SPECIFYING SHARED APPLICATION ACOUSTIC ENHANCEMENT SYSTEMS

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1 INTRODUCTION

With the application of Networked Audio and advanced Digital Signal Processing technologies, Acoustic Enhancement Systems have matured in the past decade, being applied in more and more venues. Acoustic consultants have the task of specifying the enhancement targets in design concepts and tenders. While the acoustic design challenges are increasing because of the expectation of more variability in the acoustic performance result, a more recent design challenge is the sharing of a system's infrastructure, amplifiers and loudspeakers to serve also multi-track (surround) based or object based audio systems such as Cinema reproduction and 3D Immersive Sound performances.

Sharing Acoustic Enhancement with Sound Reinforcement and Cinema has become a quite common target for multi-purpose venues, allowing the venue to be used more effectively for a variety of activities: the Sound Reinforcement system supports amplified music (Rock, Pop) and performances (theatre, musical), while the Cinema system supports surround sound for film. For acoustic performances, the Cinema system can be expanded with additional speakers and amplifiers to support an Acoustic Enhancement system, using the same audio distribution infrastructure and Digital Signal Processing (DSP) used for routing and user control. Since the loudspeaker requirements for Immersive Sound systems (also known as '3D Audio' systems') are very similar to those of combined Acoustic Enhancement and Cinema systems, this form of reproduction capability can be added to the venue's repertoire in a very cost effective way. A very positive property of such shared systems is listeners hear the same acoustics for the programme as well as for their own sounds (singing, clapping), feeling truly 'immersed' in the experience.

In an increasing number of cases, Cinema and Immersive Sound systems are object based, which means that productions can be processed for any speaker configuration in different venues in real time by means of Digital Signal Processing (DSP). This trend has a positive effect from both sides of the field: it makes it easy for multi-speaker equipped venues to reproduce content (films, performances) independently from the speaker configuration they where developed with, and it also drives the trend for composers and sound designers to develop music and performances for multichannel systems that can be played in any multi-speaker equipped venue. Note that 'panner' plug-ins for workstations such as AVID ProTools and Steinberg Nuendo have been released for popular object based systems such as IOSONO Immersive Sound and Dolby Atmos, supporting this trend.

This paper presents several specification and design considerations for shared infrastructure and speaker systems based on experiences with several recently installed systems. Targets for such an infrastructure are multi-purpose venues, but also either permanently or temporarily installed systems for concerts, live events, visitor attractions etc. As a proof of concept, the presented specification and design framework was used to design and implement a temporarily installed demonstration system, presented in September 2016 in the Berklee College of Music in Valencia, Spain, by Barco Audio Technologies, Dolby Laboratories, Yamaha, Steinberg and Nexo.

2 SPECIFICATIONS FOR ACOUSTIC ENHANCEMENT

2.1 Acoustic Enhancement targets.

Often a set of ISO3382 parameters (*1) is presented as the target for an Acoustic Enhancement system, specifying parameters such as Reverberation Time (RT), Early Decay Time (EDT), Clarity (C80), Strength (G) – based on the expectations of a similar size and shape set of venue references. In case of a shared system however, the 'default' original acoustics of the venue have to be specified to meet the requirements for amplified music and Cinema. Typically, the original RT for shared system venues is tuned down by architectural measures to well below 1 second, which requires an Acoustic Enhancement system to be applied (*2) that enhances the RT in many cases to more than double the original value. As a result of such a high RT enhancement ratio, it becomes difficult to compare the acoustic result to acoustic references – for physical reasons; eg. the response of a regenerative mode enhancement would be too loud, or the existing configuration of early reflections is out of balance, or for psycho-acoustic reasons; eg. the acoustic response would not agree with the look and feel of the hall. While it is possible to tune a relatively 'dry' system to meet certain ISO3382 parameter reference targets at high enhancement ratios, in some cases the optimal subjective tuning can give a different outcome for the system's measured response.

To indicate the scope of enhancement, figure 1 and table 1 present the RT enhancement vs original RT for 21 venues recently equipped with a Yamaha AFC3 Acoustic Enhancement system, tuned to a subjectively appropriate preset. Of these systems, 10 have an RT enhancement higher then 200% based on an original RT of less than 1 second. Also, a high variation of enhancement ratios can be observed eg. around 0,7 seconds – depending on the intended use of the venue, from a very moderate 117% enhancement for 'voice lift' in a conference room all the way to 306% to support a symphony orchestra performance in a multipurpose hall.

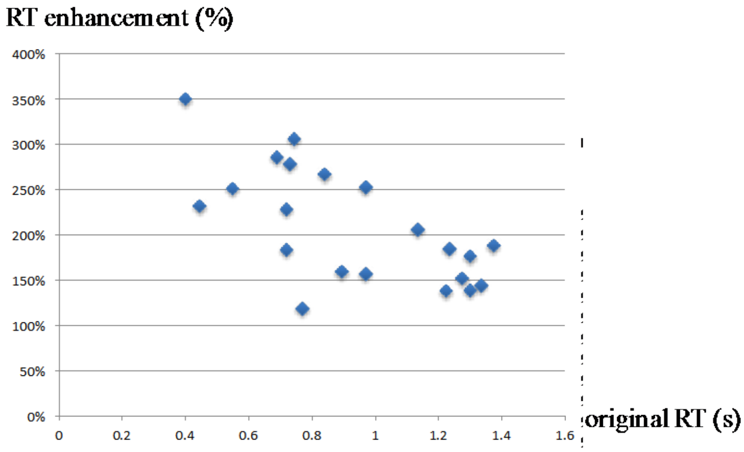

Figure 1: RT enhancement vs. original RT for 21 venues recently equipped with AFC3.

venue	AFC	RT (s)	RT enhancement (%)
concert hall, 773 seats	OFF	1,38	
	ON	2,58	188%
concert hall, 205 seats	OFF	0,72	
	ON	1,64	228%
concert hall, 429 seats (7.1 Cinema)	OFF	0,72	
	ON	1,32	183%
concert hall, 1027 seats	OFF	1,14	
	ON	2,33	205%
opera rehearsal hall	OFF	1,28	
	ON	1,94	152%
concert hall, 300 seats (7.1 cinema)	OFF	0,45	
	ON	1,03	231%
concert hall, 630 seats	OFF	0,84	
	ON	2,24	267%
concert hall, 1030 seats	OFF	1,24	
	ON	2,28	184%
concert hall, 400 seats	OFF	1,22	
	ON	1,69	138%
concert hall, 300 seats	OFF	0,74	
	ON	2,28	306%
Concert hall, 420 seats	OFF	0,97	
	ON	1,52	157%
small hall, 120 seats	OFF	0,73	
	ON	2,03	278%
small hall, 50 seats (Iosono)	OFF	0,40	
	ON	1,40	350%
Autitorium, 100 seats (Iosono)	OFF	0,55	
	ON	1,38	251%
Autitorium, 900 seats (7.1 Cinema)	OFF	1,34	
	ON	1,92	144%
Autitorium, 1100 seats	OFF	0,97	
	ON	2,45	252%
Small Hall, 75 seats	OFF	0,90	
	ON	1,43	159%
multi purpose hall, 429 seats (7.1 cinema)	OFF	0,69	
	ON	1,97	286%
Opera hall, 550 seats	OFF	1,30	
	ON	1,80	138%
Conference Room	OFF	0,77	
	ON	0,91	117%
Show / Conference Room (Iosono)	OFF	1,30	
	ON	2,29	176%

Table 1: RT enhancement results of 21 venues recently equipped with AFC3.

2.2 Speaker system design for Acoustic Enhancement.

2.2.1 Speaker system modules

The speaker design for Acoustic Enhancement systems is often separated in modules as presented in figure 2. For each individual module, the speaker selection, placement and aiming is designed to support either early reflections, reverberation or both. In both cases a main parameter is the requirement that none of the speakers may be localized by the audience. To achieve a natural and integrated acoustic response for both the audience and the performers, loudspeakers are placed both in the hall (and under balcony) and on the stage.

For the Early Reflection modules, normally wall speakers are applied, placed at locations to optimally give an appropriate spatial impression. This poses the challenge of creating a 'sweet spot' that is as big as the audience (hall) and performance (stage) areas. For this reason, side speakers are often placed at a high position to reduce the SPL spread amongst the seats, and/or column speakers are utilized (*3). Since it is sometimes difficult to place the wall speakers on stage, often ceiling speakers are also applied there.

For the reverberation modules, normally ceiling speakers are applied. The challenge is to achieve an even coverage of the audience (hall) and performance (stage) areas, de-correlating each speaker output with neighboring speakers to avoid localization. Sometimes a number of sub woofers is added to the ceiling speakers to improve the Bass Ratio (BR, 'warmth').

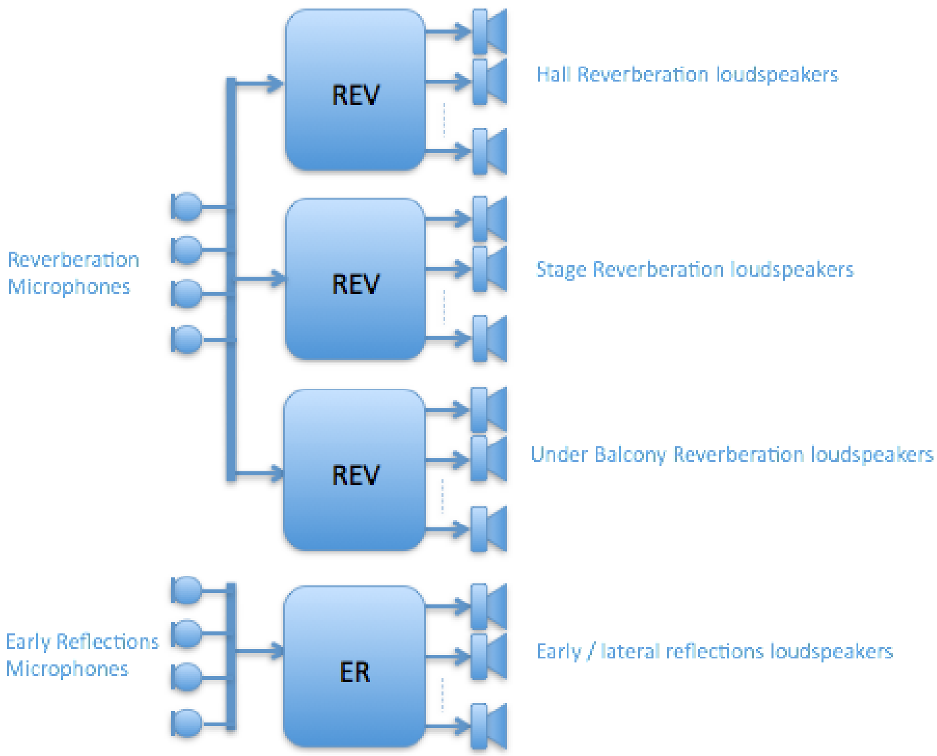

Figure 2: typical Acoustic Enhancement system block diagram.

2.2.2 Resolution requirements

The amount of speakers required for a reverberation module is determined by the height and surface of the ceiling. Ceiling speakers or suspended speakers are spread out over the ceiling area to accomplish a diffuse coverage where no single speaker can be localized by the audience or performer. The amount of early reflection speakers depends mainly on the length of the walls and the distance of the side seats to the walls.

2.2.3 SPL requirements

Because the reverberation and early reflections in an Acoustic Enhancement system are reproduced by all speakers simultaneously, with the sound image spread out to be appropriate for all listeners and performers in the venue, the SPL requirement per individual speaker is relatively low. Depending on the resolution, the minimum average and peak SPL per loudspeaker can be calculated to achieve a combined appropriate regeneration level in the hall. Note that Acoustic Enhancement systems don't use speakers as Sound Reinforcement speakers; the speakers are placed to represent the ceiling/wall they are mounted on.

2.2.4 Aiming requirements

The aiming of speakers in an Acoustic Enhancement system normally follows the physical shape of the venue's walls and ceiling. In special cases some aiming can be applied to achieve appropriate sound images, but the majority of wall and ceiling speakers are aimed tangential to the surface they are mounted on, aiming the speaker to the audience / performance area.

3 SPECIFICATIONS FOR CINEMA AND IMMERSIVE SOUND.

3.1 Reproduction targets

In case of track-based Cinema systems, the reproduction target is to support an optimal surround sound image for the screen content with a fixed number of channels depending on the surround mode (eg. 7.1 for seven surround channels and one LFE channel). In case of object-based Cinema or Immersive Sound systems, the target is to create an as high as possible resolution for the sound image, both horizontally and vertically. The sound images (eg. position of sound objects) are determined by the object metadata (eg. Dolby Atmos, IOSONO). The speaker arrangement (number of speakers) determines the resolution of the reproduction system, while any given object-based content can be played on any given speaker configuration.

3.2 Speaker system design

3.2.1 Resolution requirements

A main parameter for a speaker configuration is the amount of speakers horizontally (nr. of speakers front, back, left, right), and the number of speaker systems vertically (eg. additional speakers in the ceiling (eg. Dolby Atmos) (*4), additional vertically arranged speakers on the walls (eg. Barco AuroMax) (*5). The total density and placing of speakers determines the resolution of the system. Most systems specify a minimum quantity of speakers per surface to set a lower threshold of appropriate resolution. Also, the use of Wave Field Synthesis (eg. Barco Audio Technologies IOSONO) (*6) requires a minimum resolution.

3.2.2 SPL requirements

The SPL requirements for Cinema Surround and Immersive Sound differ significantly from the requirements for Acoustic Enhancement. Since sound objects may be positioned at any time to originate from a single speaker, that speaker must be able to reproduce the full peak SPL associated with the object. Especially in Cinema, where effects such as explosions and gunshots are not uncommon, this poses a high SPL requirement for each individual speaker. Also, philosophically, the Cinema sound reproduction concept is built on the notion of a sweet spot – with a reference listening point normally set at two thirds of the room length from the screen. This means that all speakers have to reproduce the specified maximum SPL for this location.

3.2.3 Aiming requirements

Both for Cinema and for Immersive Sound, and in contrast with Acoustic Enhancement, the sweet spot concept and the objective to be able to adress the entire audience by each individual speaker introduces aiming of the speakers towards the sweet spot area to optimize the performance of the system. Various sweet spot sizes can be used – narrow for Cinema mixing stages, broader for theatres.

4 SHARED SYSTEM DESIGN

4.1 Shared system design

Combining equipment for Cinema, Immersive Sound and Acoustic Enhancement has several implications for the system design.

4.1.1 Speakers & Amplifiers: SPL, aiming

Of the applicable SPL requirements, a shared speaker system must apply the highest. Of the three systems presented in this paper, Cinema Surround requirements are the most demanding for peak SPL, coverage and aiming. As long as the selected speaker has a high timbral fidelity and consistency it can be used for Immersive Sound and Acoustic Enhancement without any problems. Because Dolby Atmos and AuroMax most commonly use only two lines of ceiling speakers, Immersive Sound and Acoustic Enhancement systems require a small number of ceiling speakers and their respective amplifier channels to be added to achieve an appropriate resolution. In most cases, the number of wall speakers in any Dolby or Auro surround system are sufficient for Immersive Sound and Acoustic Enhancement.

4.1.2 Distribution network

Assumed that all systems make use of networked audio (eg. Dante, Ravenna, BluLink, AES67), the routing infrastructure is an IT switch which can handle all Gigabit Ethernet audio streams. Adding functionality to the system with networked amplifiers and DSP units then doesn't require any additional investment in the distribution network other than a CAT5E patch cable. For units with incompatible networked audio protocols or conventional point-to-point distribution protocols such as AES10 (MADI), cost effective bridge units are widely available.

4.1.3 DSP infrastructure

Acoustic Enhancement Systems use closed loops including microphones, DSP, amplifiers, loudspeakers and distribution, with routing, delays, parametric equalizers, FIR filters and levels for each signal path carefully tuned for stability and optimized to deliver perfect and natural enhancement. It is vital that the automation of all these parameters is designed to be in a quality controlled environment with full control of access and consistency.

Whenever an Acoustic Enhancement system is included in a shared system, the most secure method of assuring quality is to place all system functionality involving the closed loops in the Acoustic Enhancement DSP environment, accepting the Cinema and Immersive Sound channels as input only. Crucial is that the merging of these channels happens in a part of the the Acoustic Enhancement DSP dedicated to the infrastructure, so the system's loop levels and routing stay under control of the Acoustic Enhancement user interface and quality assurance. If the channel merging would take place in an external unit, then the loop functionality is divided over two separate control and user interface and quality assurance domains; quality assurance then becomes very difficult. Signal paths for the Cinema and Immersive Sound systems can be provided with full transparency, eg. from the Cinema and Immersive Sound processor's side the speakers are available as if there was no Acoustic Enhancement processor in between – apart from a small overall latency increase. Note that the Cinema and Immersive Sound user interfaces can send commands to the Acoustic Enhancement system through media control (GPI, RS232, Ethernet) so the system can still be presented as an integrated system to the user.

If a mixing audio network is included in the system allowing for FOH and monitor mixing systems to access the system's speakers (eg. for surround effects), then an isolated system entry point may be provided for the mixing network, physically separating control of the mixing (input) network patching from the shared system (output) network patching. This prevents Sound Reinforcement engineers from accidentally changing the closed loop routing in the Acoustic Enhancement system.

An example system concept is presented in figure 3.

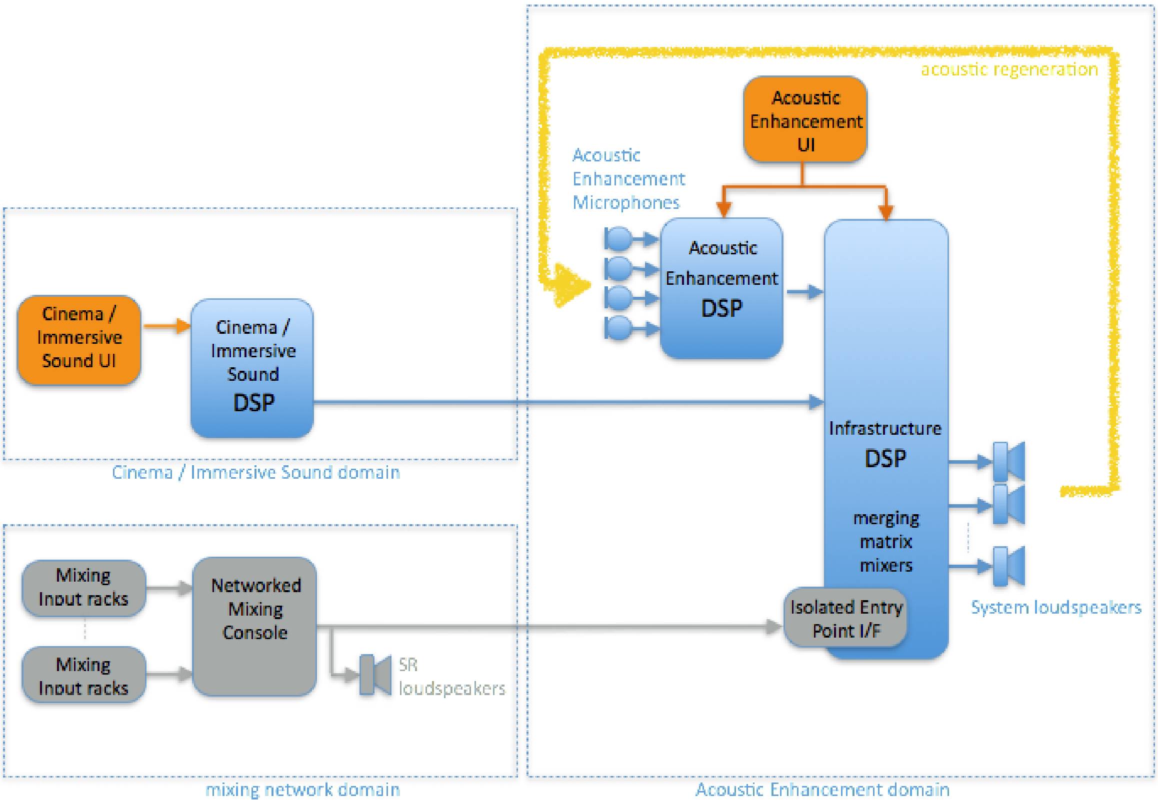

Figure 3: shared system concept with multiple DSP / user interface domains and isolated audio network entry point.

4.2 Example: Valencia Berklee College of Music

As an example, figures 4-6 present a loudspeaker system that combines a 31-channel Dolby Atmos system, a 53-channel IOSONO Immersive Sound system and a 48-channel AFC3 Acoustic Enhancement system. This system was built as a temporary installation at a System Designers Conference held at Valencia campus of the Berklee College of Music in September 2016. The Dolby Atmos system was designed and tuned by Unique Cinema Systems and Dolby Laboratories, with additional speakers added for IOSONO and AFC3. Workshops included the complete Audio-for-Cinema workflow from DAW mixing (Yamaha Nuage with Dolby Atmos and IOSONO panner plug-ins) reproduced through Dolby RMU and IOSONO Core real time object audio rendering units connected to the speaker system's networked DSP through MADI bridges. As the third application a Yamaha AFC3 Acoustic Enhancement System was implemented through Dante. All three applications were active simultaneously, allowing for shared demonstrations.

A single cost effective Dante based DSP unit was used for the DSP and network infrastructure of the Berklee system. Already multiple venues have been installed with this concept, allowing for individual speaker channels from any object based audio platforms to be merged, supporting channel counts of up to 64 channels. At the same time, the design offers clustering with dedicated mixing, PEQ and delay capacity to accept 5.1, 7.1 track based surround inputs.

Figure 4: Temporary installed Dolby Atmos / IOSONO / AFC3 system at Berklee College of Music

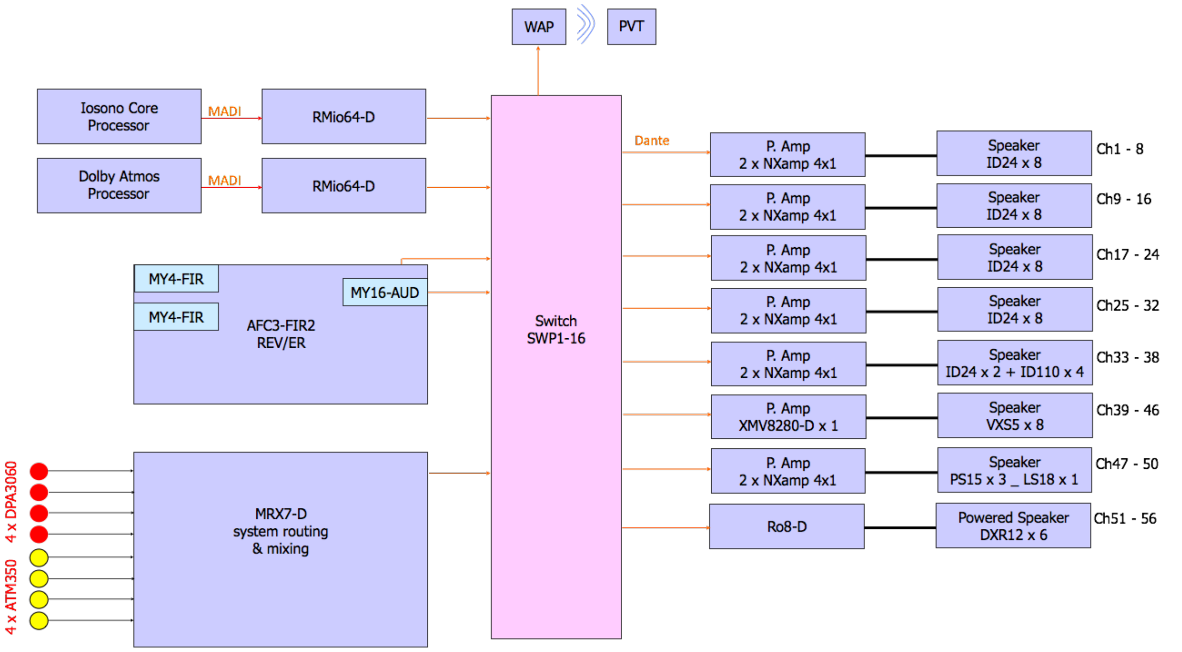

figure 5: Berklee system block diagram

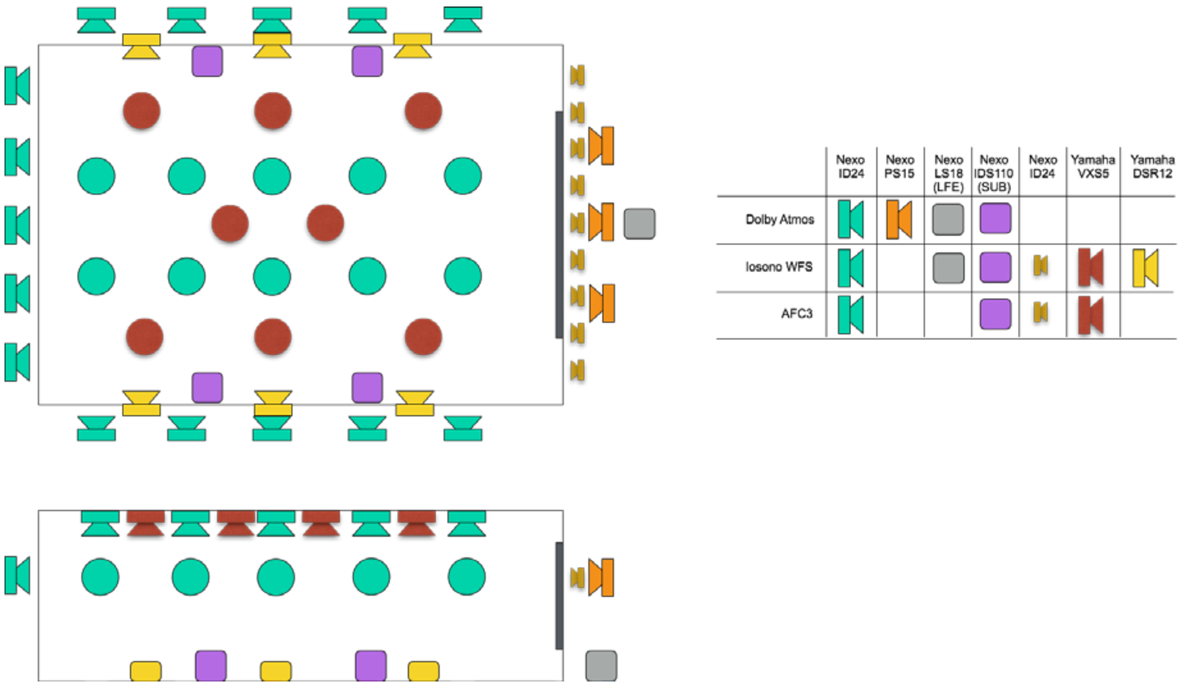

figure 6: Berklee system speaker layout (truss size: 8m x 10m x 4m)

4.3 Shared system economics

If we look at the three presented applications – Acoustic Enhancement, Cinema and Immersive Sound, it is obvious that all systems use a multitude of loudspeakers, amplifiers and infrastructure connections. Let's define the investment P in audio equipment for a single application in a given venue as:

P(speakers) + P(amplifiers) + P(infrastructure processing) + P(application processing)

Applied to the Berklee system – which used 31 channels for Dolby Atmos, 53 channels for IOSONO and 46 channels for AFC3, we can simulate a total cost of each individual system using fictive cost prices of the 4 components:

Loudspeaker	800
Amplifier channel	1.000
Infrastructure DSP	6.000
Application DSP	30.000

Using these cost levels, the total cost of each individual system calculates as:

Dolby Atmos	31 speakers/amps + infra/appl. DSP	91.800
AFC3	46 speakers/amps + infra/appl. DSP	118.800
IOSONO	53 speakers/amps + infra/appl. DSP	131.400

Taking the Dolby Atmos system as the primary system, adding a secondary function then calculates as:

Primary function:

Dolby Atmos	31 speakers/amps + infra/appl. DSP	91.800

Secondary functions:

AFC3	+15 speakers/amps + appl. DSP	+57.000
IOSONO	+22 speakers/amps + appl. DSP	+69.600

This example would indicate that the additional audio equipment cost level of adding functionality for an Immersive Sound system or acoustic performances in a Dolby Atmos equipped multi-purpose venue is less than half of the equipment cost of a adding the functionality as a separate dedicated system.

5 CONCLUSIONS

Combining multi-channel speaker systems in multi-purpose venues is practically and technically feasible, introducing the possibility to add functionality to a venue that is equipped or planned with a single multichannel function at significantly lower cost compared to the application of multiple dedicated systems. With the combination of Acoustic Enhancement, Cinema Surround and Immersive Sound already applied in several installations with very positive results, this paper presents a summary of specification and design considerations for consultants and system integrators.

- In-line and hybrid regenerative Acoustic Enhancement systems can support high quality enhancement of relatively dry spaces designed for amplified music.
    - The results of many installed systems prove that the subjective Acoustic Enhancement result is excellent.
    - However compared to moderate enhancement modes normally applied in concert halls, the measured ISO3382 parameter enhancement results may differ from those.

- Cinema Surround systems, Immersive Sound systems and Acoustic Enhancement systems can share their speakers and amplifier channels:
    - Speakers in a Cinema Surround system can also be used for Acoustic Enhancement and Immersive Sound, adding speakers to increase ceiling system resolution.
    - Acoustic Enhancement speaker configurations can adapt to the Cinema Surround and Immersive Sound positioning, SPL, coverage and aiming specifications.

- The DSP networked infrastructure can be shared between systems at low costs.
    - Network switches capacity support large channel counts at low cost.
    - Today's DSP frames have a high enough network i/o count and DSP power to support 64 channels or even more merging mix matrices.
    - The DSP system's merge matrix mixer used to merge each subsystem to connect to the loudspeakers is preferably integrated in the Acoustic Enhancement DSP, offering transparent routes to the speaker channels to the other subsystems.
    - For networked mixing systems, an isolated entry point may be included to prevent Sound Reinforcement engineers from accidentally changing the closed loop routing in the Acoustic Enhancement system.

6 REFERENCES

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