Audio Engineering Society

Convention Paper

Presented at the 144th Convention
2018 May 23–26, Milan, Italy

Comparison of Effectiveness of Acoustic Enhancement Systems—Comparison of In-Line, Regenerative & Hybrid-Regenerative Enhancement Methods

Takayuki Watanabe[1], Dai Hashimoto[2], Hideo Miyazaki[3] and Ron Bakker[4]

[1] *Yamaha Corp., Hamamatsu, Shizuoka, 430-8650, Japan*

[2] *Yamaha Corp., Hamamatsu, Shizuoka, 430-8650, Japan*

[3] *Yamaha Corp., Hamamatsu, Shizuoka, 430-8650, Japan*

[4] *Yamaha Commercial Audio Systems Europe, 25462 Rellingen, Germany*

Correspondence should be addressed to Author (takayuki.watanabe@music.yamaha.com)

ABSTRACT

Acoustic enhancement systems have become popular in recent years and are broadly used in various kinds of facilities because of their acoustic naturalness and system stability. Today, demand for acoustic enhancement systems exists not only for multi-purpose halls but also for highly absorptive spaces, especially lecture halls and theatres. To investigate an effective enhancement system for highly absorptive spaces, we compared several enhancement methods that are commonly applied in a small auditorium. This paper summarizes the features and the acoustical characteristics of systems configured according to each of the considered enhancement methods in the small auditorium.

1 Introduction

Acoustic enhancement systems to expand acoustical properties of venues have become popular in recent years and are broadly used in various kinds of facilities because of their acoustic naturalness and system stability. To date several acoustic enhancement systems have been developed with different concepts. Our group also has developed the system named AFC in 1985 as a tool for acoustical design and applied the system for more than 100 venues. Today, demand for acoustic enhancement systems exists not only for multi-purpose halls but also for highly absorptive spaces, especially lecture halls and theatres. Although we consider that twice the original reverberation time (RT) maintains naturalness both in aural and visual terms, RT greater by three times or more is often required by clients these days. For example, enhanced RT exceeding 2 seconds may be demanded for musical application in a theatre with original RT of 0.7 seconds. To realize natural acoustic in highly absorptive spaces, proper system concept has to be considered. In order to investigate essential factors of such system, we integrated several enhancement systems with different concepts in the small venue and compared their features and acoustical characteristics.

Photo 1. Experiment sound field.

Table 1. Comparison of enhancement method of acoustic enhancement systems.

System	Pros	Cons
In-line	Realization of requested sound field in a highly absorptive space.	Limitation of the controllable area.
Regenerative	Natural sound quality based on the existing sound field.	- Necessity of many independent channels to enhance large length of reverberation. - Difficult to control early reflections.
Hybrid-regenerative	Capability of large enhancement ratio with natural sound quality using small number of independent channels.	Difficult to control early reflections.

2 Applied systems and its features

Acoustic enhancement method is categorized by the configuration of microphones and loudspeakers, and its signal processing technique. Three acoustic enhancement methods are in broad commercial use today: 1) the in-line method, which uses precise reverberators in the loops and minimizes acoustic feedback, 2) the regenerative method, which actively uses acoustic feedback and maintains stability by using a number of independent channels, and 3) the hybrid-regenerative method, which is based on the regenerative method but uses multiple reverberators in the loops [1]. Table 1 lists the features of enhancement method.

We applied four systems, as shown in Table 2, in a small 100-seat highly absorptive auditorium (Photo 1). The raw RT of the auditorium is 0.6 sec. Each system had same number of speakers, but the microphone type and the number was changed based on the enhancement method. All microphones and loudspeakers were placed on the ceiling. The acoustical target of each system was three times the original RT, or 1.8 sec. Regarding the regenerative method, the prepared system had only 20 independent channels owing to physical limitations. Theoretically, it could not realize the acoustical target. Therefore, for our reference, we also prepared an 80 independent channels system using a spatial averaging function (amplitude modulation) [2]. The focus of the tuning of each system was on flattening the frequency characteristics of each bus and eliminating coloration. No processing except for the above aims was done. Each system is summarized below.

Table 2. Configuration of systems in the venue.

System	Number of microphones	Number of speakers	Independent channels
In-line	4	8+12	2
Regenerative	20	20	20
Hybrid-regenerative (medium gain)	4	20	4
Hybrid-regenerative (high gain)	8	20	8

1) In-line system: Four super-cardioid microphones were installed close to the stage. There were two systems, namely 8 speakers for the stage and 12 speakers for the audience area. Each system was configured with two independent channels with precise reverberators. To ensure system stability, four statistically independent time-variant reverberation units (frequency modulation) were also applied [3]. Figure 1 shows the equipment placement and Figure 2 shows the block diagram of the system.

2) Regenerative system: Twenty omni-directional microphones were installed on the ceiling. Twenty independent channels were implemented using 20 loudspeakers on the ceiling [4]. A spatial averaging function (amplitude moderation) was applied to achieve a gain equivalent of 80 independent channels. Figure 3 shows the equipment placement and Figure 4 shows the block diagram of the system.

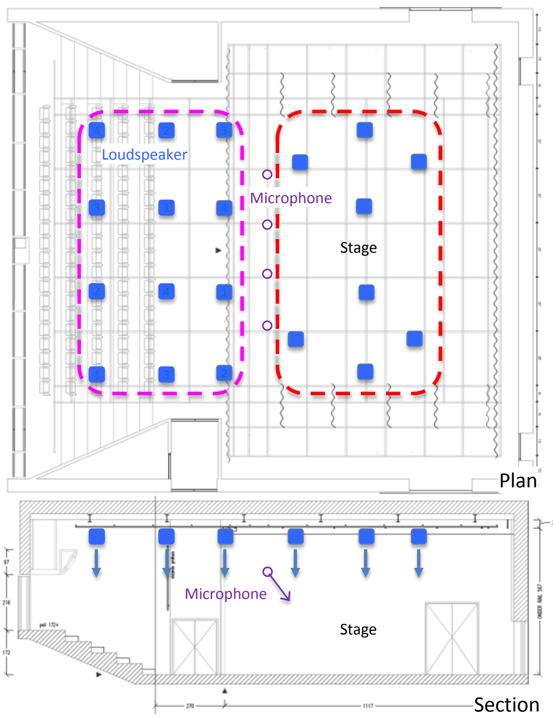

Figure 1. Equipment placement of in-line system.

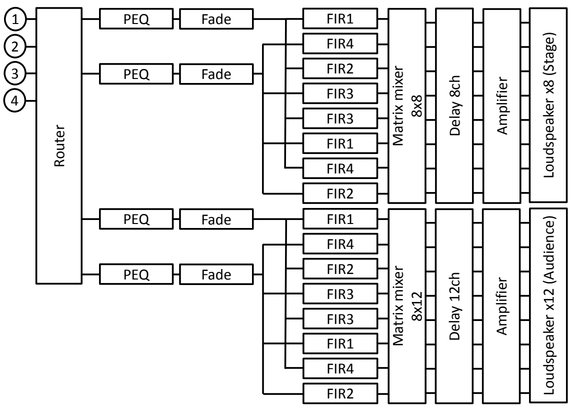

Figure 2. Block diagram of in-line system.

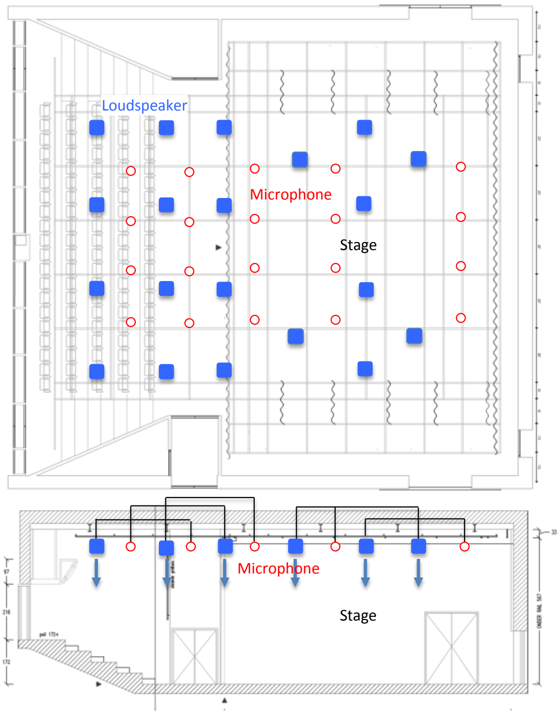

Figure 3. Equipment placement of regenerative system.

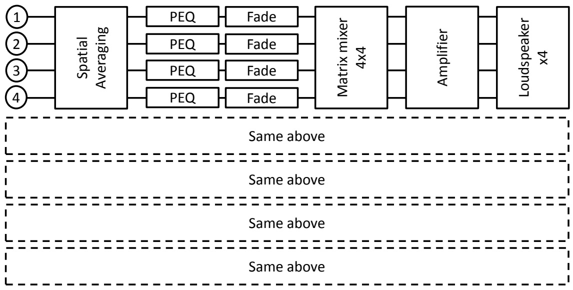

Figure 4. Block diagram of regenerative system.

3) Hybrid-regenerative system (medium gain): Four omni-directional microphones were installed on the ceiling. Four independent channels were implemented using 20 loudspeakers on the ceiling. Each channel had a FIR based reverberator for reverb creation. The applied data consisted of applied impulse responses captured at a 1,000-seat concert hall. The system used a spatial averaging function (amplitude modulation) to achieve a gain equivalent of 16 independent channels. This type of system is usually applied in hybrid-regenerative systems with small to medium RT enhancement ratios. Figure 5 shows the equipment placement and Figure 6 shows the block diagram of the system.

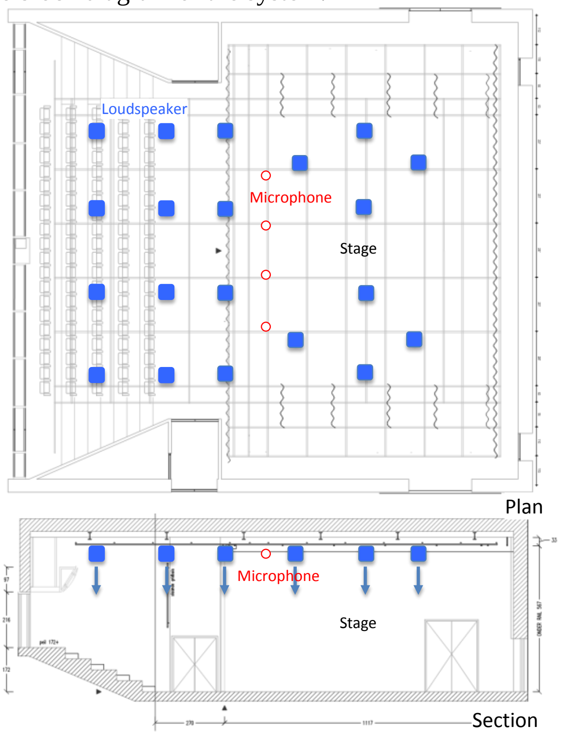

Figure 5. Equipment placement of hybrid-regenerative system (medium gain).

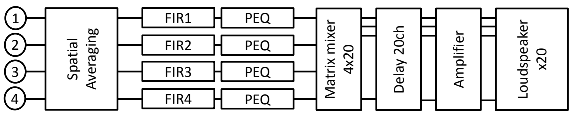

Figure 6. Block diagram of hybrid-regenerative system (medium gain).

4) Hybrid-regenerative system (high gain): Eight omni-directional microphones were installed on the ceiling. Eight independent channels were implemented using 20 loudspeakers on the ceiling. Each channel also had a FIR based reverberator for reverb creation. The applied data was the same as that for the medium gain system. The system used a spatial averaging function (amplitude modulation) to achieve a gain equivalent of 32 independent channels. This type of system is usually applied in hybrid regenerative systems with high RT enhancement ratios. Figure 7 shows the equipment placement and Figure 8 shows the block diagram of the system.

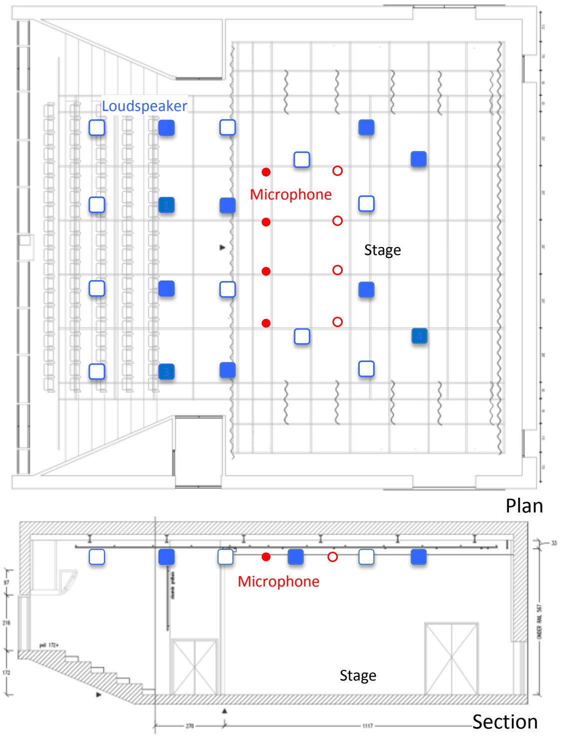

Figure 7. Equipment placement of hybrid-regenerative system (high gain).

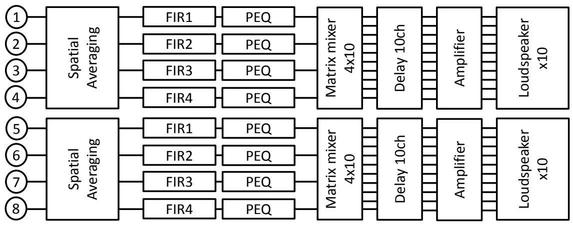

Figure 8. Block diagram of hybrid-regenerative system (high gain).

3 Measurement method

To evaluate the effectiveness of each system throughout the auditorium, we carried out measurement of impulse responses using three different sound source locations in the auditorium (S1-S3). The acoustical indices RT (T_{20}), *EDT* and *Strength G* were measured at each measurement point in the auditorium (M1-M14). To eliminate the influence of direct sound, the measurement points close to the sound source were eliminated [5]. On the stage, we measured the stage support index. Figure 9 shows the sound source locations and the measurement points.

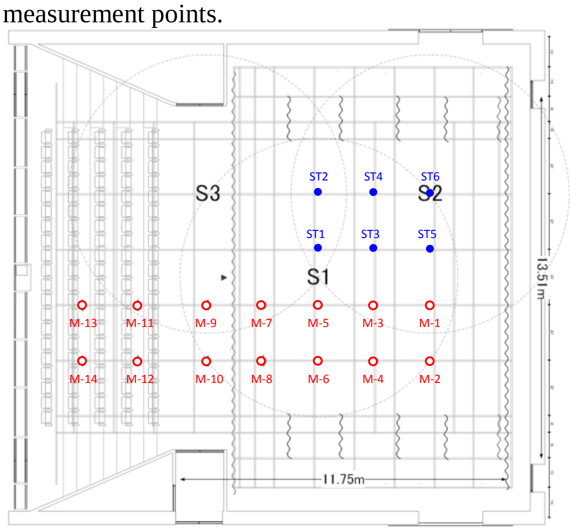

Figure 9. Measurement points.

4 Measurement results

Figure 10 shows a comparison of the T_{20} value of each system. Figure 11 shows a comparison of the EDT/T_{20} ratio value of each system. The value of EDT/T_{20} is related to subjective reverberance [6]. Each figure indicates the average, maximum and minimum values, respectively. Table 3 shows the measurement results of *strength G* and stage support index. It lists the differences in value that system use makes compared with non-use for each system.

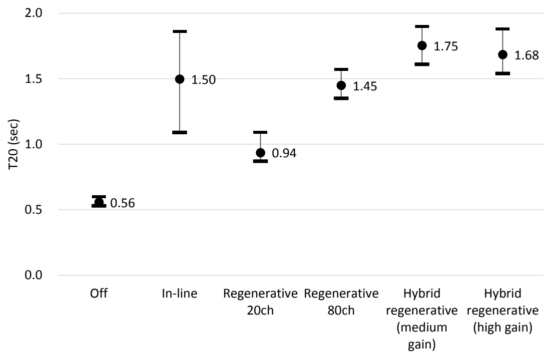

Figure 10. Comparison of T_{20} value of each system (500-1kHz avg.).

<u>Effectiveness throughout the auditorium</u>: T_{20} of the regenerative system and the hybrid-regenerative system showed a small distribution. These results were not influenced by the sound source position. On the other hand, T_{20} of the in-line system showed a large distribution. Since the independent channels of the regenerative system were limited in number for physical reasons, T_{20} could not exceed the target value of 1.8 sec even in the 80 independent channels system. To exceed the target value, 110 independent channels are required.

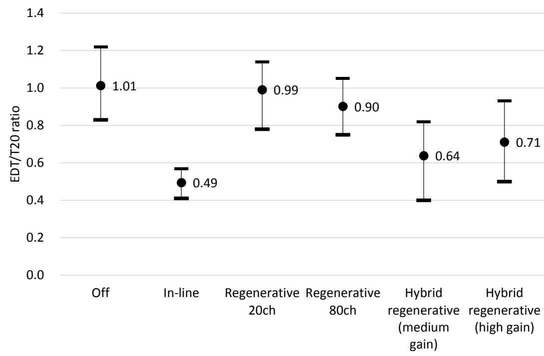

Figure 11. Comparison of EDT/T_{20} ratio value of each system (500-1kHz avg.).

<u>Secure reverberance</u>: The measured EDT/T_{20} ratios of the regenerative systems were greater than 0.9 (average) and were not influenced by the sound source positions. The EDT/T_{20} ratio of the in-line system was 0.5, that of the medium gain hybrid-regenerative system was 0.64, and that of the high gain hybrid-regenerative system was 0.71, respectively.

<u>Comparison of acoustical indices</u>: The measured *Strength G* value of the regenerative system (20 ch) was +1.2 dB higher than the value when the system was turned off. The value of the in-line system was +0.2 dB, that of the medium gain hybrid-regenerative was +0.6 dB, and that of the high gain hybrid-regenerative system was +0.7 dB, respectively. The stage support value showed the same tendency as the *G* value.

The regenerative system had greater *G* and T_{20} values for the configuration of 80 independent virtual channels than for the configuration of 20 independent channels, which is in line with the theoretical prediction.

Figures 12 and 13 show the comparison of the rms curve of each system. Figure 12 showed the energy until 300 ms of the regenerative system to be higher compared with the other systems. This explains why the EDT/T_{20} ratio, G and ST values of the regenerative system were all higher than those of the other systems. Regarding the comparison of hybrid-regenerative systems, Figure 13 showed that a higher number of independent channels produces larger energy.

Table 3. Measurement results of *G* & *ST* values.

System	*G* (dB)	ST_{early} (dB)	ST_{late} (dB)
In-line	S1: +0.3 S2: +0.3 S3: +0.1	±0.0	+1.3
Regenerative (20ch)	S1: +1.3 S2: +1.6 S3: +0.7	+0.5	+3.6
Regenerative (80ch)	S1: +2.7 S2: +3.3 S3: +2.5	+1.2	+7.3
Hybrid-regenerative (medium gain)	S1: +0.6 S2: +0.6 S3: +0.5	±0.0	+2.6
Hybrid-regenerative (high gain)	S1: +0.7 S2: +0.7 S3: +0.6	±0.0	+3.2

Table 4. Subjective impression of applied systems in venue

System	Comments
In-line	-Less effect with source S3. -Subtle effect on stage. -Less feeling of reverberance throughout the venue.
Regenerative	-Excessive loudness. -Natural reverberance. -No localization of the source. Feeling of doubling of several systems.
Hybrid regenerative (medium gain)	-Limitation of capturing area of sound source. -Reverberance higher than in-line, lower than regenerative. -Natural reverberance. -Appropriate spaciousness.
Hybrid regenerative (high gain)	-Reverberance is higher than medium gain hybrid regenerative, lower than regenerative. -Enough loudness. -Natural reverberance. -Appropriate spaciousness.

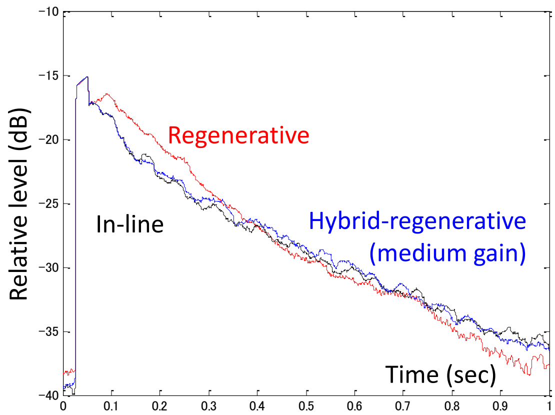

Figure 12. Comparison of rms curve between in-line, regenerative & hybrid-regenerative (S1: M-11, OA, τ =25 ms).

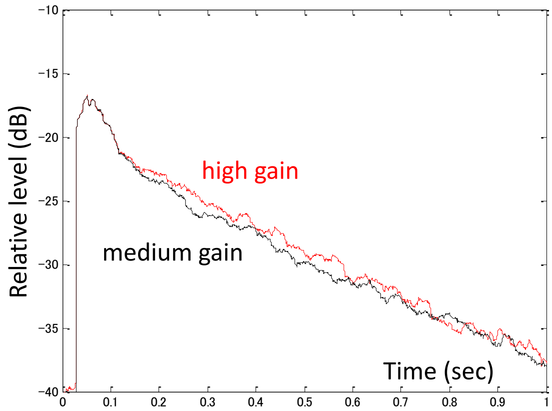

Figure 13. Comparison of rms curve of hybrid-regenerative (S1: M-12, OA, τ =25 ms).

Subjective impression: The number of participants in the experiment was quite small, but, for reference, our subjective impressions are shown in the Table 4. Most comments related to the objective measurement results.

5 Conclusions

As an investigation of major acoustic enhancement methods, we configured several systems based on each method under consideration to achieve an RT value three times the original RT, and we evaluated the features and acoustical characteristics of each system as measured in a highly absorptive space. The results showed that the in-line system suffers limitations in terms of effective area in relation to the sound source position, and that the system has difficulty maintaining appropriate reverberance because of the small value of the EDT/RT ratio. Although the regenerative system can achieve a high EDT/RT ratio, the system requires three times the power gain to realize a 2-sec sound field when the original RT is 0.7 sec. For such a power gain, the system needs to have more than 100 independent channels, which is prohibitive in terms of cost, including equipment requirements and tuning period. More importantly, with the high enhancement ratio required for highly absorptive spaces, the excessive loudness of the regenerative system may not be appropriate considering the volume of the hall. In view of such limitations, the hybrid-regenerative system might be a reasonable choice, providing high RT enhancement ratios with a balanced reverberance. However, such a system requires a sufficient number of independent channels to deliver appropriate reverberance, as well as a separate system for the control of early reflections.

References

[1] R. Bakker, "Active Acoustic Enhancement Systems" in Proc. of 27th TonMeisterTagung (2012).

[2] F. Kawakami, "Recent Progress in AFC Technology —New Ideas for Averaging the Loop Gain—" in Proc. of AES Korea Section the 2nd Audio Conference (1998).

[3] D. Griesinger, "Improving room acoustics through time-variant synthetic reverberation," in Proc. of AES 90th Convention (1991).

[4] A. Krokstad, "Electroacoustic means of controlling auditorium acoustics," *Appl. Acoust.*, 24, 275-288 (1988).

[5] ISO3382-2, "Acoustics—Measurement of room acoustic parameters—Part 2: Reverberation time in ordinary rooms," (2008).

[6] J. O'Keefe, "The Influence of Simple Room Geometries on Acoustical Parameters," *JCAA*, Vol. 26, 25-26 (1998).