ME 513 Session42 12/2/19 1

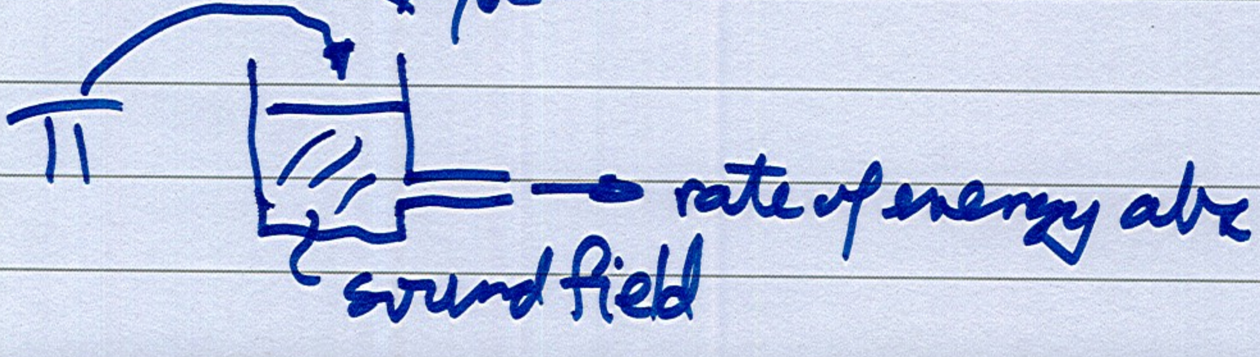
Room Acoustics

Energy Acoustics - high frequency

- reverberant = diffuse fields

Energy Densities - space and short-time averaged energy densities

$$\varepsilon_t = \frac{\boxed{\frac{1}{2}|P_t|^2}}{\rho c^2} \quad P_{t_{rms}}^2$$



$$\overline{\Pi} = V\frac{d\mathcal{E}}{dt} + \text{rate of energy loss at walls + objects}$$

$$= \frac{\mathcal{E}c}{4}\underbrace{A}_{\substack{\text{absorption area}\\ \text{in metric sabins}\\ [m^2]}}$$

$$\overline{\Pi} = V\frac{d\mathcal{E}}{dt} + \frac{Ac}{4}\mathcal{E}$$

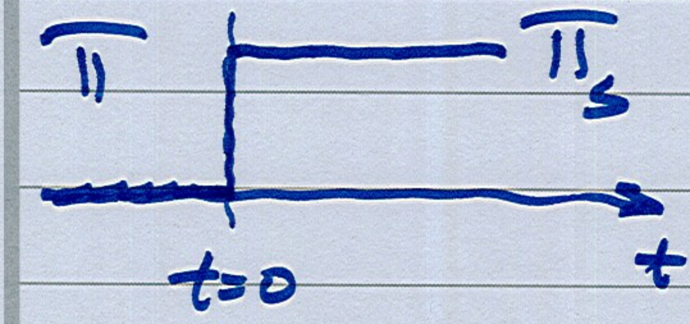
ODE governing the space and short-time averaged energy density in a space steady state $\frac{d\mathcal{E}}{dt} = 0$

$$\boxed{\Pi = \frac{\overset{\checkmark}{A}c}{4}\mathcal{E}}$$

steady state

rate of energy delivery by The source = rate of energy absorption at The walls

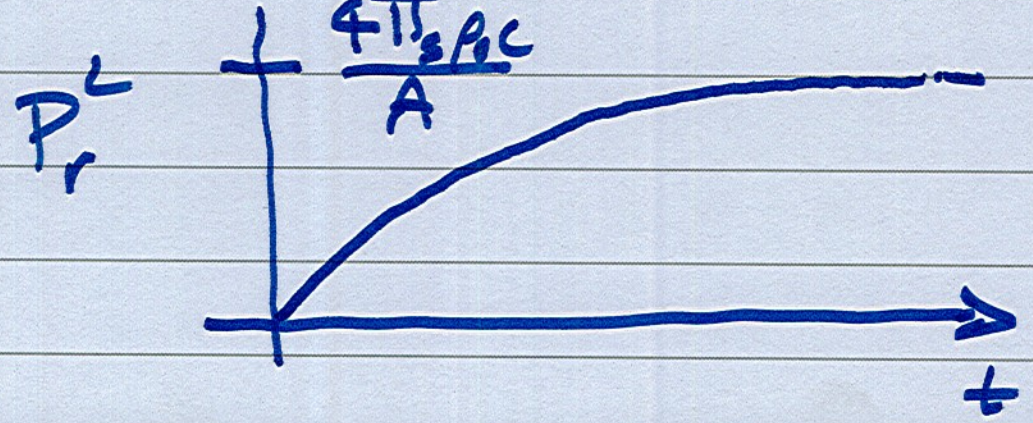
Recall $\mathcal{E} = \frac{1}{2}\frac{P_t^2}{\rho c^2}$ msp of The diffuse field solve for The time variation of The sound field using Laplace transfroms



source turned on at t=0

$$\tau_e = \frac{4V}{Ac}$$

MSP $$P_r^2 = \frac{4\overline{\Pi}_s \rho_0 c}{A}\left(1 - e^{-t/\tau_e}\right)$$



$\tau_e = \frac{4V}{Ac}$ ~ volume of the space

└ Absorption area

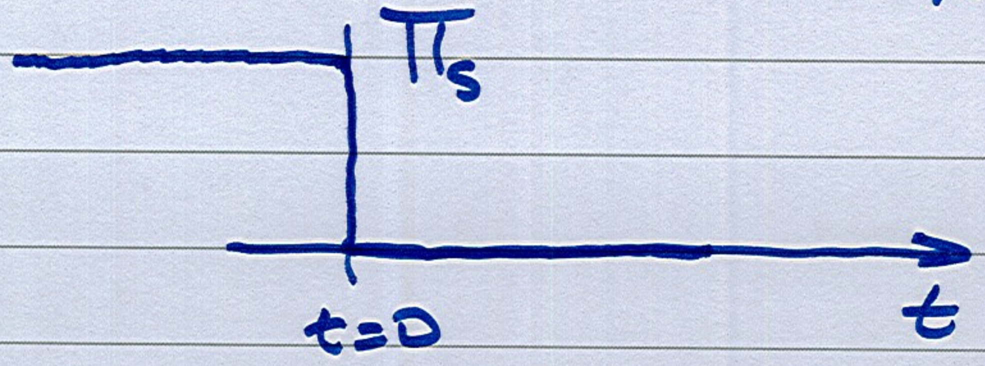
= time constant governing rate of growth or decay in the sound field

- small A & large V

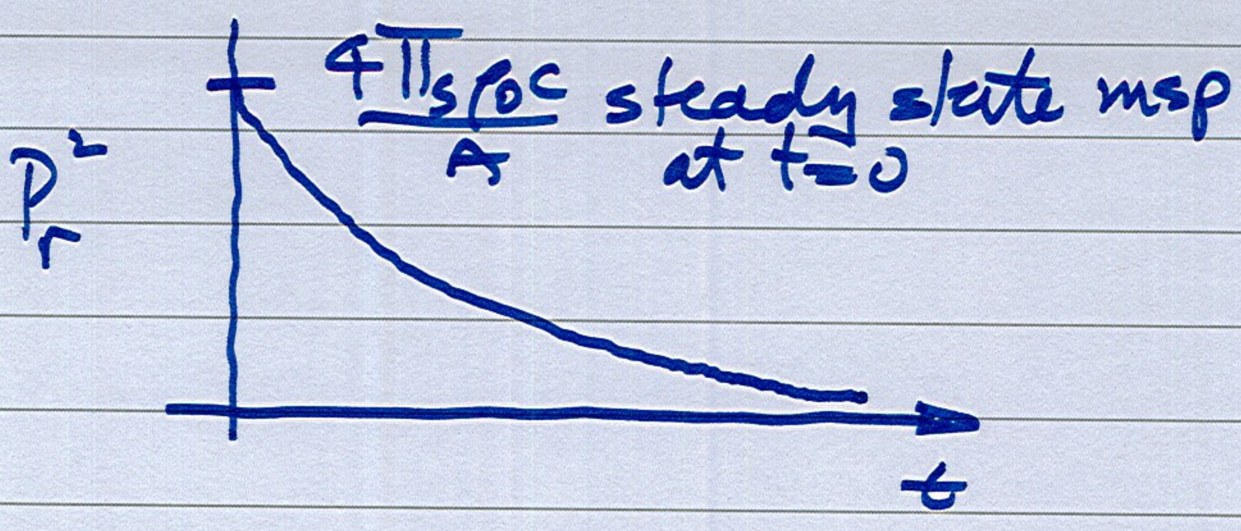
  → large τ_e

  slow transitions

Source is turned off



$$p_r^2 = \frac{4\Pi_s \rho_0 c}{A} e^{-t/\tau_e}$$



Notes: - development assumes that the sound field is diffuse at all times

$\therefore$ we cannot use this theory until the sound has experienced a number of reflections

$t > 50 \rightarrow 100$ ms

> 1 sec in a large space

- cannot be used to predict spatial variations in a space

6.4 Reverberation Time

$\leftarrow$ steadystate value

Recall $P_r^2(t) = P_r^2(0)\, e^{-t/\tau_e}$ $\qquad \tau_e = \frac{4V}{Ac}$

$$10 \log_{10} \frac{P_r^2(t)}{P_{ref}^2} = 10 \log_{10} \frac{P_r^2(0)}{P_{ref}^2} + 10 \log_{10} e^{-t/\tau_e}$$

Δ SPL $= -10 \log_{10} e^{-t/\tau_e}$

change in SPL from $t=0$ to t $= 4.34 \left(t/\tau_e \right)$

$$t = \Delta SPL \frac{\tau_e}{4.34}$$

Reverberation time - drop of 60 dB after source is turned off

↓ rev time

$$T = \frac{60}{4.34} \frac{4V}{Ac}$$

$c = 343$ m/s

$$\boxed{T = 0.161 \frac{V}{A}}$$

$V = m^3$

$A = m^2$

applies in a "proportionate" space

$$T = 0.049\,\frac{V}{A} \quad V \sim ft^3 \quad A \sim ft^2$$

Rev time T - directly proportional to volume
- inversely proportional to A

A = absorption area

$A = \bar{a}\,S$ $\qquad \bar{a}$ = average Sabine absorptivity (random incidence absorption coefficient)

S: surface area of the room interior

Usually assumed

$$A = \sum_i A_i = \sum_i s_i a_i$$

s_i = surface area of the ith surface in the room

a_i = corresponding random incidence abs coeff.

$$\bar{a} = \frac{\sum_i s_i a_i}{S}$$

defn of the average abs coeff.

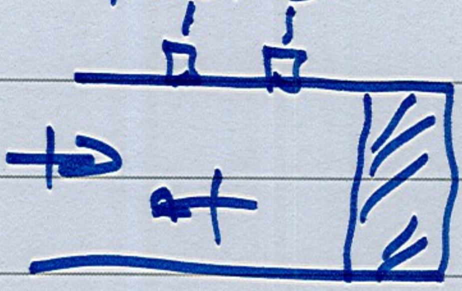
$\longrightarrow A$

a_i's are usually frequency dependent

T is also a function of frequency

α_i's determined using standardized tests

ASTM



$\alpha_n \Rightarrow$ # E 1050

$\Downarrow$

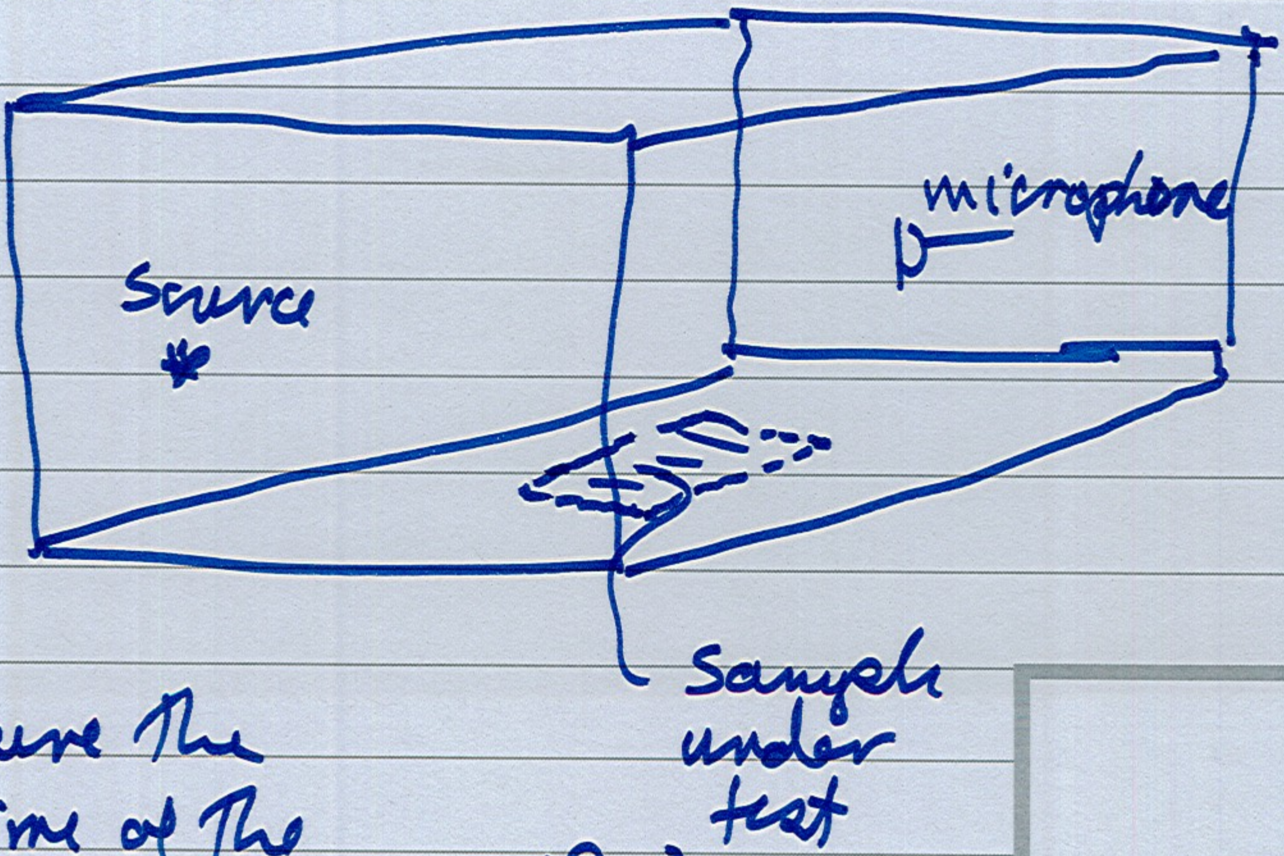
α using the Paris formula

Test in a reverberation room

ASTM C423

ASTM C423

hard
walled
space



(i) Measure the
rev time of the
empty space
(to measure average abs of
the walls)

$10\,m^2$