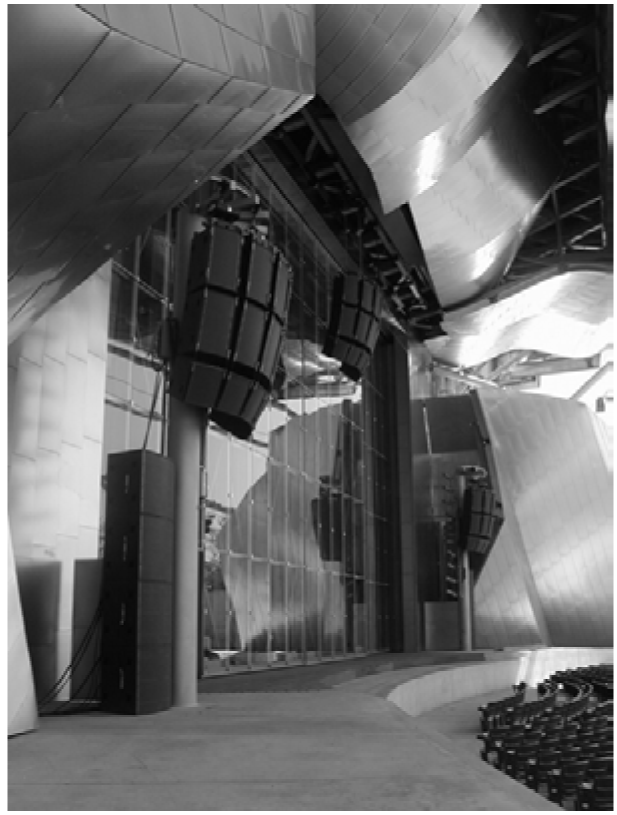

Figure 20 Millennium Park LCR system

Figure 21 Speakers on trellis

Figure 22 Chris Willis Operating Digico D5 Console

Figure 25 Sun Valley Pavilion

Figure 23 Down-firing Enhancement Speakers

Figure 26 Lawn Speakers

Figure 24 Sun Valley Pavillion

Figure 27 First Poles

Figure 28 Lawn Mix Position

Figure 29 View Towards Stage

Figure 30 Lawn at concert time

[i] Concert Halls and Opera Houses – How They Sound – Beranek, 1996, ISBN1-56396-530-5

[ii] The importance of the direct to reverberant ratio in the perception of distance, localization, clarity, and envelopment – Griesinger May 2009 JASA 157th Meeting Portland OR

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