Audio Engineering Society
Convention Paper

Presented at the 115th Convention
2003 October 10–13 New York, New York

Active Field Control (AFC)
Reverberation Enhancement System Using Acoustical Feedback Control

Hideo Miyazaki[1], Takayuki Watanabe[1], Shinji Kishinaga[1] and Fukushi Kawakami[1]

[1] Yamaha Corporation, Advanced System Development Center, Hamamatsu, Shizuoka, 430-8650, Japan

ABSTRACT

Technology for controlling sound field by electro-acoustic means is often called Active Field Control, AFC, which is used to improve auditory impressions such as liveness, loudness, and spaciousness in auditoria. The AFC system, which has been developed at Yamaha, utilizes feedback control techniques to re-create natural reverberation based on the existing acoustics of the room. Time varying control, including EMR (Electric Microphone Rotator) and fluc-FIR (fluctuating FIR), is implemented in the AFC system to improve stability, preventing the coloration caused by a feedback loop in the system. In this paper, these technologies are summarized, together with an introduction to the recent representative venues using AFC. A system plan using core devices named AFC1, which has been developed at Yamaha and released recently in the US, is also presented.

1. INTRODUCTION

The technical field of AFC is usually classified into 3 categories as shown in Table 1. According to this classification, "AFC for auditorium" refers to "A-SF (Assistance of Sound Field)" which is originally derived from the term "Assisted Acoustics" first used by one of the pipe organ builders in Japan. The term "AFC" is hereinafter used to refer to the Yamaha version of "A-SF" technology.

AFC has been under development at Yamaha for more than 15 years and installed in approximately 50 venues in Japan to date. AFC controls acoustical conditions based on the existing room condition by utilizing the acoustical feedback of a system actively.

Therefore, AFC should be distinguished from the digital reverberator to generate reverberation

Table 1. Categories of sound field control systems.

Categories		Definition
A-SF	**Assistance of Sound Field**	**Control of room acoustic condition based on the existing room condition**
P-SF	Production of Sound Field	Production of spatial sound effects, mainly for theater, movies, etc.
S-SF	Synthesis of Sound Field	Synthesis of requested condition in an anechoic or highly absorbent room

electronically [3] or the echo cancel system for eliminating feedback effects [4].

AFC is characterized by the following features: 1) Re-creation of natural reverberation based on the physical condition of the existing room by means of an acoustical feedback control, 2) Wide range controllability using FIR filters, 3) Effectiveness independent of source and receiver position in the room, 4) Stability against howling effect using time varying control, 5) Ease of operation.

In this paper, AFC technology is summarized with a focus on these features, together with an introduction to the core device named AFC1, which has been developed at Yamaha and released recently in the US.

2. BASIC CONCEPT OF AFC

The relationship between the reverberation time (T_{60}) and the energy density of the diffused sound (E_r) in a room can be described as follows:

$$E_r = (1-\bar{\alpha})WT_{60}/(13.8V) \quad (1)$$

where W is the sound source power, V is the room volume, and $\bar{\alpha}$ is the average absorption coefficient. The concept of AFC is based on this equation, which indicates that T_{60} can be extended by increasing E_r.

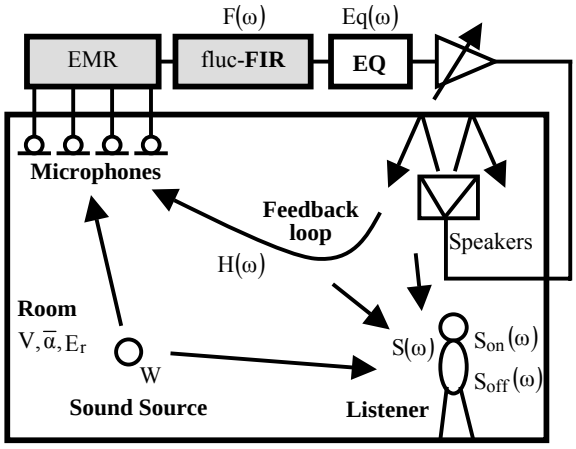
AFC consists of the following four elements as shown in Fig.1, where EMR and fluc-FIR are the kinds of time varying control techniques described in the next section: 1) Input section, which collects the musical instruments' sound or diffused sound through microphones, 2) Reflection synthesizing section, which modifies the acoustical conditions with FIR filters, 3) Equalizing section, which corrects the acoustical characteristics of the selected auditorium area, 4) Output section with speakers.

AFC actively utilizes the acoustical feedback of a system to increase the energy density of diffused sound, so that reverberation time and sound energy density can be controlled with auditory naturalness while preserving the original acoustical characteristics of a room.

In addition, by installing FIR filters within the feedback loops, wide range controllability can be realized as shown in Fig.2, where "a" is increasing the energy of each FIR tap, which is equivalent to reducing the absorption coefficient [$\bar{\alpha}$] in Equation (1), and "b" is expanding the gaps between FIR taps, which is equivalent to increasing the volume [V] in Equation (1).

3. TIME VARYING CONTROL (TVC)

Since AFC utilizes acoustical feedback as mentioned above, it is essential to prevent coloration problems caused by a closed loop condition and maintain a stable system. The stability of a system is evaluated by its loop gain [1][2]. In order to ensure smooth loop gain and a sufficient margin against howling to prevent instability, the following two types of TVC techniques are implemented in the AFC system.



Open Loop Gain: $G_o(\omega) = H(\omega)Eq(\omega)F(\omega)$

Loop Gain: $G(\omega) = Eq(\omega)F(\omega)/(1-G_o(\omega))$

Increase of $S(\omega)$ for n-ch:

$$S_{on}(\omega)^2 / S_{off}(\omega)^2 = 1/(1-nG(\omega)^2)$$

EMR, fluc-FIR: Time Varying Control System

Fig. 1. Concept of AFC system.

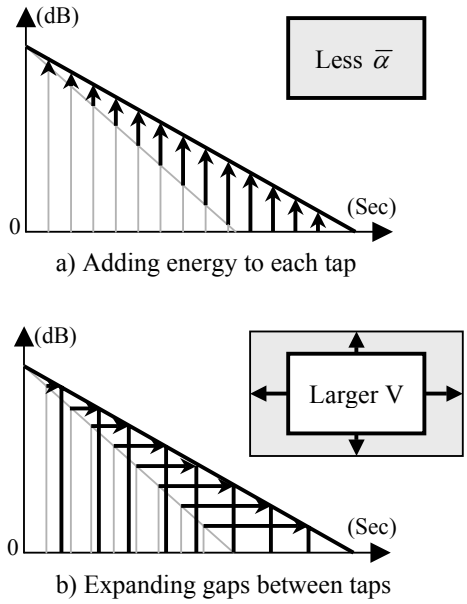


Fig. 2. Wide range controllability using FIR.

3.1. Electric Microphone Rotator (EMR)

EMR is smoothing frequency responses between microphones and speakers by changing the combinations of inputs and outputs periodically (Fig.3). The rotating cycle is usually set in the range of 0.4-3.0Hz for aural naturalness. In addition, when switching the input signal from one microphone to an other, each microphone level is controlled using VCA (Voltage Controlled Amplifier) and summed together to switch smoothly and achieve a natural sound.

3.2. Fluctuating-FIR (fluc-FIR)

Fluc-FIR is smoothing frequency responses of FIR filters and preventing coloration problems caused by fixed FIR filters, by moving each FIR tap periodically on time axis with a different frequency modulation and variable time range (Fig.4). The time range (td_i) is determined from the distance between FIR taps and the modulation frequency (F_i) is determined according to the result of the subjective experiment, which indicates their relationship for keeping auditory naturalness.

As shown in Fig.5, the howling point is diminished and the smooth frequency response of loop gain can be realized by using EMR and fluc-FIR.

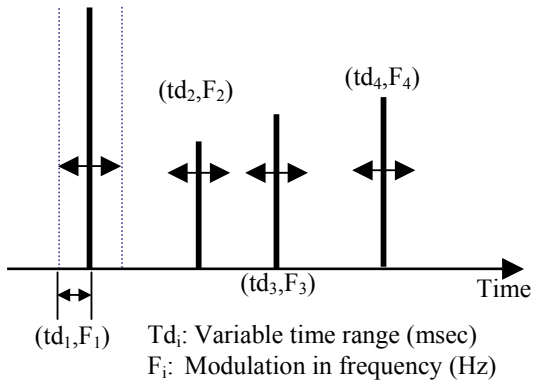


Fig. 4. Concept of fluc-FIR.

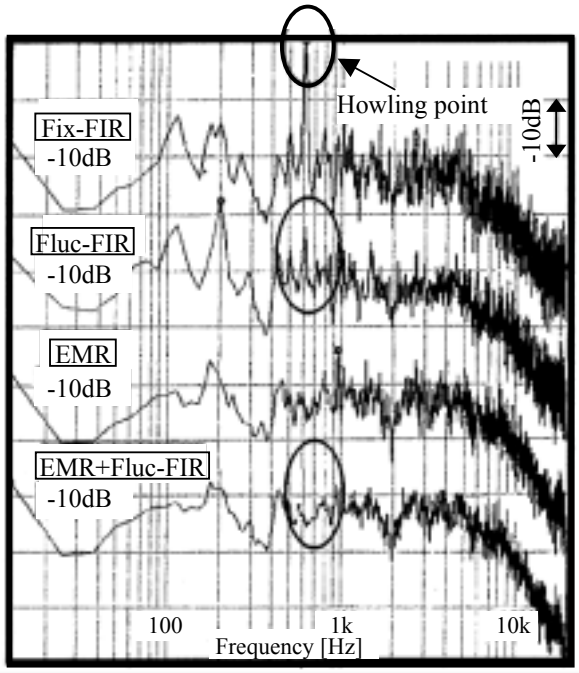


Fig. 5. Closed loop gain with TVC.

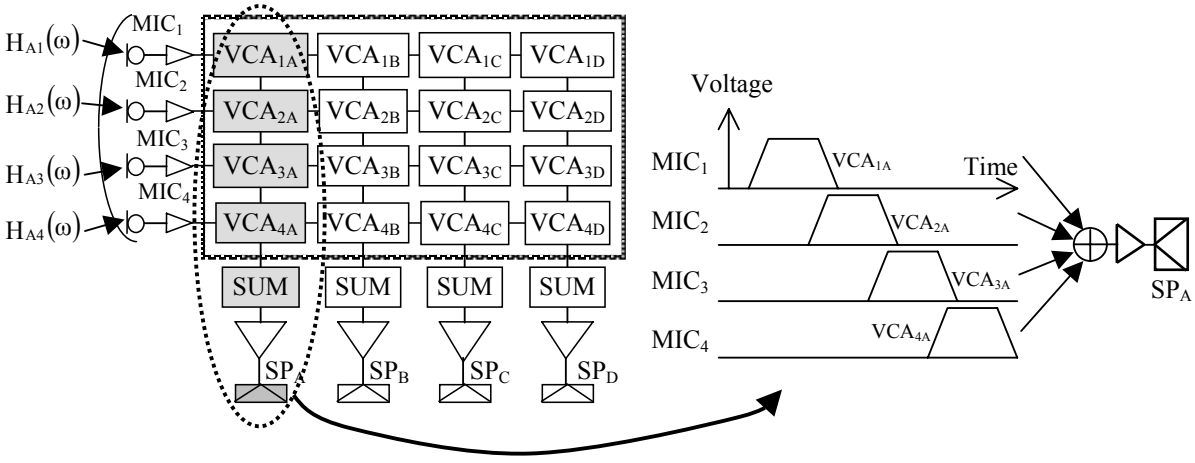


Fig. 3. Concept of Electric Microphone Rotator (EMR).

4. CONFIGURATION OF AFC SYSTEM

4.1. Basic configuration

The AFC system is basically constructed as two systems as shown in Fig. 6 and Fig.7.

The first system controls reverberation in a room by picking up the diffused sound with 4 to 8 microphones, which are placed on the ceiling away from the stage more than the critical distance. It then plays back the sound through EMR and fluc-FIR with speakers, which are placed on the ceiling facing down or on the sidewall facing the ceiling, and more than the critical distance away from the audience area to make its sound diffused. This makes AFC effective anywhere in the room for both the sound source and receiver position.

The second system controls early reflections by picking up the direct sound with 4 to 8 microphones, which are located on the ceiling relatively close to the stage, and playing back lateral reflections through FIR filters with speakers installed on the sidewalls. The speaker locations should be designed so that each speaker cannot be localized by audience members. For early reflections, fluc-FIR is not used in order to retain the information contained in the FIR reflection pattern.

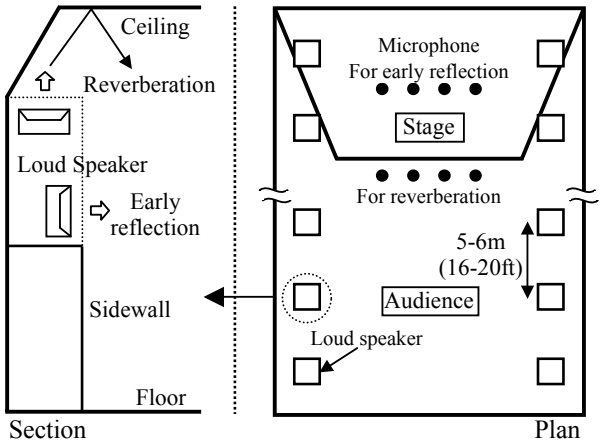


Fig. 6. Basic configuration of AFC system.

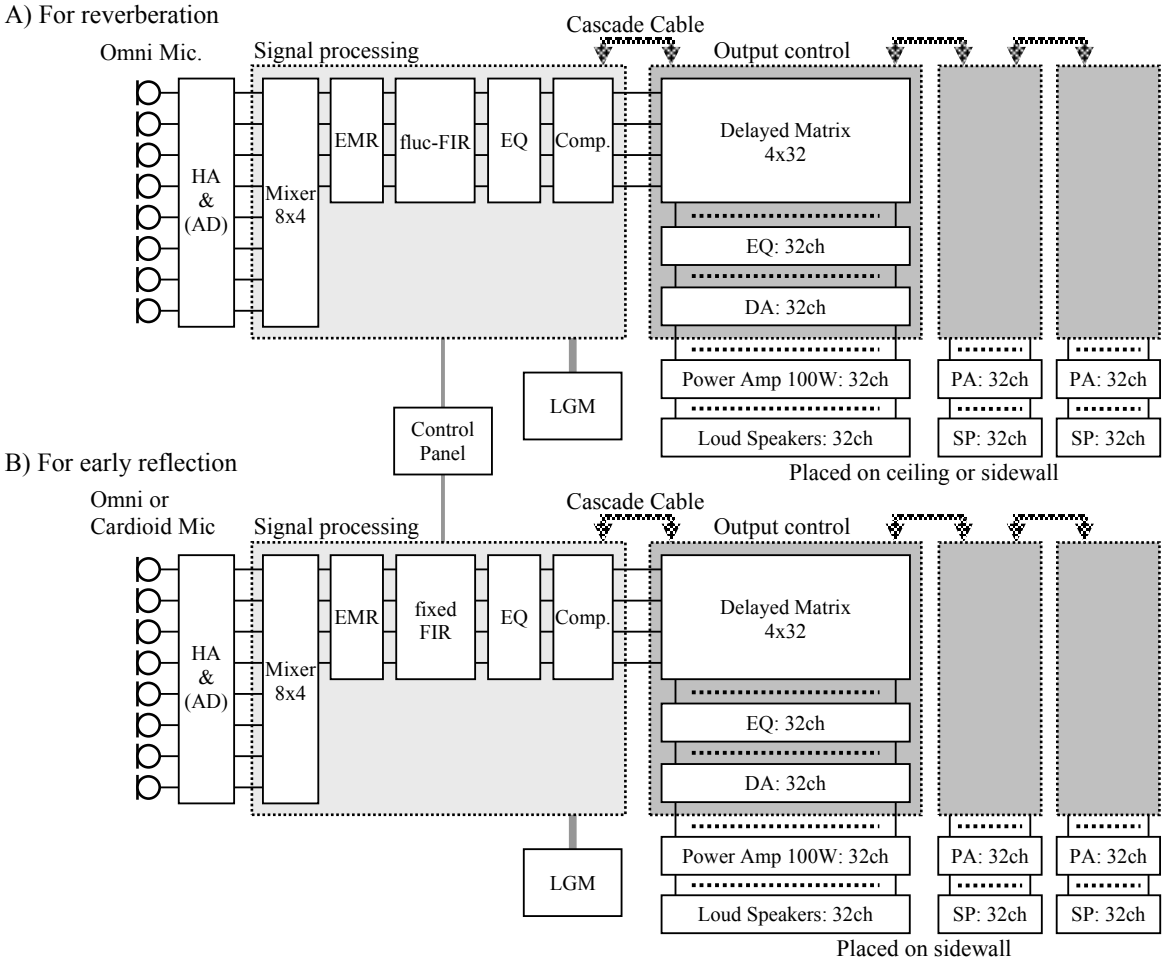


Fig. 7. Block diagram of AFC system.

4.2. Core device: AFC1

In the block diagrams shown in Fig.7, the sections indicated by dotted lines are replaced with AFC1, which has been developed at Yamaha and released recently in the US. The AFC system consists of at least two AFC1 units, one of which is used for signal processing including EMR and fluc-FIR, and an other which is used for output control including EQ and a delay matrix. The specifications of AFC1 are shown in Fig.8. AFC1 has 8-ch input and 32-ch output, and the output of the total system can be expanded to 96-ch by connecting three AFC1 units for output control to one AFC1 unit for signal processing with cascade cables.

AFC1 makes it possible to install a simple system with less equipment, improve the S/N ratio using all digital wiring, and increase the effectiveness using longer FIR filters, as compared to the previous AFC system.

Sampling Freq.	Internal 48 kHz, External 39.69-50.88 kHz
Memory	Sound field pattern: 6, Liveness: 8
Power Requirements	120 V AC, 60 Hz
Power Consumption	40W
Dimensions (W x H x D)	18.9" x 5.6" x 14.8", 3U
Weight	9.5 kg

Fig. 8. Specifications of AFC1.

5. TUNING PROCESS

Since loop gain and the sound characteristics of a system depend on the physical conditions due to acoustical feedback, it is essential to tune the system after its installation to ensure a stable system with sufficient loop gain. Moreover, it is important to adjust the system to meet the required acoustical conditions by measuring and listening to the actual sound field.

System tuning is conducted according to the process shown in Fig. 9, where the Loop Gain Monitor (LGM), which has been developed based on Yamaha DME32, is utilized. By digitally connecting LGM with AFC1, it is possible to change the loop on/off of each channel and easily select the oscillator signal and its input channel. Through this tuning process, the optimal acoustics for each program type are realized by adjusting the parameters of AFC1 units.

Each condition can be recalled easily using the user interface shown in Fig. 10, which is able to turn the system on/off and change the basic acoustical conditions with six kinds of presets, each with 8 steps of liveness.

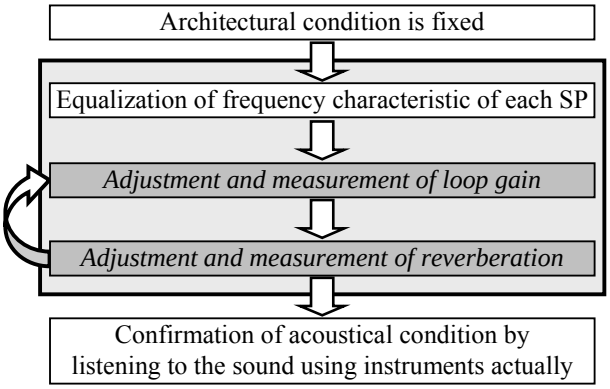
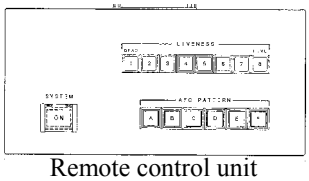


Fig. 9. AFC tuning process.

Rack mount unit



Remote control unit

Power ON/OFF, System ON/OFF
Sound field patterns: 6, Liveness control: 8

Fig. 10. Control Unit.

6. APPLICATIONS OF AFC

Table 2 indicates the application of AFC for various purposes. For the design of an AFC system, it is essential to examine the usages of the venue and the required acoustical conditions for each of them,

Table 2. Application of AFC.

Improved Condition	Functions of AFC
1. Reverberance	Extension of RT 1. Increase sound energy 2. Expand gaps between FIR taps
2. Loudness	Increase of sound energy
3. Uniformity	Energy exchange btw stage & audience area Energy & RT support for under balcony
4. Support for player	Extension of RT in the stage area
5. Spaciousness	Increase in early lateral reflections
6. Warmth	Extension of RT at low frequency
7. Presence	Extension of RT

and propose the optimum system for realizing those conditions according to Table 2.

The following are the recent representative venues using AFC.

6.1. Control of acoustical effects of room shape: Osaka Central Public Hall

This auditorium with 1,160 seats was originally built approximately 80 years ago and renovated in 2002. In this case, the renovation was required to preserve the original form of this important historical building. AFC is installed to transform only the acoustical environment without architectural changes to the room shape, ceiling height, etc.

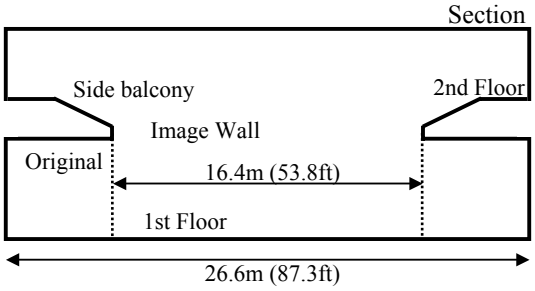


Fig. 12. Concept of "Image Wall".

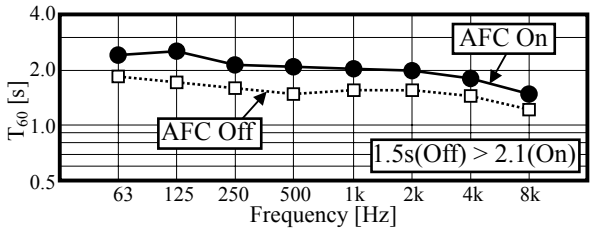


Fig. 13. T_{60} measurement results (unoccupied).

The configuration of AFC is shown in Fig.11. The AFC system is composed of two systems: A) a lateral reflection control system to compensate for the excessive room width, in which the optimum FIR is simulated by creating a model with an "image wall" as shown in Fig.12 and comparing it to the existing model, B) a reverberation control system to increase the reverberation time.

Fig. 13 shows the T_{60} measurement results. Using AFC, the T_{60} in the unoccupied condition can be increased from 1.5 s to 2.2 s at 500Hz, so that the optimum acoustics for classical music are realized in the relatively dead original space. Regarding early reflections, the maximum index Lf (Lateral fractions: the ratio between the early lateral sound and omni directional sound) in the orchestra floor can be increased by approximately 2.0%.

6.2. Optimization of acoustics for a variety of programs: Arcus Sasebo

This brand-new venue opened in March 2001. The main facility is the multi purpose hall with 2,000 seats, which has both the atmosphere and function of an opera house. In this hall, AFC is used for optimizing the acoustical conditions for a variety of programs from classical concerts to opera performances.

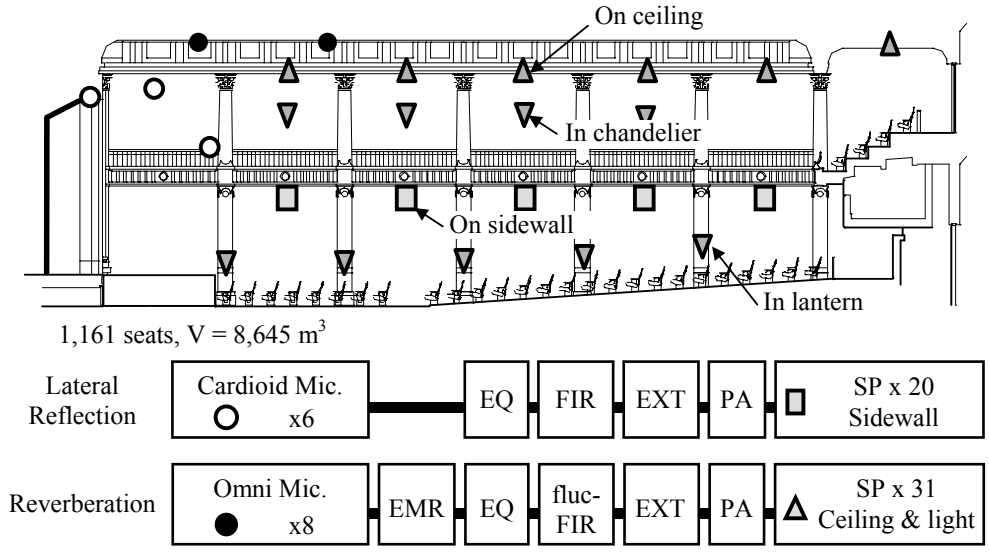


Fig. 11. AFC system configuration at Osaka Central Public Hall.

In this project, the following issues have been considered: A) Stability of the system. AFC application for opera performance is relatively difficult because of the differences in absorption and boundary conditions on stage due to the diversity of stage settings. Therefore, in order to ensure sufficient margin against howling during opera performances, the TVC techniques mentioned above are used, and the system is well tuned before the opening. B) Support for opera singers. To extend the live sound field in the audience area to the dead stage field during opera performances, the diffused sound is picked up by the microphones in the audience area and played back on the stage through FIR filters. C) Uniformity throughout the entire room. The live sound field in the main audience area is extended to the under balcony area using the same method as "B" mentioned above. In addition, for concerts with stage reflectors, the system to exchange energy between the stage and the audience using microphones and speakers installed in each area is also implemented. The system configuration is shown in Fig. 14.

Using AFC, the T_{60} in the unoccupied condition can be increased from the original 2.2s to 2.6s for concerts and from 1.8s to 2.2s for opera as shown in Fig. 15. The sound energy on stage can be increased by an average of 1dB as shown in Fig. 16.

7. CONCLUSIONS

The development of TVC and utilization of digital equipment such as AFC1 improve sound quality and make it possible to enhance the sound field with the same naturalness as architectural methods. Nowadays, AFC is gaining acceptance by classical musicians, who typically have had some reservations about the use of electro-acoustics.

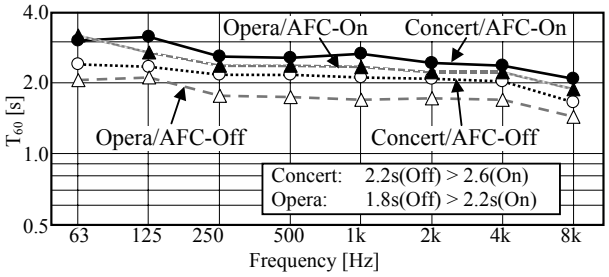


Fig. 15. T_{60} measurement result (unoccupied).

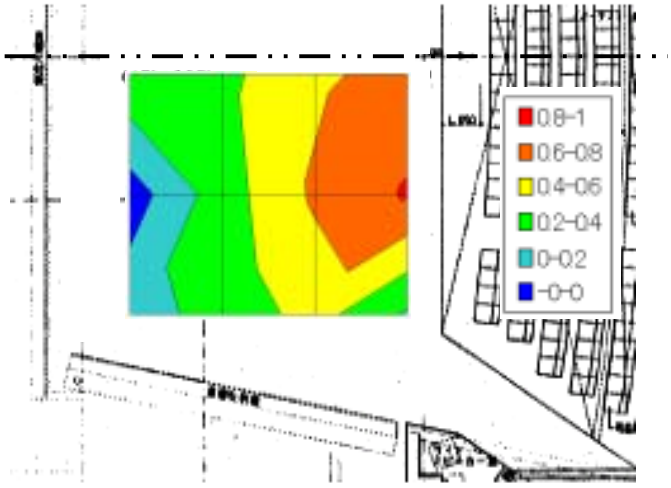


Fig. 16. Increase of sound energy on stage between AFC off/on.

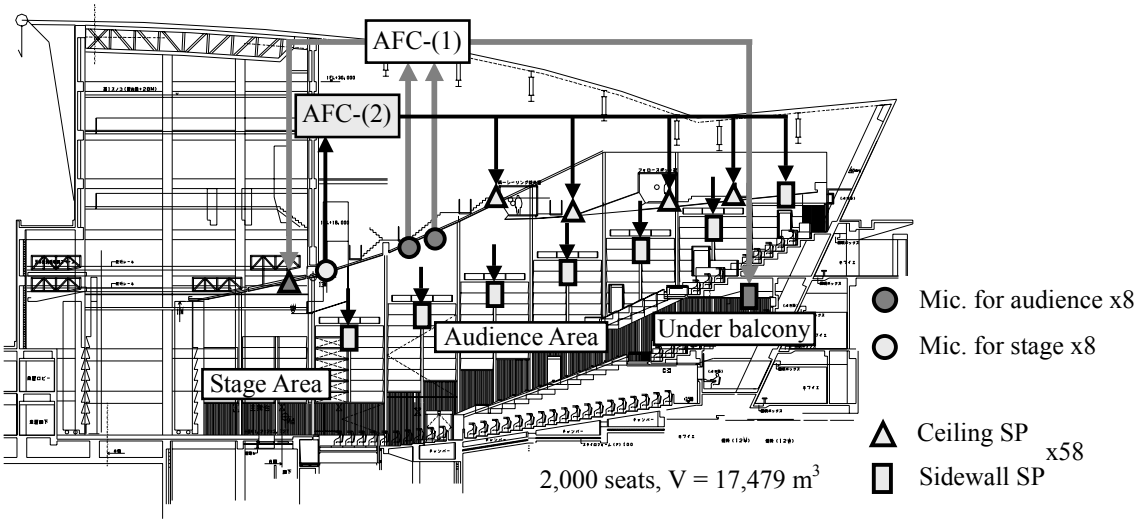


Fig. 14. AFC system configuration at Arcus Sasebo.

As the next phase of development, the solution should be proposed for a total system utilizing a digital network, which has multiple functions including AFC, SR, surround effects, etc. This kind of network system can be realized by using AFC1 and mLAN, which is a network system introduced by Yamaha utilizing IEEE1394 and an audio/control transmission protocol [5]. In the renovation project at Yamaha Hall in Tokyo, a network system using m-LAN is installed, where the AFC system using AFC1 and SR system are digitally connected to each other and the systems located in different spaces are also connected with one digital cable as shown in Fig.17. Using a digital network, a simple and flexible system can be realized [6]. This experimental project will serve as a guide for the next generation of systems.

A summary of AFC technology can also be seen at the following website:
www.yamaha.co.jp/english/acoust/technologies/afc

8. REFERENCES

[1] F. Kwakami and Y. Shimizu, “Active Field Control in Auditoria,” Applied Acoustics, vol. 31, pp. 45-47 (1990).

[2] F. Kawakami, “Recent progress in AFC technology,” presented at the AES Korea Section Convention, Korea, 1993 March.

[3] “Yamaha SREV1,” www.yamaha.co.jp/product/proaudio/homeenglish/index.htm

[4] P.A. Nelson and S.J. Elliott, "Active Control of Sound," ACADEMIC PRESS, 1992

[5] M. Ikeda, et al., “Design method of digital audio network system for auditoriums,” presented at the AES115th convention, New York, 2003 October 10-13.

[6] J. Fujimori, et al., “The application of mLAN for a digital audio network: Yamaha Hall,” presented at the AES11th regional convention, Tokyo, 2003 July 7-9.

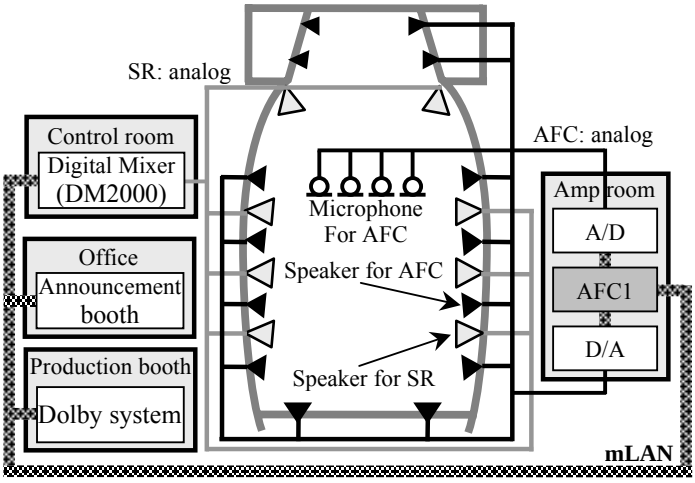


Fig. 17. Net work system using m-LAN.