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Objective Assessment of Active Acoustic System Performance

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ABSTRACT

The reverberation of a room may be controlled passively by changing the amount of absorption, or changing the cubic volume, thereby controlling the rate at which sound is subtracted from a room. A room can be controlled actively using microphone, signal processing, and speakers to control the rate at which sound is added back into a room. Active Acoustic systems can decrease the effective absorption of a space by increasing the gain between system microphones and speakers. They can affect the apparent volume of the space by adding electronic reverberation between the microphones and speakers. The range of possible change in apparent absorption and cubic volume will be predicted and measured. Examples will be given showing that the resulting warmth, clarity, and early decay time can be controlled independently from the late reverberation time, and that strength and binaural quality can be improved. It will be shown that a room with active acoustics needs half the cubic volume of an equivalent room using passive acoustics, contributing (along with other factors) to the environmental sustainability of a building as represented by LEED points.

INTRODUCTION

Just as Sabine and others [1] derived and verified the relationship between reverberation time and the bulk physical properties of a room, so too can the reverberation of rooms with active acoustic systems be predicted and verified.

In the simplest model, the physical properties of a room that affect the reverberation time are the fraction of sound absorbed by a wall on a single reflection, and the cubic volume of the room (which controls the rate at which sound encounters absorbing walls). This model works best when the absorption is small and is well distributed, and when the room geometry is simple enough to be well represented by a single cubic volume. More complicated models exist to predict rooms with more absorption, with more complicated geometries (such as coupled volumes), and include other effects such as air absorption [2].

Rooms can be designed to have a variable reverberation time by altering the physical characteristics [3]. The absorption can be changed by deploying or retracting absorption such as curtains or rotating panels. The cubic volume can be changed with moving ceilings or doors to coupled chambers. These will be referred to as "passive" because they control the rate at which sound is removed from the room.

The reverberation time of a room can also be varied with electro-acoustic transducers and signal processing. Sound in the room is picked up by microphones and processed (usually by adding reverberation) and then transmitted back into the room through loudspeakers. These systems will be referred to as "active" because they control the rate at which sound is added back into the room.

Rooms can be designed to have variable reverberation time by altering the processing of an active acoustic system. The effective absorption can be reduced by increasing the gain between the microphones and loudspeakers. The effective cubic volume of a room can be increased by adding reverberation between the microphones and loudspeakers.

PREDICTION

Because an active acoustic system can reduce the effective absorption in a space, it increases the steady state power of a given source in the reverberant field. It has been shown that the gain in steady state power for an active acoustic system with N channels and loop gain μ is [4,5,6]:

$$\Gamma = 1\Big/\left[1-\mu^2 N\right] \qquad [1]$$

If there were no reverberation added between the microphones and loudspeakers, the reverberation time would be increased by the same factor. Poletti [6] has shown that when reverberation is added between microphones and loudspeakers the reverberation time gain is:

$$\frac{T_{result}}{T_{physical}} = \frac{\alpha}{\left(\frac{1+\alpha}{2}\right) - \sqrt{\left(\frac{\alpha-1}{2}\right)^2 + \alpha\kappa^2}} \qquad [2]$$

Where T_{result} is the resulting reverberation time using the active acoustic system, $T_{physical}$ is the reverberation time of the physical room, $\kappa = \mu\sqrt{N}$ is the coupling constant, and α is the ratio of the reverberation time in the processing to the physical reverberation time: $\alpha = T_{processing}\Big/T_{physical}$

MEASUREMENT

Two rooms equipped with a commercial Active Acoustic system have been measured with a variety of gains and processing reverberation times. One room uses 24 omni-directional microphones and the other uses 24 cardioid microphones, both rooms have more than 24 loudspeakers. In typical rooms the physical reverberation time varies with frequency, usually decreasing at higher frequencies due to increasing absorption of typical materials and air absorption. In order for α to be constant with frequency the variation of the reverberation time with frequency in the processor needs to match the physical room. Figure 1 shows that the damping in the reverberation processing was chosen to approximately match the physical rooms' reverberation times at mid and high frequencies. All comparisons of theory and measurement in this paper use this matched damping and results are averaged between 250Hz and 2000Hz.

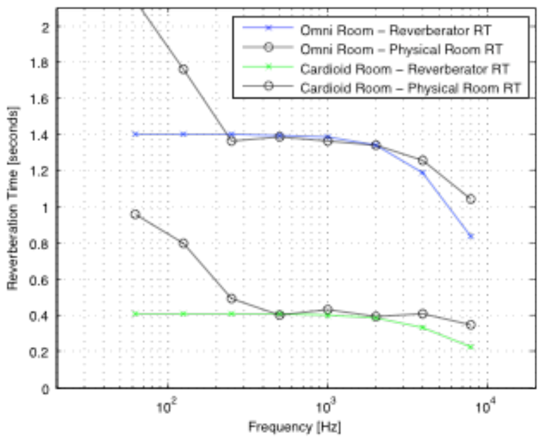

Figure 1 Reverberation Time verus Frequency of Physical Rooms and Processing

Whenever there are microphones connected to loudspeakers in the same acoustic space there is the potential for feedback. In order for designers of Active Acoustic systems to prevent unstable feedback in normal operation, the behavior of such system operating at gains near the point of feedback must be understood. In this paper the term Gain Before Feedback (GBF) is used to denote the difference between the operating gain and the gain that would produce feedback. For instance "-4 dB GBF" indicates an operating gain that is 4dB less than the gain that would produce feedback.

Figure 2 shows measured and theoretical (from Eq. (1)) power gain versus gain before feedback for 24 microphones averaged between 250 and 2000Hz and α = 1.

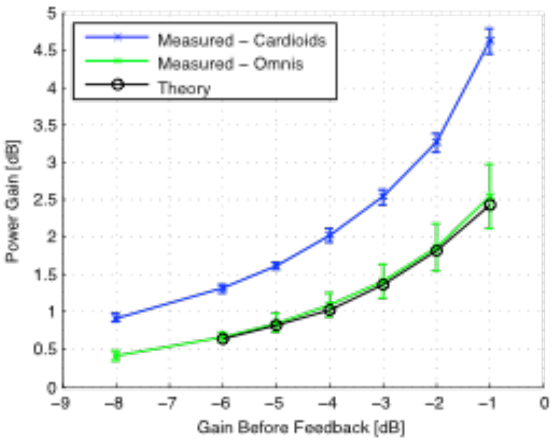

Figure 2 Measured and Theorectical Power Gain versus Gain Before Feedback for 24 microphones averaged between 250 and 2000Hz and α = 1

Next the systems were measured for two different levels of Gain Before Feedback while varying α. Figure 3 shows the reverberation gain versus α for 24 omni microphones averaged between 250 and 2000Hz.

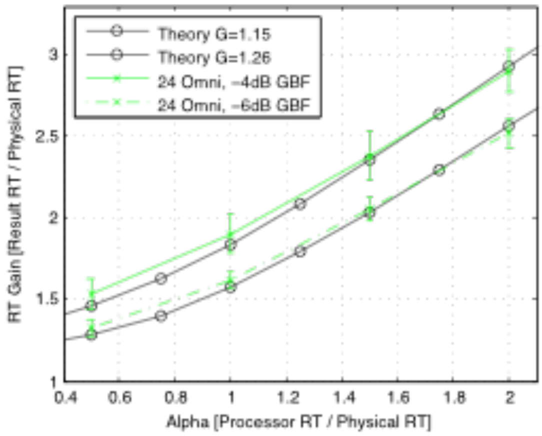

Figure 3 Reverberation Gain versus α for 24 omni microphones averaged between 250 and 2000Hz

Figure 4 shows the reverberation gain versus α for 24 cardioid microphones averaged between 250 and 2000Hz. The theoretical curves assume omni-directional microphones, so it is not surprising that measured values exceed theory for moderate values of α.

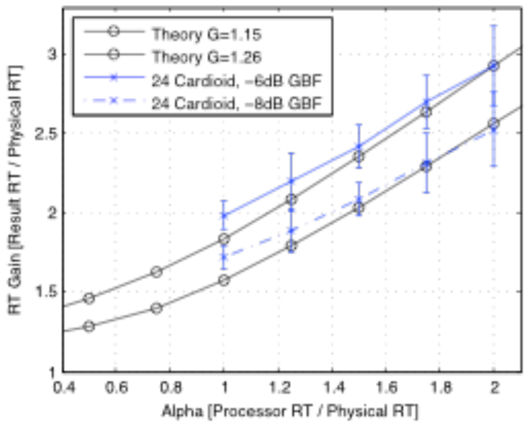

Figure 4 Reverberation Gain versus α for 24 cardioid microphones averaged between 250 and 2000Hz

APPLICATIONS

Implementing a damping filter in the reverberation processing (and equalization on the inputs and outputs) creates the possibility of changing the shape of the reverberation time versus frequency, allowing control of the resulting warmth and apparent air absorption. Figure 5 shows two different settings of the same Active Acoustic system with similar mid-band reverberation times, but with different reverberation time versus frequency shapes.

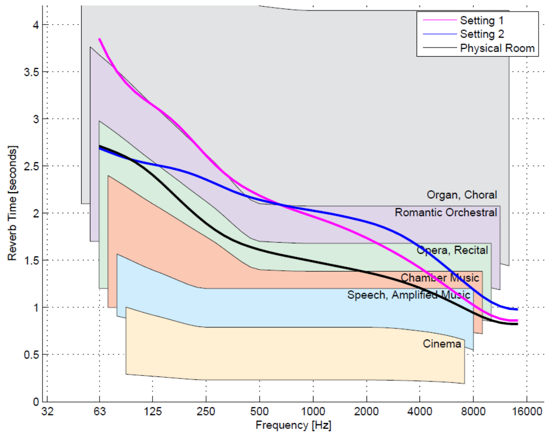

Figure 5 Two Different Settings of the Same Active Acoustic System with Different Reverberation Time versus Frequency shapes

It is possible to create two different physical rooms with different cubic volumes, but the same reverberation time. One simply has to put more absorption in the larger room to achieve the same reverberation time. Though the reverberation times in the two rooms will be the same, the Strength in the larger room will be lower because it contains more absorption.

Similarly, it is possible to create two different settings of an Active Acoustic system with the same reverberation time, but different Strength, Clarity, and other properties. A setting with a high gain and low processor reverberation time will achieve a high Strength. A setting with a lower gain and higher reverberation time in the processor can achieve the same resulting reverberation time, but will have less Strength. Figure 6 shows two settings of the same Active Acoustic system with similar reverbation times at mid and high frequencies, but with different Clarity.

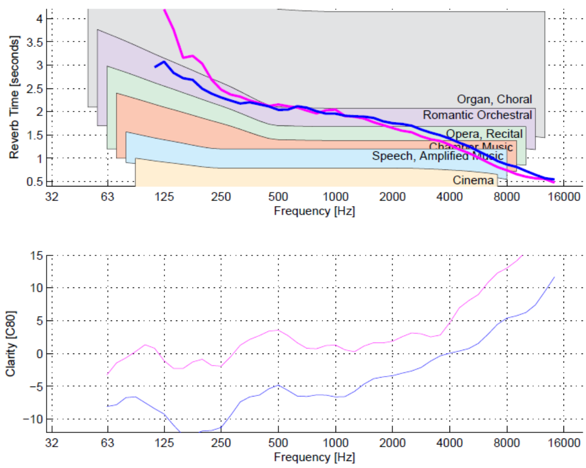

Figure 6 Two Different Settings of the Same Active Acoustic System with Different Clarity

Figure 7 shows two different settings of the same Active Acosutic system with different ratios of T30 to EDT.

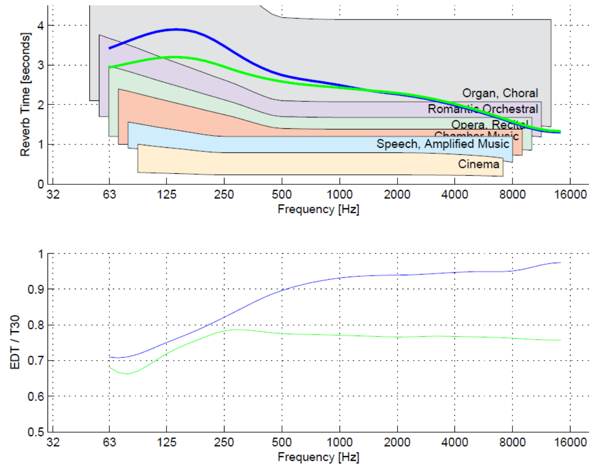

Figure 7 Two Different Settings of the Same Active Acoustic System with Different EDT / T30 Ratios

GREEN BUILDING DESIGN

The recommended reverberation times for Symphony and Choral music are so long that essentially all of the absorption must be removed from the room. The reverberation time is then determined solely by the audience absorption and the cubic volume. Beranek [7], for instance, writes, “all carpets, draperies, and sound-absorbing materials must be eliminated from the hall, and the audience must be seated in as small an area as possible”. Many authors [3,7,8,9,10] recommend that the reverberation time be longer at low frequencies than at mid and high frequencies for music performances. To accomplish this, a venue with Passive Acoustics must have hard, heavy surfaces. In *Concert and Opera Halls*, Beranek [7] writes:

> In general, all surfaces, except the stage floor, should be of heavy, dense material. This theme will be repeated many times in this book.

Egan [11] writes, “avoid thin, lightweight materials".

It has been shown that Active Acoustic system can change both the effective absorption and the effective cubic volume of a space. Knudsen and Harris [9] write:

> There are many advantages in keeping the volume per seat at a low value. […] Maintenance costs for lighting, cleaning, redecorating, air conditioning, etc. are correspondingly lowered.

If a room is designed with Active Acoustics in mind, its cubic volume is determined by the type of performance that needs the lowest reverberation time. Because venues with Active Acoustics can change the Warmth of the reverberation, their walls can be made with lightweight materials, which are absorbing at low frequencies. Under-Balcony areas designed with Active Acoustics in mind can result in a building with a smaller footprint. Because Active Acoustic systems do not require modifying the cubic volume of a building, they make it possible to reuse buildings that would not be reused, or would be more extensively renovated otherwise.

LEED is an internationally recognized green building certification program developed by the U.S. Green Building Council (USGBC). Schwenke and Duty [12] have shown that designing a room to use Active Acoustics can facilitate fulfilling the requirements of LEED credits for Reuse, Development Density, and Energy Performance, and facilitate fulfilling the intent of LEED credits for several Materials and Resources credits

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