ROOM ACOUSTICS AND LOW FREQUENCY DAMPING

by Arthur Noxon • This paper first presented at the
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Preface (Not part of the AES presentation)

The Sabine type formulas of decay rates are derived for diffuse sound fields. This restricts their use typically to 300 Hz and above. Standing wave modes dominate the lower frequency range form of acoustic energy storage. Dissipation of this energy from the room occurs in two forms: transmission out of the room and absorption within the room.

Rooms used for acoustic work frequently have heavier than usual walls to increase isolation from exterior noise. This results in less opportunity for transmission type of energy loss from the room which increases its dependence on internal acoustic absorption to provide sufficient decay rates.

Absorption of acoustic energy is by means of friction effects applied to kinetic energy components of the sound waves. This friction is usually “wall friction,” where the reflecting wave is locally transformed by the stiff and heavy wall impedance. The surface normal component of the waves’ kinetic energy density converts to extra pressure and the tangential component is exposed to opportunities for surface frictional dissipation.

There are three types of low frequency wave containment in a room: Longitudinal, tangential and oblique. The decay rates of these are not the same. The longitudinal modes are one dimensional, axial standing waves and present the lowest amount of kinetic energy density to the wall surfaces, hence they have the longest decay rates. The tangential modes impact two pairs of wall surfaces and the oblique impacts all three pairs of walls. The tangential and oblique modes produce about twice the decay rate as the longitudinal mode because their grazing impact on wall surfaces provides for more wall friction. Sabine type equations also account for this type of activity.

Bass traps are discrete devices as contrasted with a wall surface. Their performance depends on their placement relative to the energy distribution of the various modes of vibration. At a particular location, the trap may provide significant absorption at one frequency, and minimal absorption at another. Traps located in the tri corners of a room contact pressure fluctuations associated with each room resonance.

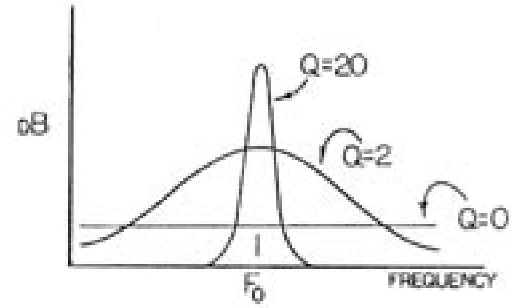
Corner loaded bass traps pull energy out of the standing wave with each pressure change that occurs. Low frequency presents pressure changes at a slower rate than would be by a higher frequency. Calculations of decay rates that are based on this understanding are derived by distributing the energy in the room into the number of pressure zones that exist for the particular mode, then dissipating a fraction of that energy each half cycle, depending on the number of traps located in these pressure zones.

This new method of calculation predicts the number and frequency response of the bass traps required to attain specified decay rate frequency response of a room. Calculation and measurements in test chambers are found to agree. For example, a 2000 ft3 chamber with each of its 8 tri corners loaded with an efficient bass trap produces an RT-60 of 0.3 seconds at 113 Hz.

The formula developed to handle this viewpoint decay rates includes a term which counts the number of fluctuating pressure zones in a room. Its appearance is very similar to the equation that predicts modal density. Another curious effect noticed with very efficient bass traps is the saturation effect of absorption. Decay rates are proportional to the amount of absorption in a corner, but they become less sensitive with higher absorption and reach a limit, indicating that a finite rate of energy can be withdrawn from a resonant field, i.e., no more than all the energy contained in the half wave length held by the corner can be extracted per half cycle, in spite of the “amount” of absorption available.

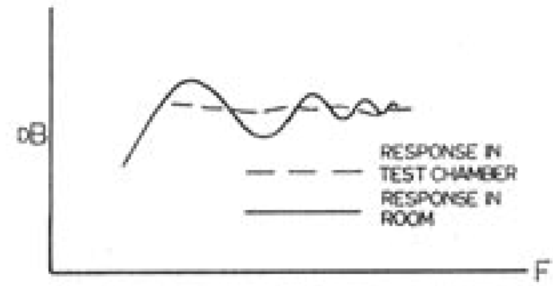
Room Acoustics and Low Frequency Damping

The quality, "Q," of a resonant system identifies its response characteristic. High-Q systems are sharply resonant. They are easy to drive and have a strong response at the resonant frequency (Fo). Low-Q systems respond less strongly and over an extended frequency range. A flat response system has zero Q.



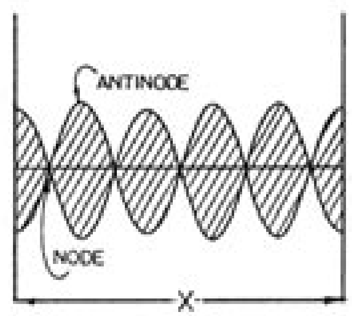
SYSTEM "Q" QUALITY

The frequency response curve of a speaker may be flat from 20-20,000 Hz in the test chamber, a room without reflections. Place the speaker in a real room with a microphone at the listening position. Measure again the response. A series of peaks and valleys are recorded. Move the speaker or mic and a different curve is developed. A room has many resonant frequencies. Which of them are stimulated is dependent on speaker placement. Each peak and null in the spectrum identifies a resonant condition.



SPEAKER RESPONSE CURVES

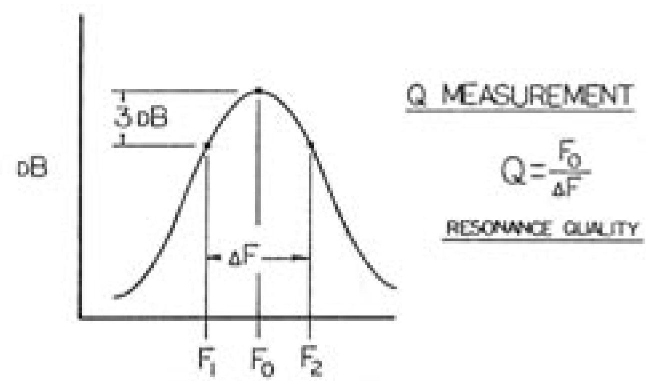
Any physical resonance will have a pressure distribution in space. The microphone at a pressure peak will register a strong signal. Move the mic ¼ wavelength to a node and no signal is received. In either case resonance is evident.



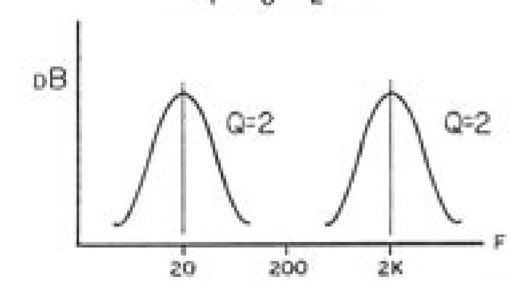
RESONANT PRESSURE DISTRIBUTION

Definitions of "Q"

The "Q" of a system can be measured from its frequency response curve. The ratio of the resonance center frequency to the bandwidth that accompanies the ½ power or 3 dB down point comprises one definition of the "Q" of a system. Usually room response curves are presented dB vs. log frequency format. Resonances occur at different center frequencies. If the "Q" is the same, the response curve shape is the same no matter which center frequency is chosen. The "Q" of an average room lies between 10 and 40. The "QP of a free piano string is 1000.



Resonant systems with slight resistance have High-Q responses. Add energy dissipations (resistance) to lower the "Q". Another definition of "Q" is 2pi times the ratio of the energy of the system to the energy lost per cycle.



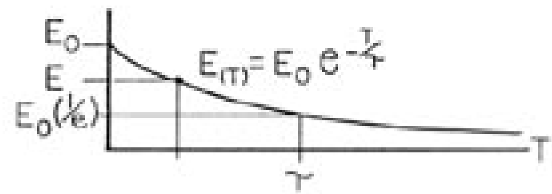
CONSTANT Q LOG SPECTRUM

Decay Relations

Ordinary resonances decay out following an exponential curve in time. The time constant (T) of the decay is the time required for the system to drop to 1/e of the original energy level.

$$Q = \frac{2\pi \cdot E}{\Delta E_{(CYCLE)}} \approx \frac{F_0}{\Delta F}$$

The exponential decay equation can be used to develop the definition of “Q” for the system. If the exponent is a small fraction, less than 1/10, then a simple approximation arises. “Q” equals 2π times the resonant frequency times the decay constant.



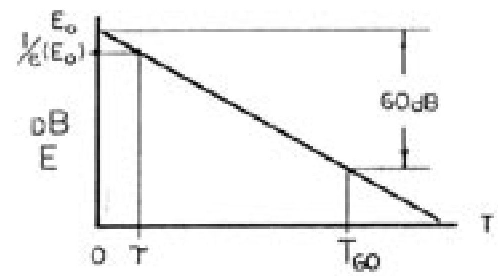
DECAY CURVE

$$Q = 2\pi \cdot \frac{1}{1 - e^{-\frac{1}{F_0 T}}} \approx W_0 T$$

LIGHTLY DAMPED Q

The traditional presentation of decay measurements is the RT60; the time required for the energy to drop 60 dB. The exponential curve appears as a straight line in its dB vs. time plot.

By combining the dB level version of energy with the exponential version, the RT60 is resolved to be 13.8 times the decay constant.



LOG DECAY

“Q” and Decay Constants

The resonance response Q can be expressed in the traditional measure of decay, RT60. It is developed by combining the lightly damped Q relations with the RT60 decay constant relationship.

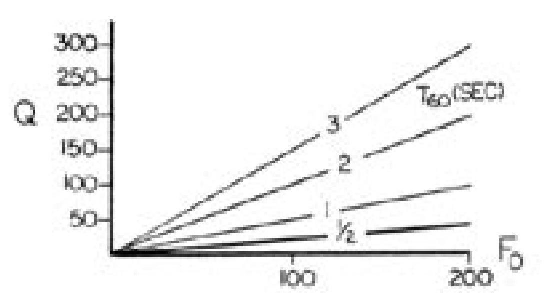
$$60\,\mathrm{dB} = 10 \log \frac{E}{E_0}$$

$$\frac{E_{(T60)}}{E_0} = L_N 10^{-\frac{60}{10}} = -13.8 = \frac{T_{60}}{T_0}$$

$$Q = 2\pi F_0 \cdot \frac{T_{60}}{13.8} = \frac{1}{2.2} \cdot F_0 T_{60}$$

QUALITY AND DECAY

The result of the previous analysis is the linear relationship between the resonant frequency of a listening room and its “Q” for a fixed RT60. For example, a room may well have an RT60 of 1 second at a resonant frequency of 90 Hz. This means that the room has a “Q” of 50 for that resonance. A current spec for listening rooms is an RT60 of .5 seconds. If this applies to room resonance modes, their “Q” varies from 5 to 100 in the 20 to 400 Hz range.



Q, RT60 AND MODAL FREQUENCY

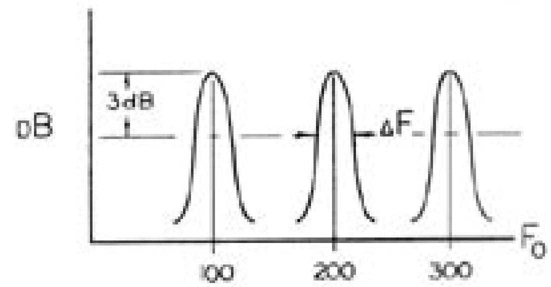
Resonant Bandwidth Relations

The “Q” of the resonant mode is linear with frequency for a constant RT60. By referring to the half power bandwidth relationship, the bandwidth is definable in terms of RT60. For a constant RT60 the bandwidth is constant.

$$\Delta F = \frac{2.2}{T_{60}}$$

RESONANT BANDWIDTH

The frequency response of a listening room can be taken with a linear frequency sweep. This will show the fixed bandwidth resonances to have the same shape regardless of center frequency.



CONSTANT BANDWIDTH SPECTRUM

If it is determined that the ”Q” of some mode needs to be reduced, the proper resistance needs to be added. The energy relations for “Q” yield the required (dQ) addition based on initial Qi and final Qf values.

$$\frac{1}{Q_F} = \frac{1}{Q_I} + \frac{1}{\Delta Q} \quad \text{Q ADDITION}$$

$$\Delta Q = \frac{Q_F Q_I}{Q_I - Q_F} = \frac{F_1}{\Delta F_F - \Delta F_1}$$

Example

The bandwidth of the 100 Hz room resonance mode may be found to be 3 Hz giving an initial Qi of 33. The desirable bandwidth might be 5 Hz for a “Q” of 20. The correction required has a strength of 50. It is developed by adding the proper amount of absorption to the resonant mode.

$$Q_I = \frac{100}{3} = 33$$

$$Q_F = \frac{100}{5} = 20$$

$$\Delta Q = \frac{100}{5-3} = 50$$

The initial RT60 of the room is .73 seconds. The additional absorption added is sufficient to establish alone in the room an RT60 of 1.1 seconds. The result of the total absorption produces an RT60 of .44 seconds.

$$T_{60I} = \frac{2.2\,Q_1}{F_0} = \frac{2.2 \times 33}{100} = .73 \text{ SEC.}$$

$$T_{60\Delta} = \frac{2.2 \times 50}{100} = 1.1 \text{ SEC}$$

$$T_{60F} = \frac{2.2 \times 20}{100} = .44 \text{ SEC.}$$

In order to provide the correction (dQ), a fraction of total energy (F) must be removed from the resonant mode each cycle. The Sabine type equations do not apply here. They are based on absorptive surfaces exposed to diffuse sound fields and are valid above 300 Hz. Here is low frequency absorption and it is related to the volume and position of the absorption relative to that of the standing wave.

$$F = \frac{\Delta E}{E} = \frac{2\pi}{\Delta Q}$$

ABSORPTIVE FRACTION

Resonant Decay by Discrete Absorption

A basic view of energy absorption allows a fraction (F) of the energy remaining in a system to be removed at a regular rate (1/N times a second). This leads to the exponential decay relations whose “RT60” expression is well known. If the fraction is less than 20%, the system is “lightly damped,” and the log term can be simplified in approximation.

$$T_{60} = \frac{-13.8}{H \log_e (1-F)}$$

FUNDAMENTAL RT60

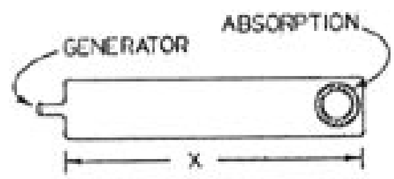
$$T_{60} \approx \frac{13.8}{HF}$$

LIGHTLY DAMPED RT60

The decay equation is very general. It remains only to define the rate and fraction of energy absorption for any particular system and the RT60 can be predicted.

One Dimension Resonance Decay

The “Impedance Tube” provides a device in which standing waves can be generated and then their decay monitored. The absorption device is located at one end of a tube while the sound source is at the other.



IMPEDANCE TUBE

$$H = 2f$$

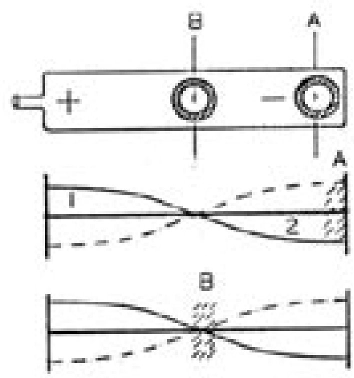
ABSORPTION RATE

$$T_{60} = \frac{-13.8}{2f \log_e (1-F)}$$

PZT DECAY FOMULA

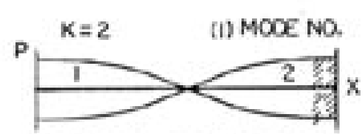
Work is done at the absorption each time there is excess pressure. This occurs twice each cycle, once when the pressure goes positive, and then again when it goes negative. The rate of absorption is twice the resonant frequency.

The fraction of energy lost by each absorption depends on the position and number of traps in the resonant field. A trap located at one end of the impedance tube (A) experiences pressure pulses and can absorb energy. The same trap located at a pressure node (B) experiences no pressure change and does no work.



POSITION DEPENDENT ABSORPTION

The single trap at the end of the tube has access to one-half the total energy in the tube. There are two pressure zones, ¼ wavelength in size for the first harmonic.

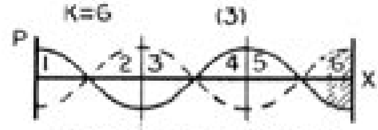


TRAPPED 1ST HARMONIC

The second harmonic has its energy split amongst four ¼ wavelength zones. The trap has access to only ¼ the total energy stored in the resonant condition.

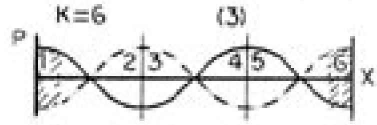
TRAPPED 2ND HARMONIC

The third harmonic has six discrete pressure zones. The trap only works 1/6 of the total energy in the field. The relative size of the trap to the zone increases with higher mode (j) numbers, so its efficiency increases.



TRAPPED 3RD HARMONIC

Multiple traps in a resonant field increase the fraction of energy removed each pressure pulse. Two properly placed traps in the third mode or harmonic has access to 2/6 or 1/3 of the system's energy.



MULTIPLE TRAPPED ZONES

The total number of ¼ wavelength pressure zones is twice the mode number. The fraction of energy lost per pressure pulse is the ratio of trapped zones (J) to the total number of zones (21) times an efficiency term.

$$F = \frac{J}{2L}\eta$$

FRACTION ABSORPTION

The RT60 equation can be written for one dimension trapping. For small absorption, the approximation is made.

$$T_{60} = \frac{-13.8}{2f \log\left(1 - \frac{J\eta}{2L}\right)}$$

$$\approx \frac{13.8L}{fJ\eta}, \quad F < .2$$

1-DIMENSIONAL PZT DECAY

The simple Sabine decay formula for one dimension is a classic derivation. A pulse is injected into the impedance tube. Absorption is located at the tube end. The fraction of energy lost upon impact is the absorption coefficient (a).

$$T_{60} = \frac{13.8\,(2X)}{C\alpha}$$

SIMPLE SABINE DECAY

The PZT decay formula can be converted into a form like the Sabine. Any frequency of resonance belongs to one of a harmonic series. It is the multiple of the mode number (L) and fundamental frequency (fo). Since absorption is only at one end of the tube for both cases, only one pressure zone is trapped.

$$f = f_0 L = \frac{C}{2X} L$$

HARMONIC SERIES OF TUBE

$$T_{60} \quad \frac{13.8\,(2X)}{C\eta}, \quad J = 1$$

PZT DECAY

The efficiency term (n) in PZT analysis and the absorption coefficient (a) in Sabine calculations have the same physical definition. It is the ratio of energy lost to initial energy. For the one dimension systems, PZT rationale results in the same conclusion as does the classic Sabine analysis.

$$\alpha = \frac{\Delta E}{E_1}, \quad \eta = \frac{\Delta E}{E_I}$$

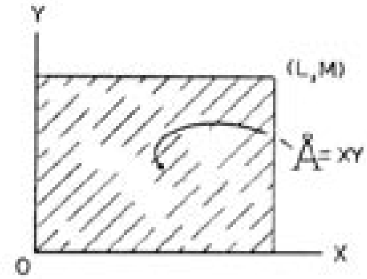
LOSS TERMS DEFINED

$$T_{60}^{\,SABINE} = T_{60}^{\,PZT}$$

1-DIMENSIONAL EQUALITY

Two Dimensional Decay Rates

The two dimensional physical space is outlined by an X and Y dimension. Each resonant mode is identified by a “mode number,” a set of two whole numbers (L,M). If one of the mode numbers is zero, the one dimensional model develops.



The standard equation for the frequency of a resonant mode has two components. They can be converted into wave numbers by dividing each mode number by its associated physical length. The mode frequency equation can be rewritten in terms of wave numbers.

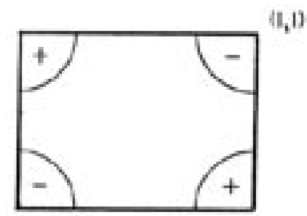
$$F = \frac{C}{2} \cdot \sqrt{\left(\frac{L}{X}\right)^2 + \left(\frac{M}{Y}\right)^2}$$

RESONANCE FREQUENCY

$$F = \frac{C}{2} \cdot \sqrt{A^2 + B^2} \quad A = \frac{L}{X},\ B = \frac{M}{Y}$$

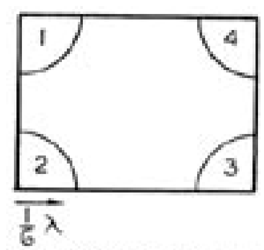
FREQUENCY IN WAVENUMBERS

The primitive cell in two dimensions is the (1,1) mode. Positive pressure in opposite corners with negative pressure in the other two marks the energy distribution at one moment. A half cycle later the polarity reverses. Between these moments are complimentary patterns of kinetic energy distribution.



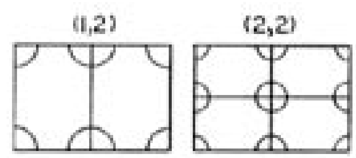
PRIMITIVE CELL, PRESSURE ZONES

There are a total of 4 quarter wavelength zones in the pressure distribution of the primitive cell. They are in the corners. All the energy in the resonant cell is found within these four zones twice each cycle. 80% of a zone is found contained within the radius, 1/6 of the wavelength from the corner.



PRESSURE ZONES

Higher mode numbers are simply more such cells packed into the same space. A (2,1) mode has two cells in the X axis and one cell in the Y. A (2,2) mode is two cells wide by two cells high. The total number of cells is the product of the two mode numbers.



HIGHER MODES

The total number of pressure zones (K) will be four times the number of cells in a mode. If some number (J) of them are absorptively trapped, the fraction of pressure zones trapped is known if the efficiency term is included.

$$K = 4LM$$

NUMBER OF PRESSURE ZONES

$$F = \frac{J}{K} n = \frac{J}{4LM} n$$

TRAPPED ZONE FRACTIONS

The RT60 formula derived for PZT methods is general and can be applied to this two dimensional case. For light absorption, a further simplification results.

$$T_{60} = \frac{55.2}{C} \cdot \frac{AB}{\sqrt{A^2 + B^2}} \cdot \frac{Å}{Jn}$$

TWO DIMENSIONAL DECAY

Three Dimensional Modes

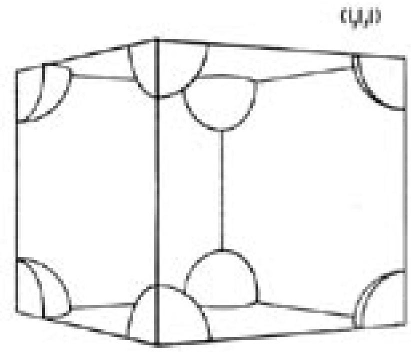
The three dimensional model of Pressure Zone Trapping also has a primitive cell, (1,1,1). It has eight corners, each containing a quarter wavelength pressure zone. If all eight zones were placed together a complete sphere would be formed.

Harmonics of the fundamental are built in terms of complete cells. The (1,1,2) will be one cell high, one cell wide, and two cells deep. It will have 8 x 2 or 16 pressure zones. The (1,1,3) mode is one by one by three cells in configuration and has 8 x 3 or 24 pressure zones. The (2,2,2) mode is accordingly two by two by two cells for a total of eight and 8 x 8 or 64 pressure zones. The total number of pressure zones for any (L,M,N) mode is 8(LMN). They momentarily hold all the energy of the resonant field two times per cycle for any standing wave mode in a three dimensional field.

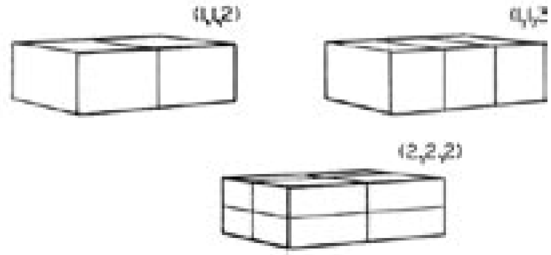
The basic Pressure Zone Trapping formula still applies. The more complicated term for frequency, well known and dependent on three terms, can be substituted. The value for absorption coefficient remains the fraction of energy absorbed per absorption event. It is the fraction of trapped zones times the efficiency term.

The formal RT60 equation can be simplified if the absorption coefficient is less than 1/5 by approximation. The complete RT60 equation is written by substituting terms for frequency and fraction of energy. This formal equation can be simplified if the absorption coefficient (F) is less than 1/5 in the log term.

The RT60 equation can be further developed. The room volume (Vr) term is introduced which converts the three mode numbers into wave numbers.



PRIMITIVE CELL



HIGHER MODES

$$A=\frac{L}{X},\ B=\frac{M}{Y},\ C=\frac{N}{Z}$$

WAVE NUMBERS

$$K = 8LMN$$

NUMBER OF PRESSURE ZONES

$$f = \frac{c'}{2}\sqrt{A^2+B^2+C^2}$$

FREQUENCY EQUATION

$$F = \frac{J}{8LMN}\eta$$

TRAPPED FRACTION OF ZONES

$$T_{60} = \frac{-13.8}{c'\sqrt{\left(\frac{L}{X}\right)^2+\left(\frac{M}{Y}\right)^2+\left(\frac{N}{Z}\right)^2}\ \log_e\left(1-\frac{J\eta}{8LMN}\right)}$$

$$\simeq \frac{1}{10}\left(\frac{LMN}{\sqrt{A^2+B^2+C^2}}\right)\frac{1}{J\eta}$$

$$T_{60} = \frac{1}{10}\frac{ABC}{\sqrt{A^2+B^2+C^2}}\cdot\frac{V_R}{J\eta},\quad V_R = XYZ$$

RT60 IN WAVE NUMBERS

Wave Number Space

Wave number space is a three dimensional coordinate system with A, B, and C axes. Each point (P) in this space defines a resonant mode for the room. This is not a continuous field space. It is more like a crystal; discrete points set apart at specific distances.

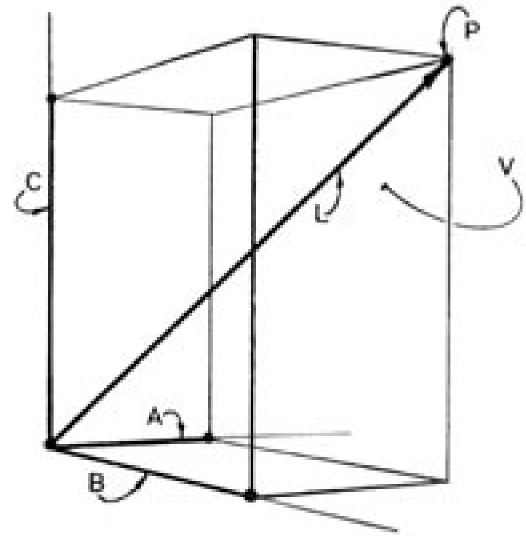
The mode point is at the tip of the resultant vector (D) whose magnitude is the sum of the squares of the components. It is also at the far corner of a rectangle whose volume (V) is known by the products of its components.

The frequency and RT60 formulas can be rewritten in terms of this wave number space geometry.

This listening room already has a decay time. Frequently improvement in the decay rate is desired. The minimum upgrade is to trap one zone for each 500 cubic feet of room volume. The resulting RT60 is a simple expression but is only valid for an absolutely rigid room whose only absorption is due to the trapped zones.

Example

Consider a room 18 by 24 by 8 feet high. We can look at mode (2,2,1). The wave numbers (1/9, 1/12, 1/8) are easily calculated along with the volume and diagonal wave number in space. The decay time for that mode is 0.3 sec. This assumes one 100% efficient absorption device per 500 cubic feet of room volume.



WAVE NUMBER SPACE

$$D=\sqrt{A^2+B^2+C^2} \qquad V=ABC$$

MODE LENGTH   MODE VOLUME

$$f=\frac{C'}{2}\cdot D \qquad T_{60}=\frac{1}{10}\cdot\frac{V}{D}\cdot\frac{V_R}{J\eta}$$

MODAL FREQUENCY AND RT60

$$T_{60}=\frac{50}{\eta}\cdot\frac{V}{D}\ ,\ J=\frac{V_R}{500}$$

DECAY TIME

$$D=\sqrt{\frac{1}{9^2}\cdot\frac{1}{12^2}\cdot\frac{1}{8^2}}=.187$$

$$V=\frac{1}{9}\cdot\frac{1}{12}\cdot\frac{1}{8}=1.16\times10^{-3}$$

$$f=\frac{1128}{2}\times.187=105\text{ Hz}$$

$$T\ \frac{50}{1.0}\cdot\frac{1.16\times10^{-3}}{.187}=.3\text{ SEC}$$

How Many Traps

The efficiency term (n) is defined as the ratio of energy absorbed to the energy presented. The ¼ wavelength pressure zone contains a discrete quantity of energy in a definable volume. The trap occupies part of that quadrant with its own volume (V). 80% of the zone's energy lies within 1/6 wavelength radius from the corner. The ratio of PZT volume to the 1/8 spherical section volume comprises the geometric efficiency (E). This is further reduced by the mechanical efficiency of the trap (a) itself; typically 50%.

$$E = \frac{V}{\frac{1}{8}\cdot\frac{4}{3}\pi\left(\frac{\lambda}{6}\right)^3} = \frac{412V}{\lambda^3}$$

GEOMETRIC EFFICIENCY

$$\eta = Ea$$

PZT EFFICIENCY

The RT60 equation can be fitted with this efficiency term. Additional substitutions and reductions provide the RT60 to have an inverse frequency dependency. Recall the Sabine equations to not be directly frequency dependent. There appears the dimensionless ratio in wave number space of the modal volume to the cubed modal length. This ratio is largest for symmetric modes (1, 1, 7) or (2, 2, 2) and smallest for the eccentric modes as (1, 2, 6). It is always less than unity and a mean value of 1/3 is chosen.

$$T_{60} = \frac{1}{10.2}\quad\frac{V}{D}\quad\frac{V_R}{J}\quad\frac{\lambda^3}{412Va}$$
$$= \frac{1}{F}\cdot\frac{V}{D^3}\cdot\frac{V_R}{aJV}$$

RT60 REDUCTIONS

$$T_{60} = \frac{V_R}{3fJaV}$$

RT60

$$\frac{1}{6} < \frac{V}{D} \approx \frac{1}{3} < \frac{2}{3}$$

WAVE SPACE RATIO

The use of traps sufficient to remedy a room's poor low end ranges from one trap per 500 cubic feet to one trap per 250 cubic feet of room volume. This simplifies further the RT60 equation. The trap volume can be resolved for the 500 cubic foot ratio to be inversely dependent on both RT60 and frequency.

$$T_{60} = \frac{167}{f(aV)},\quad J = \frac{V_R}{500}$$

DECAY-500 FT^3 TRAP RATIO

$$V = \frac{\frac{167}{T60}}{Fa},\quad a \approx \frac{1}{2}$$

TRAP VOLUME

The typical acoustic efficiency is 50% for these three commercial traps. Their volume levels cross extended through the frequency range call out the RT60 vs. frequency plot for the 250 cubic foot or 500 cubic foot rate. For example, a 4 cubic foot trap provides 2 seconds at 20 Hz, 1 second at 50 Hz and ½ second at 90 Hz RT60 times.

Conversely, for a particular resonant frequency, room volume and required RT60, the number (J) of trapped volumes can be calculated.

Example

A room of 2,000 cubic feet needs an RT60 of 1/2 second at 50 Hz and tubes having a volume of 4 cubic feet each will be used. A total of 7 traps must be placed in the pressure zones of that mode resonance.

$$J = \frac{V_R}{3f\,T_{60}\,(\alpha V')}$$

NUMBER OF TRAPS

$$J = \frac{2000}{3 \times 50 \times \frac{1}{2} \times 4} = 7 \text{ TRAPS}$$

By utilizing PZT methods, an absorptive treatment for low frequency resonance can be specified. The (dQ) change in room Q is easily approximated. The volume (Vt) of traps required to produce that change can also be defined.

$$\Delta Q = \frac{F_0 T_{60}}{2.2} = \frac{3}{20} \cdot \frac{V_R}{\alpha J V'}$$

QUALITY CORRECTION

$$JV' = V_T = \frac{3}{20} \cdot \frac{V_R}{\Delta Q \alpha}$$

TRAPPED VOLUME

Example

The 2,000 cubic foot room needed a Q adjustment of 50. The volume of PZT adjustment is 12 cubic feet.

$$V_T = \frac{3}{20} \cdot \frac{2000}{\frac{50}{2}} = 12$$

The listening room is the last link in the audio chain. It is an acoustic coupler loaded with resonances. Hundreds of rooms have been developed into satisfactory listening environments by using the 500 cubic feet per trap rule. The average trap volume is 2.5 cubic feet. A correction in Quality of 60 is what the average acoustic treatment produces. Serious listening rooms usually require a correction in Quality of 30. This means the average (Q=40) listening room must have its Q cut in half and a serious room must have a Q equal to 1/3 its untreated Q.

$$\Delta Q = \frac{3}{20} \cdot \frac{V_R}{J} \cdot \frac{1}{\alpha V'}$$

$$\approx \frac{3}{20} \cdot 500 \cdot \frac{1}{\frac{1}{2} \times 2.5}$$

$$\Delta\bar{Q} \times 60$$

A frequently asked question involves the number of traps required to reduce an existing RT60. PZT allows the answer without resorting to Sabine formulas.

$$J = \frac{V_a}{3f\alpha V'} \cdot \frac{T_I - T_F}{T_I \cdot T_F}$$

TRAPS TO SHIFT RT60

Examples

A 2000 cubic foot room has an RT60 of 1.3 sec. at 50 Hz. We wish to reduce it to 0.7 sec. using 4 cubic foot traps. Calculations show 4.4 traps will lower the RT60 as required.

$$J = \frac{2000}{3 \times 50 \times 4 \times \frac{1}{2}} \cdot \frac{1.3 - 0.7}{1.3 \times 0.7} = 4\frac{1}{2} \text{ TRAPS}$$

A 2000 cubic foot soft room with an RT60 of 0.5 seconds needs to be reduced to 0.3 seconds. Using 4 cubic foot traps, calculations show 9 are needed.

$$J = \frac{2000}{3 \times 50 \times 4 \times \frac{1}{2}} \cdot \frac{0.5 - 0.3}{0.5 \times 0.3} = 9 \text{ TRAPS}$$

If RT60 equipment is not available, a slow sine sweep frequency response will suffice. Measure the 3 dB down bandwidth dF. Substitute its relation for initial RT60. The desired RT60 is often specified and doesn't need conversion to final bandwidth.

$$T_{60} = \frac{2.2}{\Delta F}$$

INITIAL BANDWIDTH RT60

$$J = \frac{V_0}{3f(\sigma V')} \cdot \frac{\frac{2.2}{\Delta F} - T_F}{\frac{2.2}{\Delta F} \cdot T_F}$$

Reverb Chamber

Absorption is usually measured in reverb chambers using RT60 values and the Sabine absorption formula. PZT equations can be rearranged into the same format. The distinctive frequency dependence of PZT absorption is clear. This relation connects standard Sabine lab methods to PZT theory.

$$A_{SABINE} = \frac{V_R}{20} \cdot \left(\frac{1}{T_F} - \frac{1}{T_i}\right) = \frac{J\sigma V'}{6.6} \cdot f$$

SABINES OF PZT ABSORPTION

Conclusion

A listening room does not have an acoustically flat response. Most rooms can play better when their Q is reduced by a factor of 2 or 3. Room color is damped out from the listening ambience. It is the Q not the EQ that distinguishes the listening room from a standard room. Pink noise is an appropriate test signal for EQ settings. Pure tone, not 1/3 octave sweeps or RT60 are required to monitor the room Q.

The Pressure Zone Trap (PZT) approach provides a rational view of discrete absorptive devices in the resonant field. It allows specifications to reduce the RT60, or Q of the room to acceptable levels.