Theater Sound
MAE 5083

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Contents

"You ain't heard nothing yet" *Al Jolson*

1 Introduction

The movie theater is a creation of the 20th century. While both pictures and reproduced sound existed earlier, their joining didn't occur until the 1920's. The movie theater requires syncronization between the eyes and ears of the producer to the projectionist. The technology required to create and show a movie is vast; optics, acoustics, mechanics, psychology and electronics only scratch the surface. This paper only concerns the sound reproduction acoustics of the modern movie theater. The paper discusses three fundamentals: Sound Transmission and Recording, Theater Construction, and Sound Equipment.

2 Sound Recording

The fundamental method of sound recording is to capture the vibrations of air. The frequencies of interest to the human ear vary by a factor of 10000. Sound recorders are challenged to capture this tremendous range of frequencies and amplitudes. Theater sound followed the general sound recording trends from mechanical to optical and then magnetic media.

2.1 Mechanical Schemes

The first mechanical sound recording and reproducing machine was the phonograph. Thomas Edison patented the sound recording and reproducting phonograph in 1878. His first phonograph captured sound on tin foil cylinder.

An American, Frank Lambert, experimented with a tin foil phonograph in 1878[1]. Over 100 years later, Lambert's voice clearly states the hours. As he already held patents on clock design, it appears that his experiments were aimed at a talking clock. In any event, the joining of a visual and acoustical mechanism didn't occur. A recording of his 1878 experiment is available at
`http://www.tinfoil.com/cm-0101.htm`

The first successful talking films were based on mechanical sound reproduction with the phonograph. Warner Brothers developed VitaPhone as a movie sound system based on the phonograph. VitaPhone was critically limited from the start. First, it only contained 8 minutes of sound[2]. Second, the sound was manually sychronized without any feedback from the actual optical film.

2.2 Optical Schemes

In light of the phonograph's limitations, the movie sound industry moved the sound track onto the optical film. Optical representations of the sound were photographed onto the film. Movietone by 20th Century Fox Two types of modulation emerged: variable area and variable density. Figure 1 shows variable area (left) and variable density (right) sound tracks.

Figure 1: Variable Area and Variable Density Sound Tracks (from Moir)

The optical sound recordings allowed for quick visual coupling of the sound and picture. "Editors . . . were in the habit of using the modulation on optical sound film as an index of synchronization.[3] Plus, any problem with noise or an unwanted sudden sound could be "blooped" out with a touch of ink. Optical sound tracks are still in use; however, modern optical films are variable area because of better reproduction consistency[2].

2.3 Magnetic Schemes

Magnetic recordings are made by modulating the magnitism of a moving "tape". Magnetic recording has the advantage of a high recording density and a variable recording speed. Modern high performance theater sound is based on digital magnetic recordings.

2.3.1 Tape Noise

A major problem with magnetic tape recording is the background tape noise. Figure 2 shows the noise spectrum from an analog magnetic recording - reading cycle. Notice that low frequencies have a particularly large amount of "recorded noise". The frequency band from 500 Hz to 5 kHz has approximately 100 times less noise than the 50 Hz to 200 Hz band.

The earliest major application to theater was in 1953 when Fox released Cinemascope, a four channel magnetic sound format[4].

Cinemascope placed the 4 magnetic tracks on either side of the film's sprocket holes. Figure 3 shows the general layout. Surprisingly, the magnetic tracks were not overly susceptible to damage.

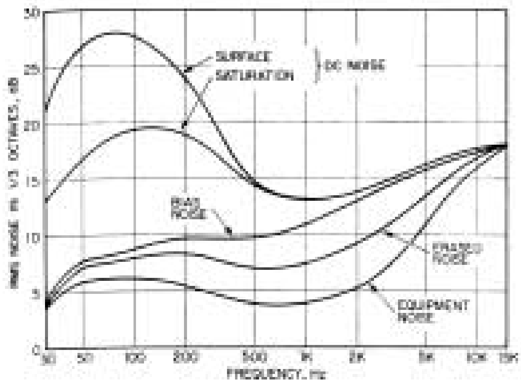

Figure 2: Magnetic tape noise spectrum (from Daniel)

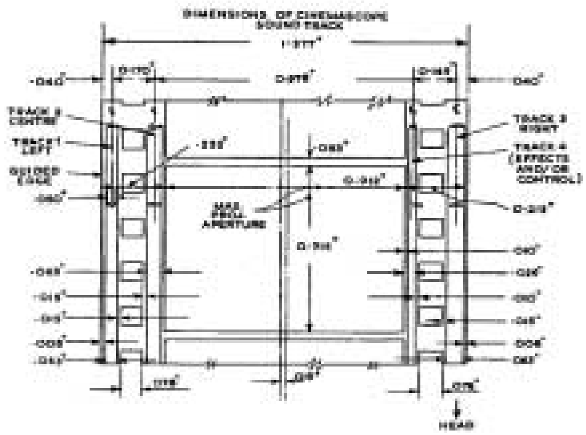

Figure 3: Cinemascope (from Moir)

3 Theater Construction

Quality theater sound requires a properly designed and constructed viewing room. Movie theaters have the problem of projecting both voice and music simultaneously. These sounds contain all audiable frequencies and wildly varying SPLs from total silence to 100+ dB. Not surprisingly, a perfect theater doesn't exist.

3.1 Room Sizing and Materials

Surround sound depends on identification of time delay. So, reverberation time for a surround sound theater needs to be as low as possible. The leading theater surround sound manufactor, Dolby "recommends a Reverb Time of 0.5 to 0.7 seconds for a stereo cinema"[5] A general guideline for theater geometry and material selection is the Sabine relationship[6]. The english Sabine reverberation time in seconds is,

$$RT = 0.049 \cdot \frac{V}{Sa}$$

where Sa is the absorptivity surface area in ft^2, V is the total volume in ft^3. Large theaters may have difficulties increasing the absorptive areas. Super-large screened theaters such as the IMAX may require considerable extra effort[7]

> Since a relatively 'dead' environment enhances intelligibility, as well as the ability to identify the location of the sound source, the reverberation time for IMAX and OMNIMAX theatres is specifies in the range of 0.5 to 0.7 sec. . . Given the volume required for an IMAX theatre, almost all available surfaces will require acoustical treatment to achieve the desired reverberation times.

The acoustical properties of the room are made more complex by the screen. The screen tends to reflect sound at high frequencies and distort at medium frequencies. Theaters with speakers behind the screen (Figure 5) usually have holes in the screen. However, absorptivity is still low for high frequencies as seen in Figure 4.

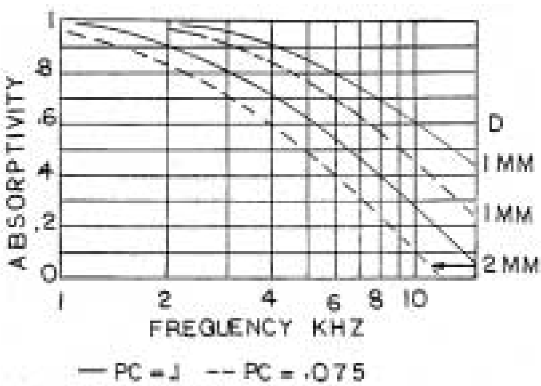

Figure 4: Screen Transmission losses versus perferation percentage (from Rettinger)

Wetmore[9] found that the only way to ensure uniform speaker coverage is "to place the speakers above and below the screen".

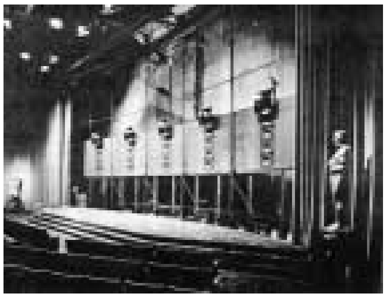

Figure 5: Theater Speaker Array at MGM[8]

3.2 Seating

Theater seats affect the sound distribution. Low frequencies are attenuated as they pass over theater seats[10]. Selective resonant chambers between the seats can improve transmission. According to Ando [10], the ancient Romans inserted resonators between their auditorium seats.

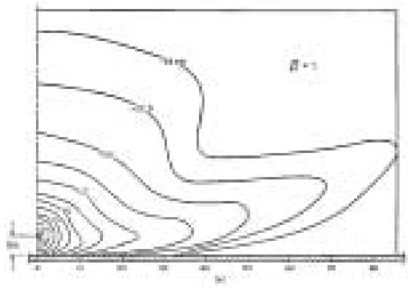

Figure 6: Pressure Contours for kh=5 (from Schultz)

3.3 Large Theater

The Shan-cheng wide screen theater in China seats 1300 people in a 260 thousand cubic foot volume. The theater was designed for surround sound and thus required a low reverberation time. The theater contains a typical floor seating arrangment plus a balcony as shown in Figure 7.

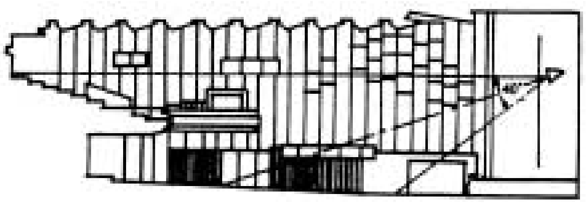

Figure 7: Large Theater in China (from Yanxun)

Yanxun[5] reports the following characteristics

	Frequency [Hz]				
	125	250	1000	2000	4000
T_{60} (empty)	0.75	0.67	0.61	0.61	0.61
T_{60} (filled)	0.89	0.64	0.65	0.65	0.58

Table 1: Reverberation Time Data (from Yanzun)

Yanxun reports that "the sterophonic sense is outstanding, the speech sound is articulate and the music sound is good."[5]

3.4 Small Screening Room Theater

The new 20th Century Fox screening room[9] in New York City is typical of a small theater. The primary design criteria was "high performance". The theater is a 28 by 23 by 12 foot room (Figure 8) seating 30. The reverberation time of the room is 0.2 seconds or less over the ranges of 125Hz to 4kHz, which corresponds to an average absorptivity of 0.75.

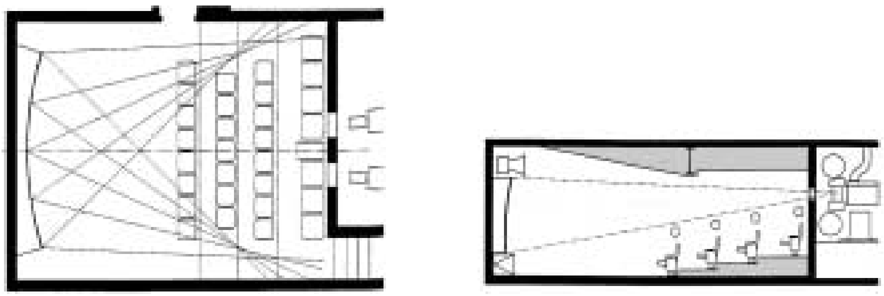

Figure 8: High Performance Theater (from Wetmore, Nash and Berggren)

4 Sound Equipment

4.1 Terminology

Dolby A group of sound systems created by Dolby Laboratories. Dolby is a collection of sound recording and reproduction techniques to reduce noise.

5.1 A sound system where there are 5 main channels and one limited bandwidth low frequency channel.

LFE A non-directional Low Frequency Effects Channel for frequencies below 120 Hz. The LFE channel is not a subwoofer.

Perceptual Encoding Modify the sound signal to account for human hearing limitations. Normally,

Riding the Gain A crude method of changing the gain in response to the current sound track loudness. Riding the gain tends to "pump" the loudness especially in rapidly changing sound. The method is equivalent to turning up the volume during the soft parts and reducing the volume during loud parts.

Surround Sound Sound system with side speakers. The speakers may be on different channels. Multichannel sound is not new, a stereo transmission of the Paris Opera was made in 1881 by Ader[11]

Subwolfer A low frequency sound channel with possible directionalilty. The sound system determines the speaker and mixing.

THX Sound quality certification group formed by Lucasfilm. Mostly ineffective because the sound quality testing falls to the individual theater.

4.2 Dolby

4.2.1 Noise Reduction Theory

The idea of noise reduction during recording goes back as far as recording itself. Reducing noise initially came from acoustically isolated recording studios, yet the most persistent noise introduction came from the recording media itself. Various primitive methods were used by telephone and other low bandwidth applications to reduce noise. However, the first successful and widely accepted noise reduction system for commercial recording came from Ray Dolby with the system that bears his name. The classic paper on Dolby noise reduction is the October 1967 article, *An Audio Noise Reduction System*[12].

Noise reduction theory rests on a single point; keep the signal to noise ratio (SNR) as large as possible during the entire capture-record-transmit-play cycle. A large SNR implies an effectively used media bandwidth. Unfortunately, the lowest bandwidth for theater sound is the optical or magnetic signal on the film. Figure 9 shows an ideal noise reduction system.

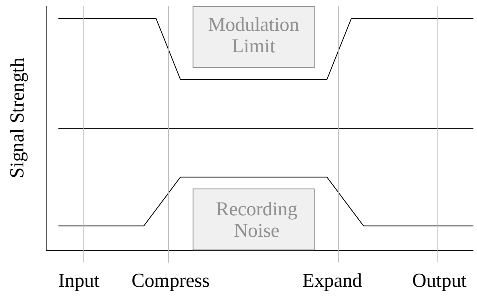

Figure 9: Bandwidth

Dolby[12] proposed and created a noise reduction system based on system theory. For a recording system, the input-output flow is shown in Figure 10, where G_1 and G_2 are input and output operators.

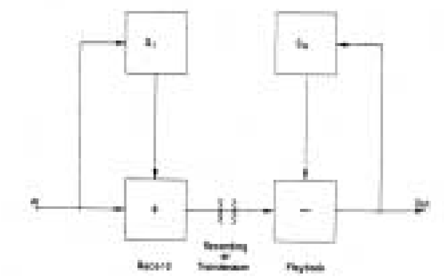

Figure 10: Noise Reduction System: Block Diagram[12]

From the figure, the recorded signal is

$$y = [1 + G_1]x$$

The output signal is

$$z = (1/[1 + G_2])y$$

Substitution yields a total input-output relationship of

$$z = ([1 + G_1]/[1 + G_2])x$$

Clearly, if G_1 and G_2 are equivalent, the system exactly recovers the input signal while recording a transformed signal. All of this theory is just a mathematical way of saying that decoding of an recorded signal is possible if the encoding method is known. The critical idea is that the recorded signal can be adjusted without destroying the eventual output.

Dolby's unique contribution to noise reduction consisted of tailoring the gain transformation operator G in a way to reduce noise from the storage media. In particular, low amplitude signals needed amplifying without creating distortion or amplifying the larger amplitude signals. Figure 11 a. shows an input-output gain map. The diagonal line represents an unamplified signal. Above the diagonal line is amplification (output $>$ input); below is attenuation (output $<$ input).

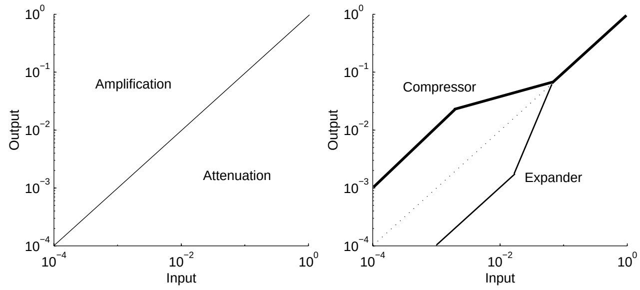

Figure 11: Noise Reduction: a) Gain Map b) Compressor-Expander Gain Map

Dolby A, Dolby's first commercial product, contained a gain map as shown in Figure 11 b. The system provided a 10 dB noise reduction above 500 Hz. The input is divided into four frequency bands, each with a unique gain map. The Dolby process introduces six desirable attributes:

1. The gain is unity for high amplitude signals.
2. The gain is positive for low amplitude signals.
3. Transient signals are not distorted (see Ken's Corner [13]).
4. The process is easily divided into frequency bands.
5. The recorded signal contains higher amplitude signals.
6. The output signal is unchanged.

Later Dolby systems are based on the above theory with modifications to the frequency-gain relationship. In particular, the digital schemes allow for a microprocessor controlled encoding and decoding system. These later systems provide more than 10 dB noise reduction.

4.2.2 Analog

The initial Dolby theater system was released in 1975. The system operated off of an encoded optical soundtrack which resided on the movie film. Dolby analog has 5 channels: left, right, center, surround and a subwoofer. Figure 12 shows the typical speaker layout.

4.2.3 Digital

Dolby Digital is based on the digital AC-3 coding scheme. "[Dolby Digital] enables the transmission and storage of up to five full-range audio channels, plus a low-frequency effects channel (LFE), in less space than is required for just one linear PCM-coded channel on a compact disc."[14] Dolby Digital adds a rear channel to the basic surround sound configuration as seen in Figure 13.

The latest Dolby theater sound system, Surround EX, adds an independent rear channel for a total of 6 channels and 1 LFE channel. Figure 14 shows the configuration.

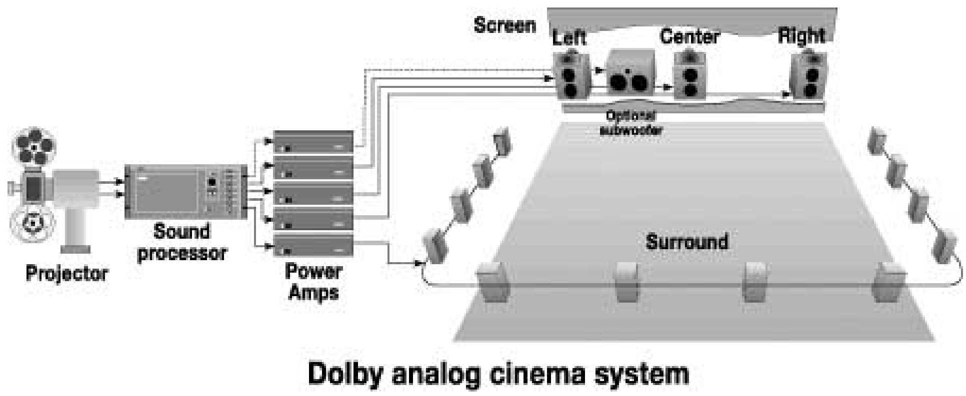

Figure 12: Analog Dolby Layout (www.dolby.com)

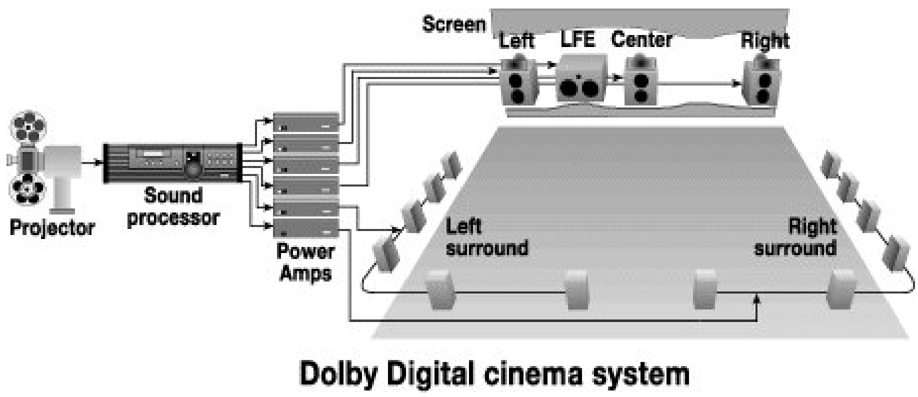

Figure 13: Digital Dolby Layout (www.dolby.com)

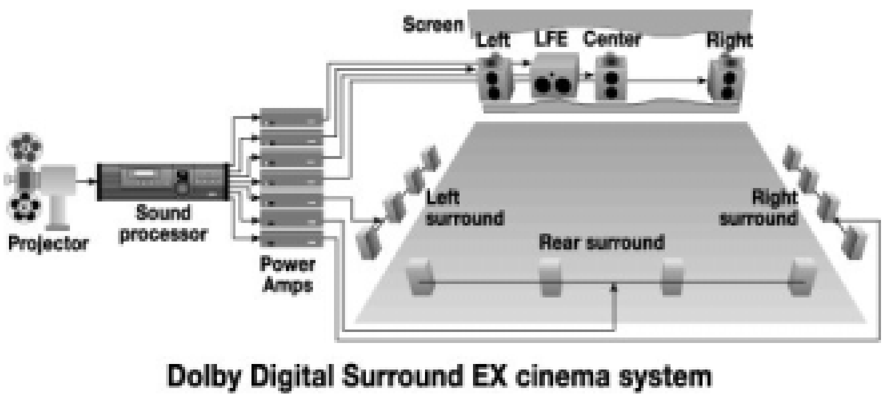

Figure 14: Digital Surround EX Dolby Layout (www.dolby.com)

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