The science behind

CREATING QUALITY SOUND

CSI MULTIMEDIA

VENUE SOUND

"VENUE, *A place for large gatherings, as a sports stadium."*
The American Heritage(r) Dictionary of the English Language, Fourth Edition

In the high quality audio world there are many varied sound applications and system requirements, from easily controlled to ever changing:

- Personal sound systems (MP3 players etc.) utilize headphones, a predictable, static, environment; the ears are always in the same relationship to the transducers (speakers).
- Auto sound systems (constantly growing bigger and better) are also, for the most part, a controlled environment. With the exception of the number of people or the amount of luggage the "room" is intimate and predictable and the ears, for the most part, are always in the same relationship to the transducers (speakers).
- Audiophile sound (expensive to extravagant home audio systems) must be designed for the specific local, but, in most cases, the equipment is designed for a narrow range of room sizes and sound pressure levels "spl" (volume).
- But, the sound systems with the greatest number of variables and there for, the most demanding on the designer, the equipment and the budget are the venue sound systems.

The universal and primary requirement is for the best sound quality at any spl and the same spl for each listener no matter where they are sitting. Expectations are thumping low frequencies, full rich bass, articulate mid range and clean crisp highs. From indoor arenas to outdoor stadiums; theaters to concert halls; school auditoriums to churches; movie theaters, restaurants and nightclubs the challenges are as varied as the equipment.

Differing acoustical layouts (wall angles, materials and audience placement), absorption ratios due to more or less bodies (full or empty venue), wide temperature variants and air currents and eddies all conspire to make high sound quality a moving and difficult to hit target. Since the customer does not have to buy the system, but is, in essence, only paying rent, there is also an expectation of the highest quality sound. We want sound that is felt as well as heard, sound that has the power to change and even evoke emotions and sound which carries all the impact which its creators desired to communicate. Sound generators are very different in method and effect; whether actors, preachers or sports announcers, from solo performers to large orchestras, rock bands to intimate jazz groups the requirements for the sound system are wide-ranging, but the most challenging task for the venue sound designer is that in most venues the specifications are to accommodate most or all of the different sound generators in the same venue.

ACOUSTIC CRITERIA

Many of the acoustic characteristics of rooms and auditoriums can be directly attributed to specific physically measurable properties. Because the music critic or performing artist uses a different vocabulary to describe these characteristics than does the physicist, it is helpful to survey some of the more important features of acoustics and correlate the two sets of descriptions.

"Liveness" refers directly to reverberation time. A live room has a long reverberation time and a dead room a short reverberation time.

"Intimacy" refers to the feeling that listeners have of being physically close to the performing group. A room is generally judged intimate when the first reverberant sound reaches the listener within about 20 milliseconds of the direct sound. This condition is met easily in a small room, but it can also be achieved in large halls by the use of orchestral shells that partially enclose the performers. Another example is a canopy placed above a speaker in a large room such as a cathedral: this leads to both a strong and a quick first reverberation and thus to a sense of intimacy with the person speaking.

"Fullness" is the relationship of the amplitude of the reverberant sound relative to the direct sound, if the amplitude of the reverberant sound is equal to or greater than the direct sound the result is referred to as full. Fullness generally implies a long reverberation time. A fuller sound is generally required of Romantic music or performances by larger groups.

"Clarity" the opposite of fullness, is achieved by reducing the amplitude of the reverberant sound. Clarity implies a shorter reverberation time. More clarity would be desirable in the performance of rapid passages from Bach or Mozart or in speech.

"Warmth" refers to the reverberation time at low frequencies relative to that at higher frequencies. Above about 500 hertz, the reverberation time should be the same for all frequencies. But at low frequencies an increase in the reverberation time creates a warm sound.

"Brilliance" if the reverberation time increased less at low frequencies, the room would be characterized as more brilliant.

"Texture" refers to the time interval between the arrival of the direct sound and the arrival of the first few reverberations. To obtain good texture, it is necessary that the first five reflections arrive at the observer within about 60 milliseconds of the direct sound. An important corollary to this requirement is that the intensity of the reverberations should decrease monotonically; there should be no unusually large late reflections.

"Blend" refers to the mixing of sounds from all the performers and their uniform distribution to the listeners. To achieve proper blend it is often necessary to place a collection of reflectors on the stage that distribute the sound randomly to all points in the audience.
Although the above features of auditorium acoustics apply to listeners, the idea of ensemble applies primarily to performers. In order to perform coherently, members of the ensemble must be able to hear one another. Reverberant sound cannot be heard by the members of an orchestra, for example, if the stage is too wide, has too high a ceiling, or has too much sound absorption on its sides.

TRANSDUCERS

A transducer (microphone or speaker) converts sound waves (moving air) to electrical current and visa versa. With the exception of electronically (example; some electronic organs or a Theraman) or digitally (example; non sampled synthesizers) produced sounds, all music has a transducer at both ends and the quality of the final product is due primarily to the quality and design of those transducers.
The ear, which is also a transducer, has an enormous range of response, both in frequency and in intensity. The frequency range of human hearing extends over three orders of magnitude, from about 20 hertz to about 20,000 hertz, or 20 kilohertz. The minimum audible pressure amplitude, at the threshold of hearing, is about 10-5 Pascal, or about 10-10 standard atmosphere, corresponding to a minimum intensity of about 10-12 watt per square meter. The pressure fluctuation associated with the threshold of pain, meanwhile, is over 10 Pascal's-one million times the pressure or one trillion times the intensity of the threshold of hearing. In both cases, the enormous dynamic range of the ear dictates that its response to changes in frequency and intensity must be

SOUND PHYSICS

At this point it is efficacious to understand a bit about the physics of sound. Sound propagates by moving waves of air, to use a simple analogy, the same way a pebble dropped in a pool sends out waves of water.

Once an audible oscillation is produced by a vibrating body, it moves away from its source as a spherical pressure wave. Its rate of passage through any medium is determined by the medium's density and elasticity; the denser the medium, the slower the transmission; the greater the elasticity, the faster. In air at around 60 F, sound moves at approximately 1,120 feet per second, the rate increasing by 1.1 feet per second per degree of rise in temperature.

Sound waves move as a succession of compressions through the air. The wavelength is determined by frequency; the higher the pitch, the shorter the wavelength. A pitch of 263 cycles per second (middle C of the piano) has a wavelength of around 4.3 feet (speed of sound / frequency = wavelength).

By the time a wave has moved some distance, it has changed in some of its characteristics. The journey has robbed it of intensity, which is inversely proportional to the square of the distance. Its timbre has been altered slightly by objects within its path that disrupted an equitable distribution of frequencies, particularly the high-frequency waves, which, unlike the low, move in relatively straight paths from their sources.

The area within which a sound occurs can have considerable effect upon what is heard. Just as a string or reed or air column has a natural resonance period (or rate of vibration), any enclosure-whether an audio speaker cabinet or the nave of a cathedral-imposes its resonance characteristics on a sound wave within it. Any tone that approximates in frequency the characteristic resonance period of an enclosure will be reinforced through the sympathetic response, or natural resonance, of the air within the enclosure. This means that tones of frequencies differing from the resonance of the enclosure will be less intense than those that agree, thereby creating an inequity of sound intensities.

Fortunately, most rooms where music is performed are large enough (wall lengths greater than about 30 feet) so that their natural resonance periods are too slow to fall within the range of pitches of the lowest musical tones (usually no lower than 27 cycles per second, although some organs have pipes that extend to 15 cycles per second). Smaller rooms can produce disturbing sympathetic resonance unless obstructions or absorbent materials are added to minimize that effect. (Bathroom singers revel in this phenomenon because the band of resonance sometimes lies close enough to the pitches of the male voice to support it, making it appear richer and more powerful.)

In addition to resonance, any enclosure possesses a reverberation period, a unit of time measured from the instant a sound fills the enclosure (steady state) until that sound has decayed to one-millionth of its initial intensity. Anyone who has spoken or clapped his hands inside a large, empty room has experienced prolonged reverberation. There are two reasons for such protracted reverberation: first, the space between the surfaces of the enclosure is so great that reflected sound waves travel extended distances before decaying; and, second, the absence of highly absorbent materials precludes appreciable loss of intensity of the wave during its movement.

The reverberation period is a crucial factor in rooms where sounds must be heard with considerable fidelity. If the period is too long in a room where speech must be understood, spoken syllables will blend into each other and the words will be mumbled confusion. If, on the other hand, the reverberation period is too brief in a room where human "presence" and music each contribute to the acoustics, only a "cold" and "dull" feeling will persist, because no reverberative support of the prevailing sounds can be provided by the enclosure itself.

Although all sound waves, regardless of their pitch, travel at the same rate of speed through a particular medium, low tones mushroom out in a broad trajectory while high tones move in straight paths. For this reason listeners in any room should be within a direct path of sound propagation. Seats far to the side at the front of an auditorium offer occupants a potentially distorted version of sound from its source. Thus the high-frequency speakers (tweeters) in good audio reproduction systems are angled toward the sides of the room, ensuring wider coverage for high-frequency components of all sounds.

Sites of musical performance in the open demand quite different acoustical arrangements, of course, since sound reflection from ceilings and walls cannot occur and reverberation cannot provide the desirable support that would be available within a room. A reflective shell placed behind the sound source can provide a boost in transmission of sounds toward listeners. Such a reflector must be designed so that relatively uniform wave propagation will reach all locations where listening will occur. The shell form serves that purpose admirably since its curved shape avoids the right angles that might set up continuous reflections, or echoing. Furthermore, sound waves are reflected more uniformly over a wide area than with any other shape, diffusing them equally over the path of propagations. (The needs here are similar to those of the photographer who wishes to flood a scene uniformly with flat light rather than focus with a spotlight on a small area.)

OCTAVE BANDS

In most cases it is sufficient to measure the sound pressure level in bands of frequencies, rather than at individual frequencies. The width of the band usually

31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	16000 Hz

{Subwoofer}{Woofer} {Midrange}{HighFrequency}

The limits of the octave bands are shown in the Table below:

Center frequency, Hz	Limits of Band, HZ
31.5	22 - 45
63	45 - 89
125	89 - 177
250	177 - 353
500	353 - 707
1000	707 - 1414
2000	1414 - 2828
4000	2828 - 5657
8000	5657 - 11314
16000	11314 - 22627

Note that the center frequency is the geometric mean and not the average of the band limit frequencies.

OCTAVE BANDS

chosen is the octave band - this is a band where the upper frequency is twice that of the lower. Each band is denoted by its centre frequency. Those usually measured are the Internationally Preferred Frequencies shown in the chart above.

If you drop a rectangular brick in a pond the waves will still form a circle as they radiate the same with sound. Speaker manufacturers use different approaches to shape the sound because all rooms are not round they are not even the same shape but the sound waves will still propagate in a wave form. A square peg in a round hole comes to mind.

Frequency *(number of waves that pass a fixed point in unit time)* The size of the pebble determines the magnitude (frequency); larger pebbles make larger waves which are further apart; smaller pebbles make smaller waves which are closer together. Sound is made up of different frequencies (pebble sizes). Higher frequencies have shorter wavelengths lower frequencies have longer wavelengths. A sound which consists of a single frequency is called a pure tone. Nearly all sound sources emit sounds of more than one frequency.

Intensity (The amount of energy flowing per unit time through a unit area that is perpendicular to the direction in which the sound waves are traveling is its intensity.)

The height from which the pebble is dropped determines the intensity (energy or force) of the wave. In acoustics, that attribute of sound that determines the intensity of auditory sensation produced (volume). The loudness of sound as perceived by human ears is roughly proportional to the logarithm of sound intensity. Due to entropy and friction this energy diminishes over time and distance. A large orchestra might produce 140 decibels "dB" (measurement of sound volume) at one meter this could drop to 115 dB, at ten meters 105 dB and at 60 meters 90 dB. Decibels are geometric so 2 dB has twice the sound pressure level as 1 dB

CANCELLATION AND REINFORCEMENT

If a bag of different size pebbles were dropped into a pool a plethora of waves of different sizes would be created, some of the waves would override other waves making then null (cancellation) and some of the waves would travel in unison making them larger (reinforcement), and so it is with sound.

DIFFRACTION

Diffraction is the capacity of sound waves to bend around corners and to spread out after passing through a small hole or slit. If a barrier is placed in the path of half of a plane wave, the part of the wave passing just by the barrier will propagate in a series of *Huygens wavelets, causing the wave to spread into the shadow region behind the barrier. If the size of the obstacle is the same order of magnitude as the wavelength, diffraction may occur, and this may result in interference among the diffracted waves. This would create regions of greater and lesser sound intensity, called acoustic shadows, after the wave has propagated past the obstacle. Control of such acoustic shadows becomes important in the acoustics of auditoriums.

In light waves, wavelengths are very small compared with the size of everyday objects, so that very little diffraction occurs and a relatively clear shadow can be formed. The wavelengths of sound waves, on the other hand, are more nearly equal to the size of everyday objects, so that they readily diffract.

Diffraction of sound is helpful in the case of audio systems, in which sound emanating from loudspeakers spreads out and reflects off of walls to fill a room. It is also the reason why "sound beams" cannot generally be produced like light beams. On the other hand, the ability of a sound wave to diffract decreases as frequency rises and wavelength shrinks. This means that the lower frequencies of a voice bend around a corner more readily than the higher frequencies, giving the diffracted voice a "muffled" sound. Also, because the wavelengths of ultrasonic waves become extremely small at high frequencies, it is possible to create a beam of ultrasound. Ultrasonic beams have become very useful in modern medicine.

The scattering of a sound wave is a reflection of some part of the wave off of an obstacle around which the rest of the wave propagates and diffracts. The way in which the scattering occurs depends upon the relative size of the obstacle and the wavelength of the scattering wave. If the wavelength is large in relation to the obstacle, then the wave will pass by the obstacle virtually unaffected. In this case, the only part of the wave to be scattered will be the tiny part that strikes the obstacle; the rest of the wave, owing to its large wavelength, will diffract around the obstacle in a series of *Huygens wavelets and remain unaffected. If the wavelength is small in relation to the obstacle, the wave will not diffract strongly, and a shadow will be formed similar to the optical shadow produced by a small light source. In extreme cases, arising primarily with high-frequency ultrasound, the formalism of ray optics often used in lenses and mirrors can be conveniently employed.

REFRACTION

Another important case in which sound waves bend or spread out is called refraction. This phenomenon involves the bending of a sound wave owing to changes in the wave's speed. Refraction is the reason why ocean waves approach a shore parallel to the beach and why glass lenses can be used to focus light waves. An important refraction of sound is caused by the natural temperature gradient of the atmosphere. Under normal conditions the Sun heats the Earth and the Earth heats the adjacent air. The heated air then cools as it rises, creating a gradient in which atmospheric temperature decreases with elevation by an amount known as the adiabatic lapse rate. Because sound waves propagate faster in warm air, they travel faster closer to the Earth. This greater speed of sound in warmed air near the ground creates *Huygens wavelets that also spread faster near the ground. Because a sound wave propagates in a direction perpendicular to the wave front formed by all the *Huygens wavelets, sound under these conditions tends to refract upward and become "lost." The sound of thunder created by lightning may be refracted upward so strongly that a shadow region is created in which the lightning can be seen but the thunder cannot be heard. This typically occurs at a horizontal distance of about 22.5 kilometers (14 miles) from a lightning bolt about 4 kilometers high.

At night or during periods of dense cloud cover, a temperature inversion occurs; the temperature of the air increases with elevation, and sound waves are refracted back down to the ground. Temperature inversion is the reason why sounds can be heard much more clearly over longer distances at night than during the day-an effect often incorrectly attributed to the psychological result of nighttime quiet. The effect is enhanced if the sound is propagated over water, allowing sound to be heard remarkably clearly over great distances.

Refraction is also observable on windy days. Wind, moving faster at greater heights, causes a change in the effective speed of sound with distance above ground. When one speaks with the wind, the sound wave is refracted back down to the ground, and one's voice is able to "carry" farther than on a still day. When one speaks into the wind, however, the sound wave is refracted upward, away from the ground, and the voice is "lost."

Another example of sound refraction occurs in the ocean. Under normal circumstances the temperature of the ocean decreases with depth, resulting in the downward refraction of a sound wave originating under water-just the opposite of the shadow effect in air described above. Many marine biologists believe that this refraction enhances the propagation of the sounds of marine mammals such as dolphins and whales, allowing them to communicate with one another over enormous distances. For ships such as submarines located near the surface of the water, this refraction creates shadow regions, limiting their ability to locate distant vessels.

HARMONICS

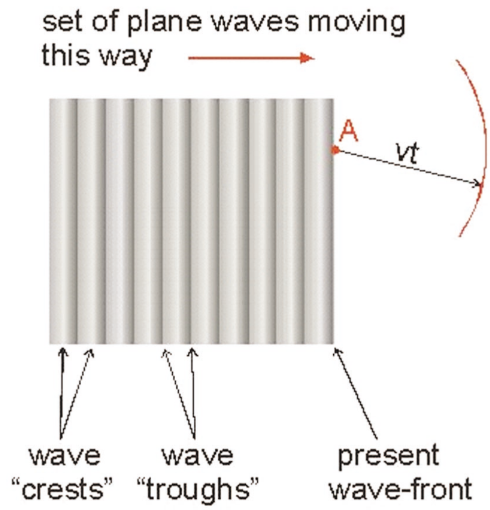
Musical sounds contain a fundamental frequency plus several harmonics (i.e. sounds with frequencies that are integral multiples of the fundamental frequency at a lower volume level). This combination tends to sound pleasant to the ear. In some cased cancellations and reinforcements can create new size waves in a different frequency, these will also have harmonics.

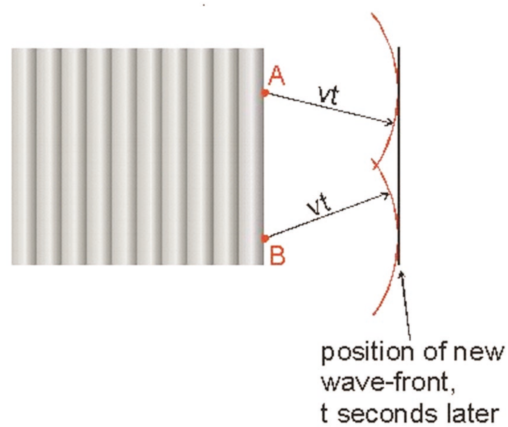
Our pebble analogy becomes more complex if several bags of different size pebbles were dropped into a pool at different locations, then the waves would cross each other and cause even more frequency cancellation and reinforcement. That is precisely the case of multiple sound generators.

If all the waves need to reach the edge of the pool, then the size of the pool would determine the force required (height from which they are dropped) for the dropping pebbles. If all the waves needed to reach multiple points in the pool (the audience) at the same time with the same intensity and without losing any frequencies, then you would have the venue sound challenge.

HUYGENS PRINCIPLE

A very general principle applying to all forms of wave motion which states that every point on the instantaneous position of an advancing phase front (wave front) may be regarded as a source of secondary spherical wavelets. The position of the phase front a moment later is then determined as the envelope of all the secondary wavelets (ad infinitum).





The Dutch scientist Huygens suggested a graphical method of predicting the future position of a wave-front.

This principle, stated by Dutch physicist Christian Huygens (1629-95), is extremely useful in understanding effects due to refraction, reflection, diffraction, and scattering of all types of radiation, including sonic radiation as well as electromagnetic radiation and applying even to ocean-wave propagation.

HUYGENS WAVELETS

The assemblage of secondary waves asserted by Huygens to be set up at each instant at all points on the advancing surface of a wave, or phase front.

Many phenomena of wave optics can be neatly explained on this assumption (Huygens principle) of the continual creation of new wavelets and the subsequent destructive or constructive interference between the wavelets to set up the next-imagined state of the advancing wave front.