NATURALISTIC ACOUSTICS FROM ELECTRONIC CONTROL

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1 INTRODUCTION

It is well understood, by designers, performers and composers alike, that music is a very broad art form, demanding a very broad range of listening conditions if it is to be appreciated in a form not far from how it was created. When Bach composed for grand cathedrals, he wouldn't expect the result to play out well in a smoky Jazz club, any more than Sergei Rachmaninoff might have expected his piano concertos to retain their best qualities if played on a church organ.

A musical or spoken performance takes place in an acoustic space, as it was conceived and crafted in one. The relationship between what the creators heard, when they made the decisions and found the art, and what the audience then receives is paramount to the success of the art.

When we choose to design, we choose to set priorities. These priorities become cast in the physical form and finishes of the space, as well as in the tools and features that offer us the options of flexibility, whether they are mechanical or electronic in nature. As soon as we intervene in what the space would have been without us, we are already pulling the auditorium, as a piece of acoustic architecture, away from it's 'natural' position. That is the point of our role, and our duty to the project is to do that for the good of the project, which means (amongst many other things) for the good of the Art.

As an audience and a market, concert-goers and theatre fans are, quite rightly, very ready to scrutinize the results of our design interventions: we had better get them 'right', where 'right' means that not only does the space perform well acoustically, it allows and engenders excellent performances while providing the audience with a heightened sense of collective witness to it.

Tools to vary the acoustic response of the space, whether mechanical or electronic, give us the potential to match the space more closely to the needs of the particular performance, which would be key to setting priorities in a space that must be both flexible in what it can support and excellent in how it supports it.

Electroacoustic solutions to variable acoustics are variously termed Acoustic Enhancement (AE), electronic reverberation, assisted reverberation, acoustic control, active field control, virtualized acoustics and other labels gained over their 65 year history. We will stick to the AE label for the purposes of this paper.

However it is called, AE has perennial credibility problem, perhaps not helped by it's beginnings in the early years of both modern audio and at the dawn of the 'enlightenment period' in auditorium acoustics that progressed from the 1970s and so quickly through the 1980s, 1990s and to the present day.

There is a perception, perhaps, that an acoustic effect or flexibility that has employed electronics and loudspeaker is somehow less 'natural' than one achieved though the rearrangement of physical features. This is probably routed in a distrust of the aural validity of hearing, through the familiar pistonic paper cone and the audio processor more at home in the studio production, a performance that was never intended to be played that way.

The distrust of ‘audio processing’ in a highly regarded aural experience may also have been influenced by the failings of the more clumsy attempts to influence studio recordings, or even to the styles of music that have been evolved and produced entirely within the studio, which might be considered by many as the ‘natural’ home for audio trickery!

So for any form of electronic variable acoustics – Acoustic Enhancement systems - there will understandably be doubters of to validity of the listening experience created: that the result will no longer be ‘natural’, no longer sound acoustically feasible and therefore of lower value and quality. Neither this paper or it’s presentation will have the facilities to convince the doubters of the potential virtues of AE as a tool in high quality acoustic design: this must be done by listening in spaces. This is not so easy to arrange unless sought out, especially if the systems are doing their job well and not announcing their presence to the listener. How would you know if you have been in an event supported by an AE system if the AE system has been successfully integrated?

What this paper does set out to do is to arm the reader with the facts about AE systems, inform a little on the history, and specifically draw out the factors and features of the different forms of AE that will have an influence on the notion of naturalness, and on the design decisions and strategic priorities in realizing the architectural, acoustic and technical solutions of a space for listening. Ideally, we ant to move the question of “is it real?” on to the question of “is it good?”

2 ACOUSTICS – PURPOSE AND DESIGN

2.1 Purpose

The purpose of any design of the acoustic response of a performance space is to influence how the room responds too (and supports) musical and speech-based performances. By choosing to intervene (ie manage the location of finishes, type of seating, size of room, angle of walls and reflectors) we are, by definition, making the room respond (acoustically) differently to how it would have if we had not.
We do that in the pursuit of acoustic conditions that:

i. provide a good listening experience, with regard to the art form
ii. support the performers, and so facilities their provision of an expressively optimised (artistically enhanced) performance
iii. connect the audience back to the performers, giving further opportunities for the performers to refine and enhance their performance
iv. connect the audience with itself - heightening the drama of the event and the sense of collective witness

2.2 Design

Many familiar studies have helped us document those physical aspects, as observed, that affect the success of the resulting acoustic conditions at the 4 aims above. These include works from Leo Beranek[1], Mike Barron[2, 3] as well as the technical documentation in ISO 3382[4]

The range of acoustic environments most readily understood by considering ‘liveness’ or ‘reverberance’. Amongst acoustic professionals, that quality will be most familiar through the metric of Reverberation Time (Figure 1). The converse concept is that of Intelligibility, which can be though of as increasing with reducing RT - though not strictly so, in the hands of skilled acoustic designers. The trends, however, are clear.

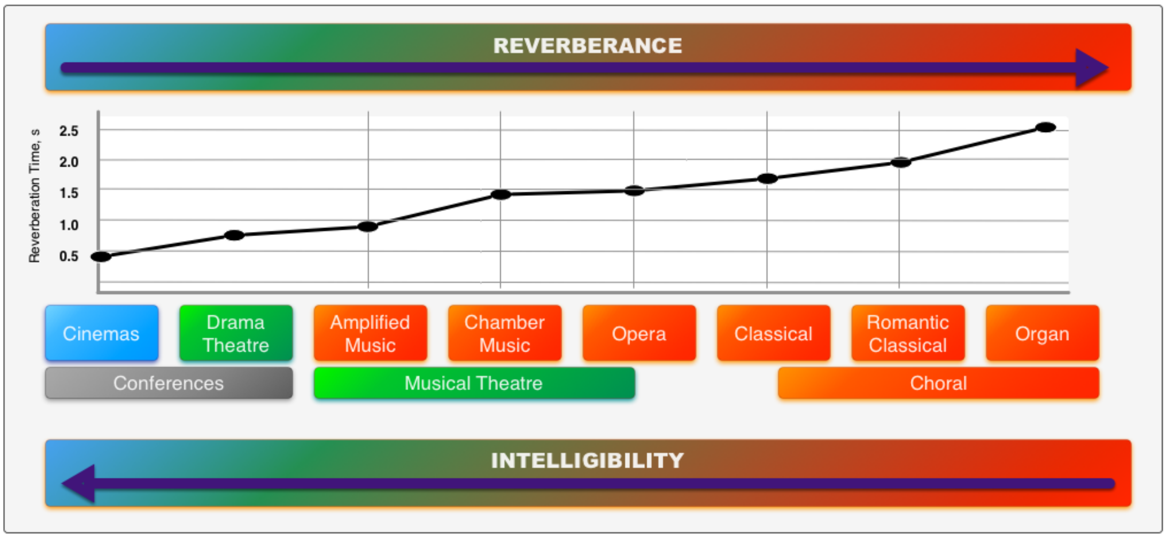


Figure 1: Reverberance and Intelligibility - variable requirements by type of performance

It will be of no surprise to hear that the actual character of the acoustic space holds far more dimensions than that of RT, or even of any or all of a whole host of very well considered metrics defined under ISO3382. These are, however, invaluable for tracking the route and relative successes of the range of design and commissioning options, and not least for communicating the these qualities as 'performance indicators' across the Design Team:

QUALITY	METRIC	CLUES TO:
Reverberation Time	RT	'Liveness'
Early Decay Time	EDT	
EDT Ratio	EDT/RT	'Intelligibility'
Clarity	C_{80} etc.	
Strength	G	'Intimacy'
Lateral Energy	LEF/ELEF/IACC	

Not forgetting that all of these qualities, and their associated metrics, will vary with frequency over the full human register, affecting musical and spoken qualities differently from bass to treble. The metrics are therefore nearly always broken down into octave bands for careful analysis.

3 METHODS AND TOOLS IN ACOUSTIC VARIABILITY

3.1 Mechanical Methods

3.1.1 Principles

Variability in acoustic response is achieved through providing methods and tools that affect the acoustic experiences listed under Section 2.1, in relation to the performance type. Mechanical tools refer to those that afford a physical change, ie without electronic audio aspects (though electronic systems are often required to reliably deploy and retract the features as required).

Areas of acoustic absorption can introduced, affecting both liveness and intelligibility qualities. For example, arrangements can expose and conceal absorption through use of flipping panels or rotating reveal/conceal systems. Alternatively, systems can furl and unfurl absorption in the form of banners, drapes and other forms of heavy material.

In addition to varying the area of absorption, the air volume can be increased or decreased by the use of moving walls and ceilings. Additional air volumes can also be selectively exposed or isolated through large, controllable openings to large, connected spaces.

Reflection patterns can be varied, to respond to different priorities for intimacy, to optimize clarity (such as when additional reverberance may be reducing it), or to create improved ensemble conditions amongst the players and/or a better connection between stage and audience. This can be achieved by lifting and rearranging reflectors, such as over the stage, to affect the intimacy and early reflections amongst the performers and/or audience

3.2 Suitability & Limitations

Mechanical method most commonly take the form of adding absorption that isn't normally there. As a result, they are prioritized towards spaces that have an acoustic optimized for more 'lively' performances, which can then then be made less reverberant when required.

The mechanics of retractable or rotatable areas of absorption have two essential limitations:

- It is inherently difficult to provide significant low frequency absorption in a deployable form, without also providing significantly greater amounts of mid- and high-frequency absorption. This leads to a spectral imbalance at lower RT targets, and/or a need to moderate the low frequency reverberation lift in the 'live' setting with the absorption fully retracted.
- When retracted, the absorption needs to be sealed off from he acoustic of the space in order to prevent a remnant affect on reducing the upper range of the liveness settings. This is particularly a problem at the lower-mid frequencies where heavier containment is required to prevent either the absorption or the containment from affecting the acoustic response when 'away'.

3.3 Electronic Methods

3.3.1 Principles

Acoustic Enhancement systems get the name from their historic use in correcting an acoustic condition that is not suitable to the space. They are discussed here in terms of their ability to give flexibility to the acoustic conditions that can be used to good effect though a wide range of reptoire.

AE systems always involve microphones and loudspeakers, as well as a network of routing and processing. The loudspeakers absolutely must be 'inaudible' in use, ie the user must be unaware of their role, or at least feasibly be able to consider them no more a part of the performance than the walls, floors and ceilings.

It is important to stress that AE systems are not sound reinforcement (SR) systems, in that their design concept is quite different to AE systems, despite sharing many of the ostensible technologies. The disciplines employed in successfully designing and tuning an AE system diverge considerably from those of SR. For example:

- SR systems are strictly centered on maximizing direct-to-reverberant (D:R) ratio, whereas AE systems work very much in the far and reverberant fields, eluding discernment,
- SR systems, to maximize intelligibility in an acoustic space, work on achieving very even coverage, whereas evenness of coverage is a different concept when there is a dimension of time in an AE system
- SR about maximizing gain-before-feedback, AE is about harnessing feedback and using it to an acoustic advantage

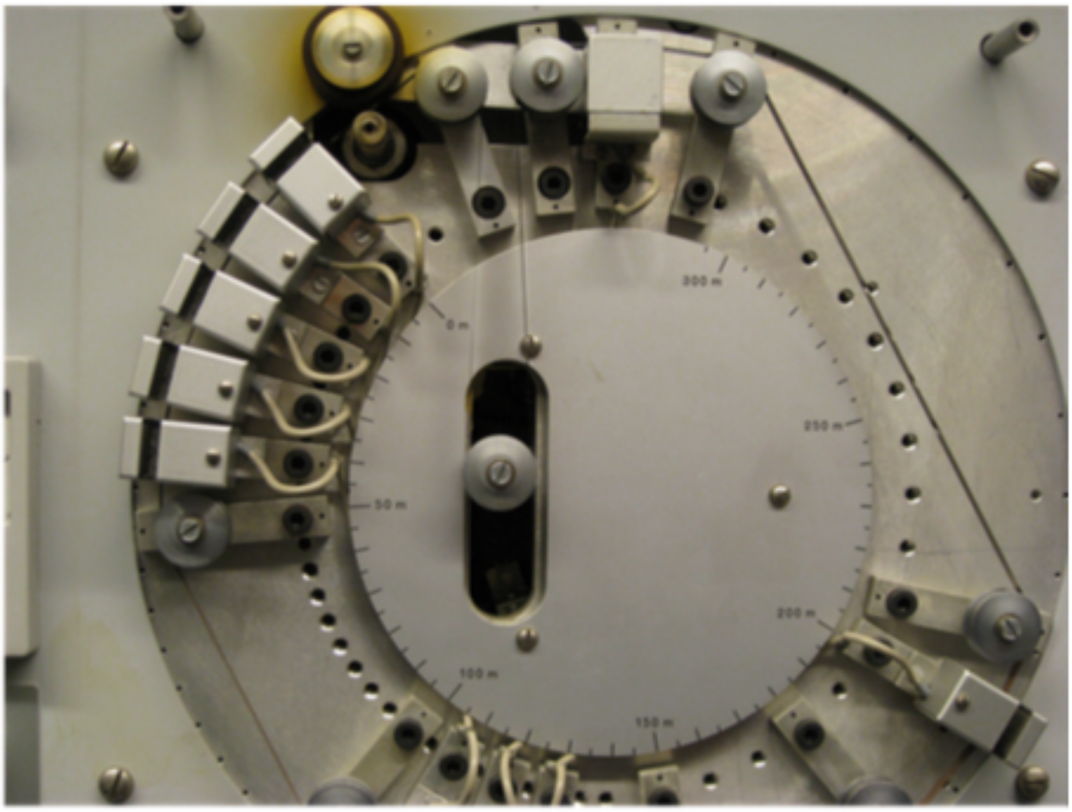
Technology concept most famously started with the Assisted Resonance system put into the Festival Hall in 1964[5], formed from a series of tuned narrow-band feedback systems, each tuned to a different third-octave to achieve some form of stability. This method was as much mechanical as it was electronic, with the electronics providing nothing more than amplification.

However, the AR system formed the precursor to a form of electronic enhancement termed the ***regenerative*** method, or more formally the **Assisted Sound Field (ASF)** principle. Regenerative Systems are discussed in more detail further on in this paper, in so far as relates to the concept of acoustic naturalness and the particular factors and considerations that affect that. Essentially, 'Regenerative' methods are centered on using the sound of the space and on recycling that back into the space, in a form of broadband, precisely managed feedback.

The idea of electronics mimicking the effect of different architectural acoustics can in fact be traced to an even earlier technology, to 1959 and Philips' patented Ambiophony system[6]. This comprised a loop of magnetic tape, with one record head and numerous replay heads, spaced along the loop to represent physical distances of sound travel. The sound field picked up was therefore replayed a number of times, delayed or, virtually, shifted by calibrated 'distances' (based on the tape speed). See Figure 2.

This elementary method of expanding the acoustic space by a repeating signal delay was picked up in 1975 in the ERES system by Jaffe Acoustics[7], based on digital, multi-tap delay lines to generate early reflections. Both systems picked up the stage sound - including the direct sound and the early reflections on stage - and repeated the reflections in appropriate patterns to construct a realistic reverberation field in the audience part of the hall. The resulting signals are played back by loudspeakers, pointed to the audience and away from the stage microphones, creating enough gain before feedback to provide a stable system. Today, the results would not have satisfied our expectations, but in 1959 the results were perceived as excellent. This is the reason the ambiophony system was built into many halls in Europe, including La Scala in Milan.

Ambiophony and ERES formed the precursor to a second form of electronic enhancement termed the ***in-line*** method, or more formally the **Synthesized Sound Field (SSF)** principle. As for *regenerative* systems, *in-line* systems are discussed further, later in this paper. The concept of achieving acoustic naturalness with either system starts with understanding the essential workings of each and applying these to the form and priorities of the performance venue in question.



Courtesy of Institute of Sonology at the Royal Conservatoire, The Hague, Netherlands

Figure 2: Philips' Ambiophony unit, 1959

4 THE QUANDARY

In delivering a successful arts facility, unless the facility comes with the privilege of allowing itself to be single-minded with regards to repertoire (and often even then), providing flexibility is more than a virtue. In fact, in many very real situations, it may quite likely be a pressing necessity as part of the business model and income stream.

The economic mechanics often present an interesting conundrum. It is clear that a wider range of repertoire suitability (at least in terms of the acoustic conditions) can lead to a greater marketability of the venue and a fuller booking schedule.

It is also likely to be the case that, for many venues, the event types likely to bring in the most regular revenue, such as comedy, theatre, awards ceremonies, conferences, corporate presentations and launches, cinema, and banquets, are the ones demanding a drier, more intelligible, perhaps more intimate acoustic condition.

Not far away from this point, touring acts, jazz performances and even musical theatre and pantomime may well all be on the ‘regular income’ list, while favoring an acoustic that may be more lively than for the first list, but nonetheless dry.

Continuing along the spectrum, opera, chamber orchestras, symphonic performances and choral performances require acoustics more lively, with other important properties beyond the Reverberation Time descriptor, with organ music, particularly organ/choral arrangements of church music, begging to take the extreme further.

So it might be an easy point to make that the ‘dead acoustic’ events provide the majority of the regular income, so of course you would design a space to prioritize those. However, balanced against that factors that are as important due to their financial value as their art value. There is an instinct that it is the more high-brow events, such as those at the ‘live’ end of the acoustic scale, that attract the greatest scrutiny, and define the sort of credibility, as a cultural facility, that may well define the success of the venue and the strength of it’s case in attracting first rate acts, not to mention arts funding, when it is on offer.

There is the quandary that presents to every venue considering its priorities, at its birth or its rejuvenation: where to set the acoustic priorities, and how much compromise to accept outside of the optimum, with both ends of the acoustic scale (Figure 1) having very real effects on the business model.

To have aspirations of being considered an excellent venue for high art, you have to provide the best conditions for those audiences that, quite rightly, value the aural quality of their spaces as they do the performance quality of the art. The acoustic conditions for chamber, opera and symphonies have to be just right, and they have to be, in many ways, credible.

So the ‘safe’ position has been to design such that the ‘high-brow’, higher RT conditions maintain maximum integrity, introducing variability to achieve the lower RT conditions and careful design to mitigate the limitations and compromises of doing this. For example, the low frequency ‘bass rise’ in RT that is important to romantic classical music may be moderated down so that the predominantly mid- and high frequency affect of flying in banners does not result in an aural imbalance and the risk of intelligibility loss through upward masking.

If the concerns over the credibility and ‘naturalness’ of AE systems could be satisfied, and a commitment made to a solution employing AE, the design can take quite different priorities, architecturally, acoustically and in terms of technical provision.

5 ACOUSTIC ENHANCEMENT TECHNOLOGIES

As introduced in Section 3.3, two principle methods of electronic acoustic enhancement have formed over the last 60 years: *in-line* systems and *regenerative* systems. Since 1987 we have also seen systems developed to combine the techniques of each to allow flexible blending, which we will term *hybrid* systems.

With only a few hundred systems having been installed anywhere in the world in that whole period, the market for commercial systems is very contained and we can be fairly comprehensive in a review of the available products – see Figure 3

The choice of AE method employed both defines the physical form of the system (ie how it maps onto the designs for the venue) as well as the range of acoustic character the particular AE installation can be manipulated into providing.

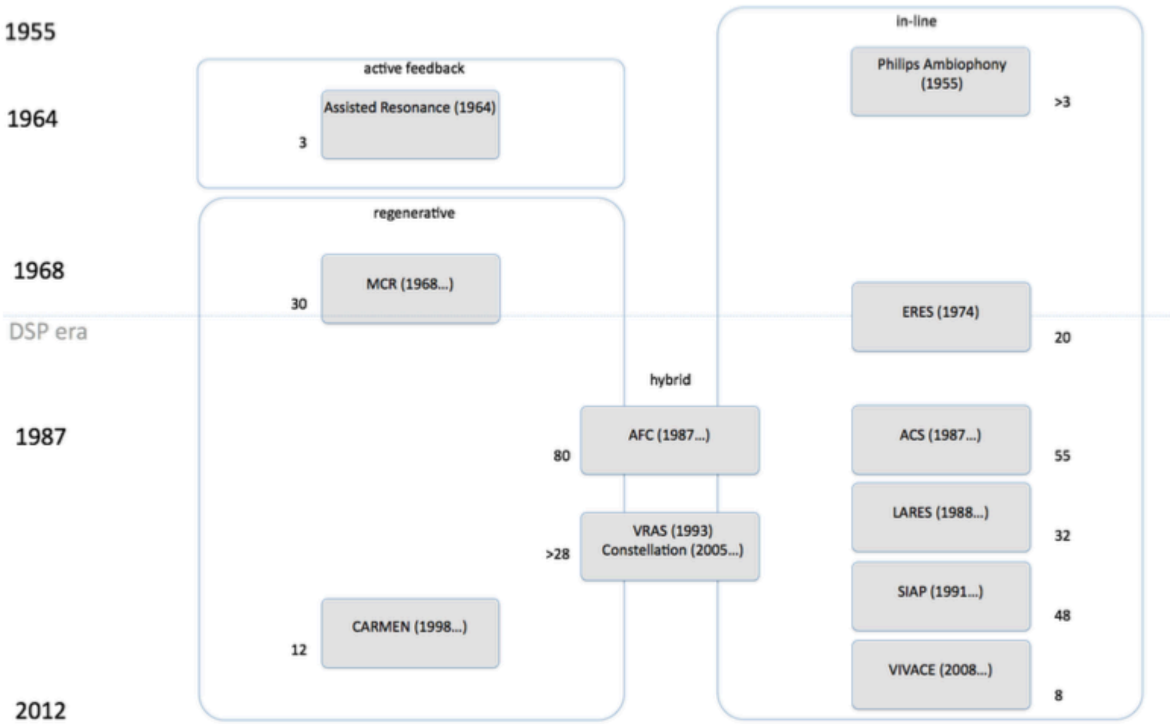


Figure 3: Historic overview of commercially available acoustic enhancement (AE) systems

6 REGENERATIVE METHODS

6.1 Principles

As mentioned already, 'Regenerative' methods are centered on using the pre-existing unaffected acoustic response of the space, and on recycling that acoustic back into the space, in a form of broadband, precisely managed feedback. 'Broadband feedback' is, in fact, essentially what reverberation is, and so it is not hard to see the appeal of the Regenerative method to those looking to emulate the architectural mechanics of the acoustics, with the flexibility of electronics.

Delay time can be used to affect the apparent size of the space and/or the apparent distance of virtual reflective surfaces. Of course, delay can be added but can never be subtracted electronically, only by affecting the distances to the microphones or from the loudspeakers.

The format of the modern *regenerative* system was established, again by Philips, in 1969 with the 'Multi Channel Reverberation" or MCR system[8]. Founded on the principle of open microphones connected to open loudspeakers, both in the reverberant field, the issue of coloration or unstable feedback is paramount. Philips recognized that with a loop gain of -21dB or less, the system would be inherently stable, meaning that with around 100 or so independent microphone and loudspeaker channels the acoustic energy of the space can be doubled, resulting in a corresponding increase in reverberation.

The MCR system has been built into many concert halls in Europe, and is now still offered by the Dutch company Event Acoustics as XLNT-MCR. The French public research organisation "Centre Scientifique et Technique du Bâtiment (CSTB)" developed the Carmen system - an alternative way of using the MCR concept by offering integrated microphone/speaker modules to form a "virtual wall." [9]

6.2 Naturalism

Regenerative methods can be thought of as recycling the natural acoustic of the space. In concept at least, this method already offers an element of 'naturalism', in that any extended acoustic response is not being created by a DSP processor convolution: it is the acoustic of the actual space, 'exaggerated' through recycling.

Running counter to this instinct is the risk of 'localising' loudspeakers. In order to recreate the density of reflections as would result from the altered architecture being mimicked, so much is relied on in level from each loudspeaker that the potential to identify and locate them as loudspeaker sources (and not acoustic reflections) becomes very real. This risks destroying any illusion and the 'naturalness' of the result.

Also running counter to the intuitive authenticity benefit is that, if the room itself exhibits any particular acoustic character or anomaly, such as a flutter echo, a resonant reverberation, a focus or even a high background noise, a *regenerative* method will unavoidably exaggerate that, part and parcel with the room acoustic.

A genuine benefit of the *regenerative* approach is that the microphones are located in the far field, which is likely to include pick up of both the performance and the response of the audience. Remember our principles listed in Section 2.1, how it is important that both the audience and performers occupy the same, or at least connected acoustic space. *Regenerative* systems also allow loudspeakers to be placed in the performance area (as the microphones are more remote from that), meaning that the audience response, as well as the response of the hall, can be corralled to affect the performers' experience. It can be argued that the cycling of acoustic energy between auditorium and stage is in fact unnatural, and it is true that acoustic energy does not typically respond in that way, especially through a defined proscenium. However, when an auditorium is designed to be of higher RT, the stage area would be expected to experience something similar or related, so to *not* recycle in this way would likely be judged far less '*naturalistic*', despite that physics argument.

6.3 Flexibility

Where the Assisted Resonance method used channels with a narrow bandwidth and high gain, the MCR concept showed that full bandwidth channels can be used, as long as the loop gain per channel stays below -21dB. Channels could be added without the risk of colouration and oscillation, provided the channels are not correlated i.e. they have independent open loop transfer functions. This can be achieved by carefully distributing the microphone/speaker pairs across the hall.

However, it is essential in considering options that the regenerative method is limited in scope to enhancement of the response by amplifying what is already there. In addition, making the reverberation time longer always means that the amount of acoustic energy has to be amplified:

longer means louder and louder means longer. This constraint corresponds, in Figure 4, with the slope of the reverberation tail changing with increasing loop gain.

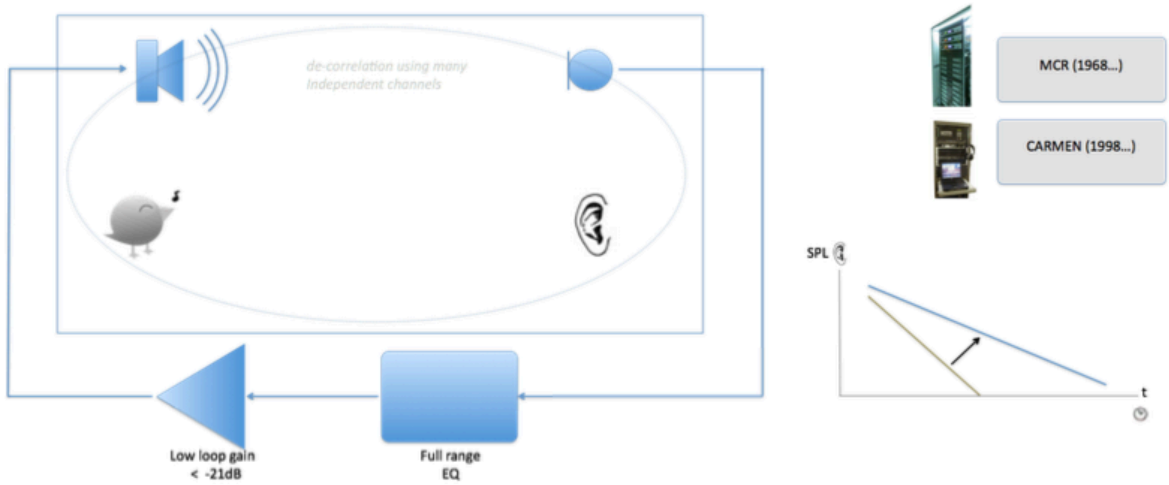


Figure 4: *Regenerative* (ASF) System Concept

6.4 Critical Features

Apart from the microphones, loudspeakers and routing system that are common to all AE solutions, *regenerative* systems must have, at their proprietary hearts, systems and tools for harnessing the feedback they are courting, to tame it for colouration, to stay clear of instability, and to very single-mindedly maximize the gain before *tonal or unstable* feedback. Acoustic quality and success of the result will rely heavily on the system's methods of maximizing loop gain by highly precise equalization of the acoustic response paths between each microphone and active loudspeaker on the same channel. 'Ringing' the system for peaks in response is one of the first and most fundamental tasks of the System Tuner.

7 IN-LINE METHODS

7.1 Principles

In-line methods concentrate on picking up sound from points closer to the performance area, subtly adding electronic reverberation, through the use of convolution engines, along with calculated signal delays to mimic larger spaces, and delivering this sound though a series of distributed loudspeakers in the audience space.

An *in-line* AE system has, at its heart, a series of DSP convolution engines, working in parallel across the signal channels, adding acoustic responses to the picked-up sound and delivering the effected result to a matrix of loudspeakers throughout the auditorium.

In any system of open microphones and loudspeakers, there will be an element of regeneration working in parallel with the in-line effect. However, pure in-line systems have developed along the principle of keeping the loop gain very low (much lower than for *regenerative* systems) so that the reverberation increase is predominantly controlled by the DSP effects. Various systems have evolved to use this method.

From 1987 to 1991, three systems were brought to the market taking a completely different approach that would break away from the regenerative "longer is louder." constraint: ACS (1987, ACS bv, van Berkhout)[10], LARES (1988, Lexicon, D. Griesinger)[11], and SIAP (1991, SIAP bv, van Munster & Prinssen)[12]. In 2008, Stagetec brought the Vivace system to the market (Stagetec, Muller-BBM)[13].

Each system uses specially developed reverberation algorithms running on DSP hardware that became available at that time, minimising acoustic feedback by placing directional (cardioid, supercardioid) microphones as close as possible to the stage so the loop gain can be maintained as low as possible. Additionally in LARES, ACS and Vivace, time variance is sometimes applied to modulate the reverberation algorithm delay times by a small amount. Although it is reported to be slightly audible in some circumstances, it suppresses feedback, avoiding colouration and instability for systems using a limited amount of independent channels. If an in-line system is installed with many independent channels, de-correlation occurs automatically, and time variance is no longer required (ACS, SIAP).

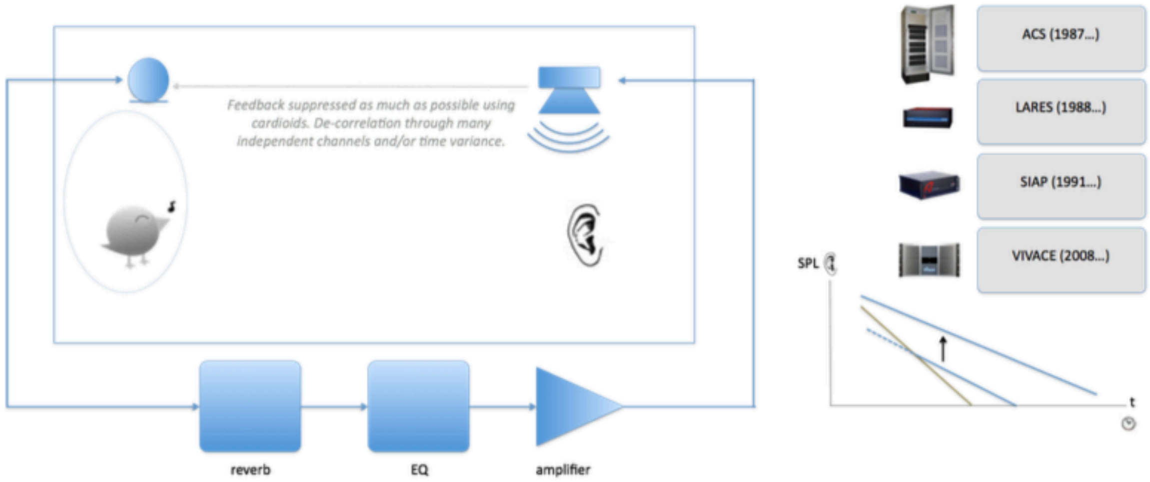


Figure 5: *In-line* (SSF) system concept

7.2 Naturalness

At first concept, the 'in-line' approach might resemble a studio effects unit, and in fact some of the successful systems on the market have grown out of a strong heritage in those applications. However, there is far more to the concept than adding a convolution response, with the acoustic signals from a large array of microphones being processed separately (or in distributed batches) through separate and independently-seeded convolution engines, each controlled to provide a suitable blend of responses when distributed to a large series of loudspeakers secreted around the walls and ceilings of the audience space. It is through these tools that the better in-line systems can achieve the illusion of a dense acoustic reflection and reverberation pattern, with the all-important spatial and temporal diversity through the space to contribute to the illusion.

7.3 Flexibility

Assuming that in-line systems are feedback-free, any reverberation pattern can be added to the existing acoustics. If the existing acoustics are "dry," (low energy/low reverberation time), the result is almost fully dependent on the active system, which is ideal to achieve multi-purpose usage of venues. Also, because the reverberation and early reflection patterns can be designed in detail, and directional microphones are used close to the performance space, powerful Early Reflections and localization features can be supported.

7.4 Critical Features and Limitations

In-line systems clearly rely heavily on the quality of their DSP convolution engines, and of the response tails they use to create the acoustic environment. In some, the responses have been sampled from a range of spaces, including excellent halls and other applications, but this should not be confused with an attempt to mimic those source acoustics as the deployment in this way creates significant other factors. It is reassuring, however, to know that the acoustic 'DNA' in the responses being created comes with good provenance.

Also critical to the success on an *in*-line system is the diversity in the spatial locations of loudspeaker locations, circuits and microphones, helping keep the loop gain down, to maximize opportunities for spatial and temporal blending and to offer facilities for influencing the timing and direction of reflections and energy packets.

An *in-line* system, in its purest form, includes very little of the room's actual acoustic response in the audio produced. While the imposition of an independent acoustic response characteristic offers significant flexibility advantages, the risk is of the room sounding quite different to how it looks, throwing up subliminal clues that the acoustic heard is not entirely that of the room. Any change to the acoustics without changing the room, electronic or mechanical, runs the risk of aural/visual incongruity and either a suspicion or at least a discomfort on the part of the viewer and listener, but one with minimized reuse of the unaffected acoustic runs this risk maximally.

The main disadvantage of an in-line solution is that only the area covered by the directional microphones – e.g. the stage - is enhanced. Sound coming from other areas e.g. from the audience - are not included unless they are equipped with their own system. It is very difficult for in-line systems to support a natural acoustic behavior covering a complete hall, where the musicians on the stage would not only hear something of their performance as it plays out in the hall, but also a similar (but different) response form the stage area itself, offering support across the ensemble.

With an in-line system, the audience's responses (applause, laughter and other involuntary sounds) are not picked up by the microphones, which are usually located around the inside of the proscenium and closer to the performers. This can result in an abrupt difference between the 'acoustic space' occupied by the performance and that one occupied by the audience. With alternative approaches (regenerative and hybrid) loudspeakers can be placed within the performance area and the microphones within the space, along with the processing, will naturally lift both the audience and performance spaces together and mutually.

8 HYBRID SYSTEMS

Applying a combination of in-line and regenerative system concepts, a *hybrid* (or "hybrid regenerative") system can be constructed with fewer channels compared to pure regenerative systems, e.g. with 16 microphones and 16 loudspeakers, constituting 16 independent channels. In medium sized and large halls, this is probably insufficient to increase the acoustic energy required to significantly enhance the reverberation time using only regenerative techniques. By applying a digital reverberator per channel, the reverberation time can be increased without adding energy, while the number of 16 independent channels is just sufficient to increase the acoustic energy to an appropriate level. This way, the system allows for more freedom in changing the acoustic response compared to purely using many independent channels. This approach also escapes the "longer is louder," constraint of pure regenerative systems. An example of a hybrid regenerative system using digital reverberators within its channels is the LCS VRAS system, renamed in 2005 to Constellation by Meyer Sound[14].

Constellation still uses the method of multiple independent channels in a system to achieve a colouration free sound field, but far fewer channels than found in pure regenerative systems. To achieve consistent sound pressure level (SPL or L_P) coverage over the hall and to avoid localization of speakers, multiple speakers can be connected to each channel. It is important to note that increasing the number of loudspeakers on a channel does not constitute an increase in the count of independent channels - the number of independent channels is equal to the number of independent microphones.

By using a loop-flattening algorithm, the open loop gain of a system's channels can be flattened to allow for higher loop gains. This way, fewer independent physical channels have to be used to add the same amount of acoustic energy to the room. An example of this approach is the Yamaha AFC system[15]. This design uses a spatial averaging flattening algorithm that cross fades only 4 system busses through 4 microphones, preventing feedback energy from accumulating at peak frequencies[16]. Additionally, Finite Impulse Response (FIR) filters are used, to add early reflection patterns to the reverberation channels without causing colouration. Compared with the VRAS system, AFC uses fewer physical channels and fewer reverberation modules but achieves a similar result.

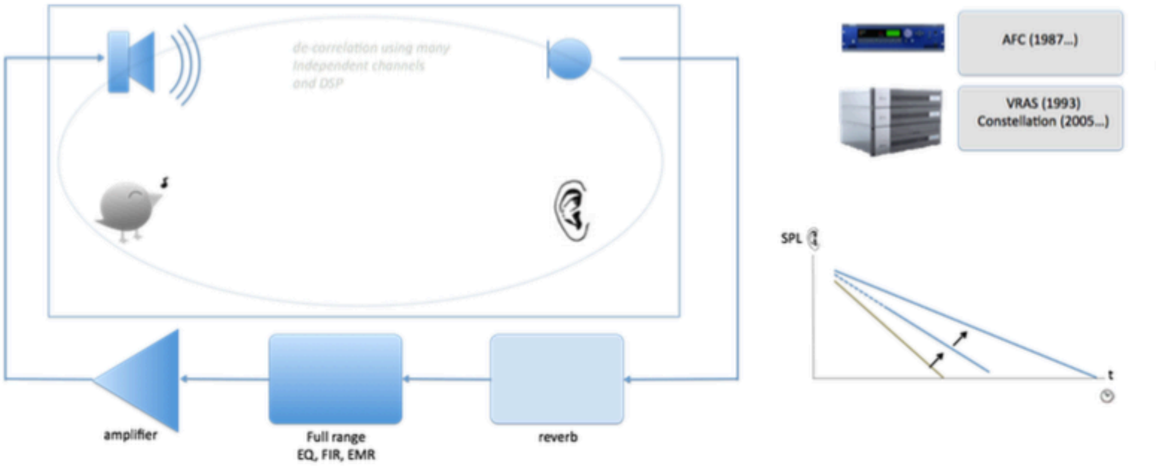


Figure 6: *Hybrid* regenerative system concept

9 CONCLUSION

With modern active technology, using microphones, DSP engines, power amplifiers and speakers, and with very careful design and tuning of the system, it is possible to enhance a room's acoustics at a very high quality level. This must be heard to be believed, and the reader is encouraged to seek out opportunities to do this, and to perhaps consider (successful) ones when they may have already experienced a system without knowing.

The success depends on the applicability of the particular system and system design, to the space, to the acoustic priorities and to the architecture. In fact, understanding the mechanics and relative advantages of each approach can inform the decisions and strategies made in planning the listening space, affecting the disciplines applied to its acoustic design, architectural form and technical provision.

Well conceived and executed Acoustic Enhancement systems can not only achieve a high quality acoustic space, but can be part of raising the opportunities for spaces to aspire to the highest qualities of performance without compromising their business viability.

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