# Session 7

# Acoustics in the Environment

Rachel Edwards

Nick Roberts

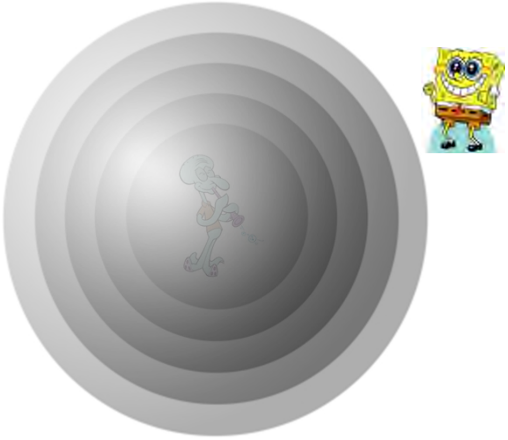
& Gavin, a bit

Science of Music

## Today's session

- Wave spreading
- Amphitheatres and reflections
- Reverberation time / absorption and their effect on room acoustics
- Anechoic chambers
- Acoustics in the environment
- Testing of rooms!

# Wave spreading



Sphere surface area

$$A = 4\pi r^2$$

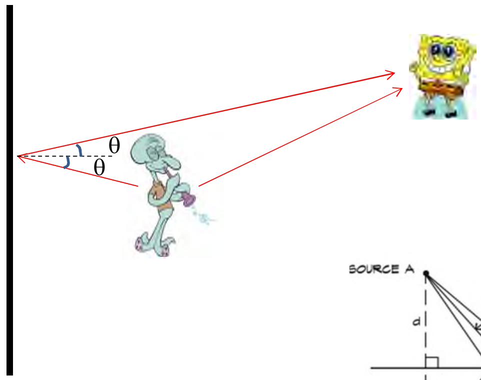
Area of an ear

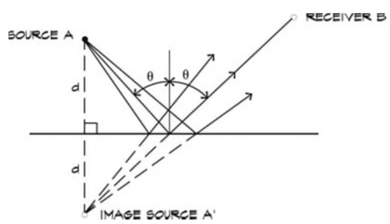
$$A_{ear} \approx 12cm^2$$

Energy of sound collected

$$E = E_0 \left( \frac{A_{ear}(m^2)}{4\pi r^2} \right)$$

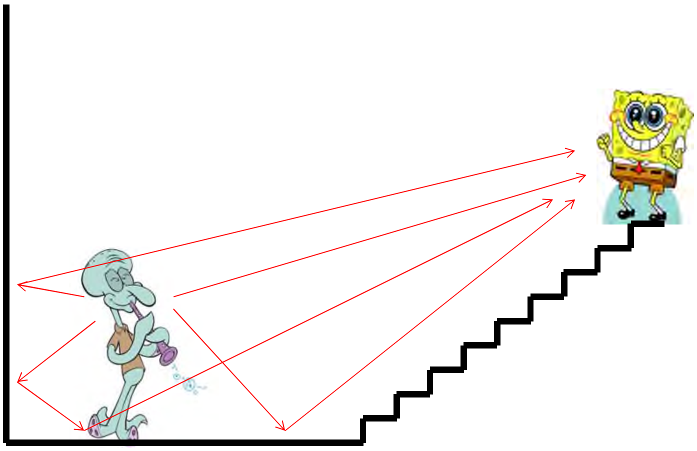
# Reflecting walls



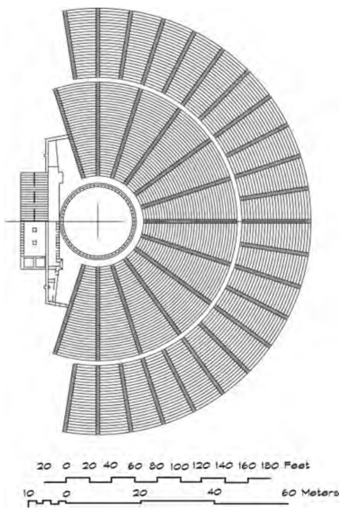




Architectural acoustics, Marshall Long

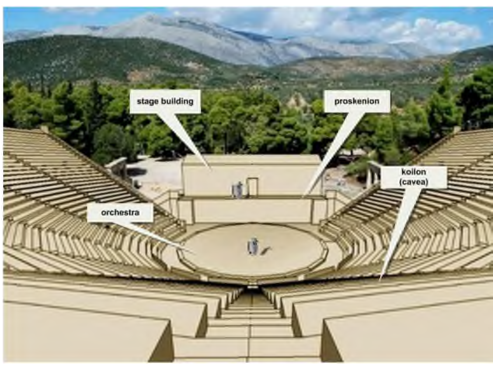
# Amphitheatres



# Amphitheatres: Epidaurus

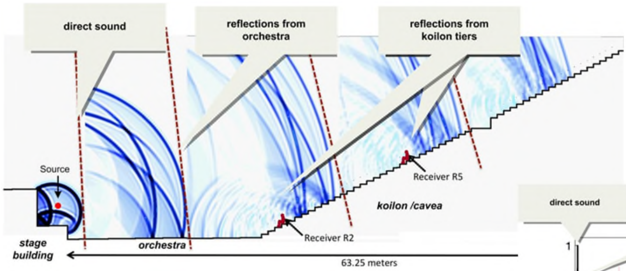


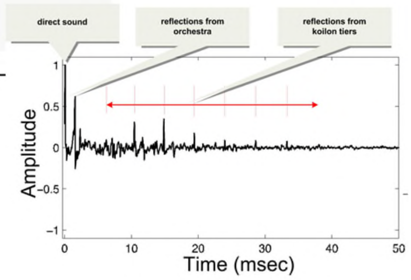

Architectural acoustics, Marshall Long




The Origins of Building Acoustics for Theatre and Music Performances – John Mourjopoulos
*169th ASA Meeting*

# Amphitheatres: Epidaurus



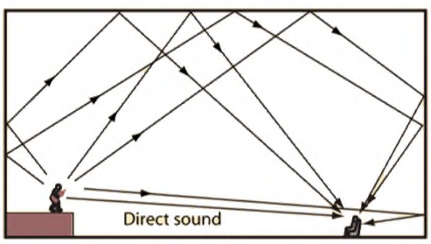



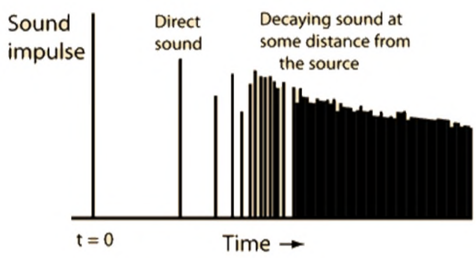

Acoustic response measurement for the Epidaurus theatre, assuming that the source emits a short pulse and the microphone is at a seat at 15 meters.

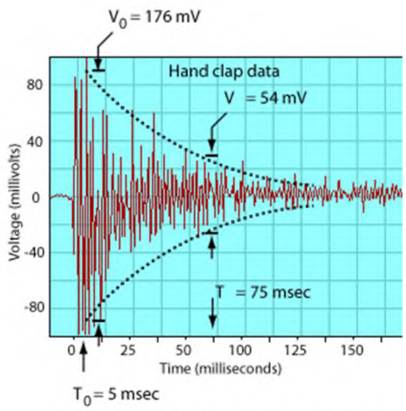
The Origins of Building Acoustics for Theatre and Music Performances – John Mourjopoulos
*169th ASA Meeting*

# Reverberation

- Sound waves can take many paths
- Use a sharp sound (clap, or gun firing) and listen for echoes

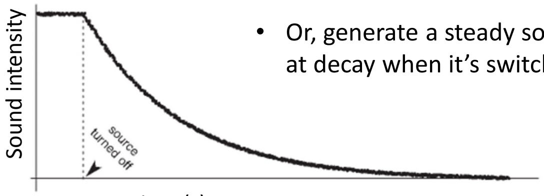


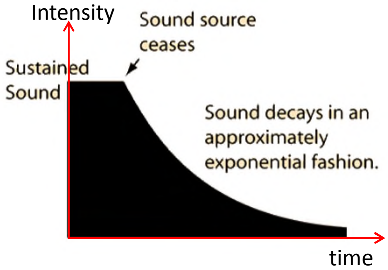

Figures from hyperphysics website

# Reverberation




- Or, generate a steady sound and look at decay when it's switched off

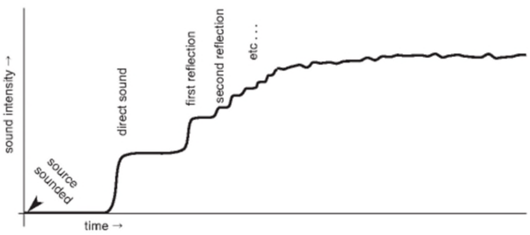
From Measured Tones



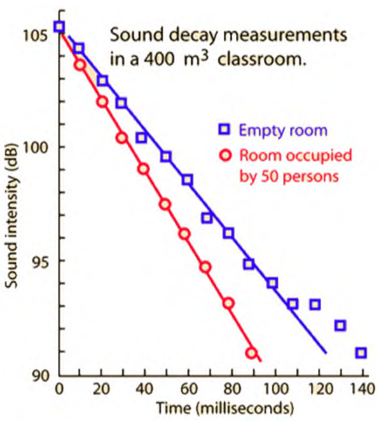

Reverberation time;

$$I(T_{60}) = I(0) \times 10^{-6}$$

# Absorption




From Measured Tones

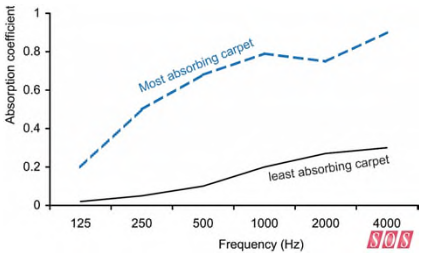


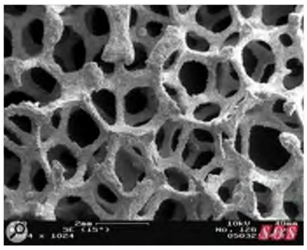

From hyperphysics website

Effective absorbing area = real area x absorption coefficient

# Absorption

Treble absorber



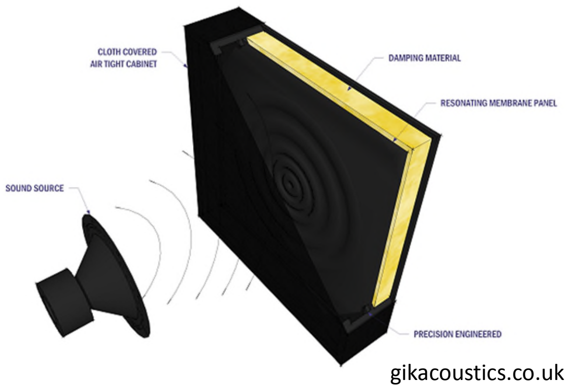



Soundonsound.com

- Rough, porous surface
- Long wavelength ignored, small wavelength scattered

# Absorption

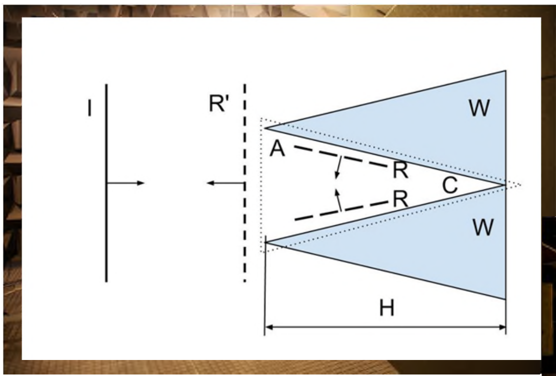
Bass absorber




gikacoustics.co.uk

- E.g. wood panels
- Large surface that can vibrate and trap energy for low frequencies

# Anechoic chamber

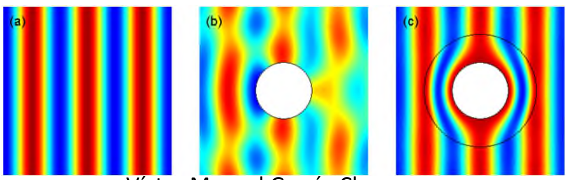



University of Salford

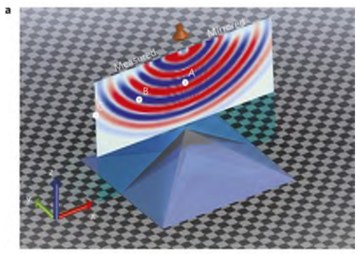
DTU, Denmark
(photo: Alastair Philip Wiper)

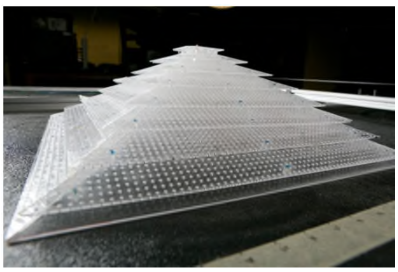
# Acoustic cloaking?

Metamaterials: control, direct and manipulate waves

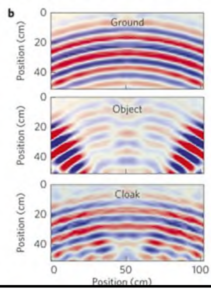



Víctor Manuel García-Chocano



Steven Cummer, Duke University



# Absorption

Effective absorbing area, *Sa* = real area x absorption coefficient
Measured in Sabines

| | FREQUENCY (Hz) | | | | | |
|---|---|---|---|---|---|---|
| | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| Marble or glazed tile | .01 | .01 | .01 | .01 | .02 | .02 |
| Brick wall | .01 | .01 | .02 | .02 | .02 | .03 |
| Wood floor | .15 | .11 | .10 | .07 | .06 | .07 |
| Plywood on studs | .60 | .30 | .10 | .09 | .09 | .09 |
| Plaster on laths | .30 | .15 | .10 | .05 | .04 | .05 |
| Carpet with felt underlay | .08 | .27 | .39 | .34 | .48 | .63 |
| Heavy curtains against wall | .14 | .35 | .55 | .72 | .70 | .66 |
| Cane fiber tiles on concrete | .22 | .47 | .70 | .77 | .70 | .48 |

From Measured Tones

# Absorption

Effective absorbing area, *Sa* = real area x absorption coefficient
Measured in Sabines

Volume of the room

Reverberation time

$$T_{60} = \frac{24 \ln 10}{c_{20}} \frac{V}{Sa} \approx 0.1611 \frac{V}{Sa}$$

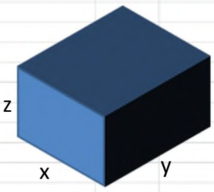
Speed of sound in air at 20°C

# Reverberation time

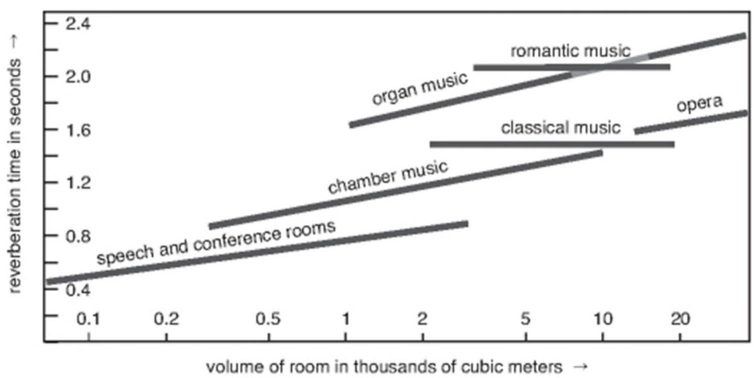
| | | |
|---|---|---|
| Dimensions (m) | x | 10 |
| | y | 30 |
| | z | 8 |
| Volume (m^3) | | 2400 |
| Frequency (Hz) | | 500 |
| Ceiling | Area (xy) | 300 |
| | Absorptio | 0.1 |
| | Eff Area | 30 |
| Floor | Area (xy) | 300 |
| | Absorptio | 0.1 |
| | Eff Area | 30 |
| Wall 1 | Area (xz) | 80 |
| | Abs. | 0.02 |
| | Eff. A | 1.6 |
| Wall 2 | Area (xz) | 80 |
| | Abs. | 0.02 |
| | Eff. A | 1.6 |
| Wall 3 | Area (yz) | 240 |
| | Abs. | 0.02 |
| | Eff. A | 4.8 |
| Wall 4 | Area (yz) | 240 |
| | Abs. | 0.02 |
| | Eff. A | 4.8 |
| Number of people | | 0 |
| | Eff. A | 0 |
| Effective area | | 72.8 |
| Reverb time | | 5.274725 |

Absorption

| | |
|---|---|
| Tile | 0.01 |
| Brick | 0.02 |
| Wood | 0.1 |
| Plywood on studs | 0.1 |
| Plaster | 0.1 |
| Carpet | 0.39 |
| Curtains | 0.55 |
| | All at 500 Hz |




# Reverberation time

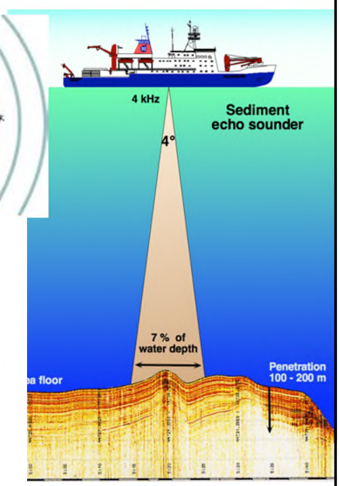



From Measured Tones

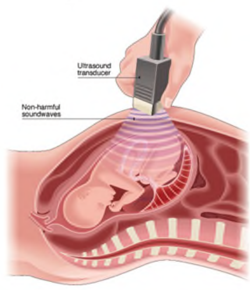
# Butterworth Hall

# Acoustics in the environment

$v = d/t$





# Acoustics in the environment

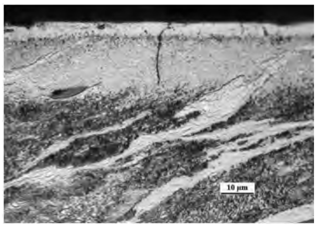
Video and image © Aaron Corcoran - www.sonarjamming.com

# Non-destructive testing

How to make sure this doesn't happen;

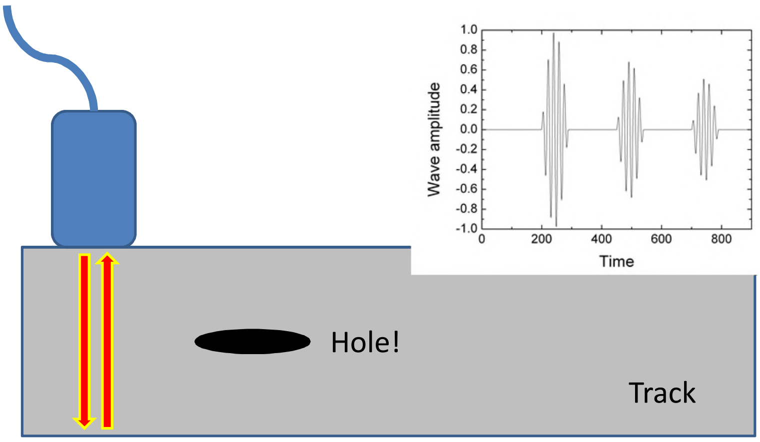
Broken axle on
second car

# Non-destructive testing

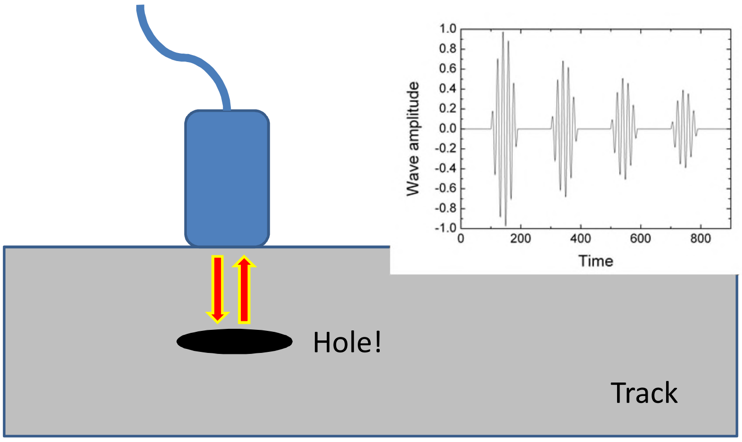


- Look at reflection or transmission of sound

# Non-destructive testing

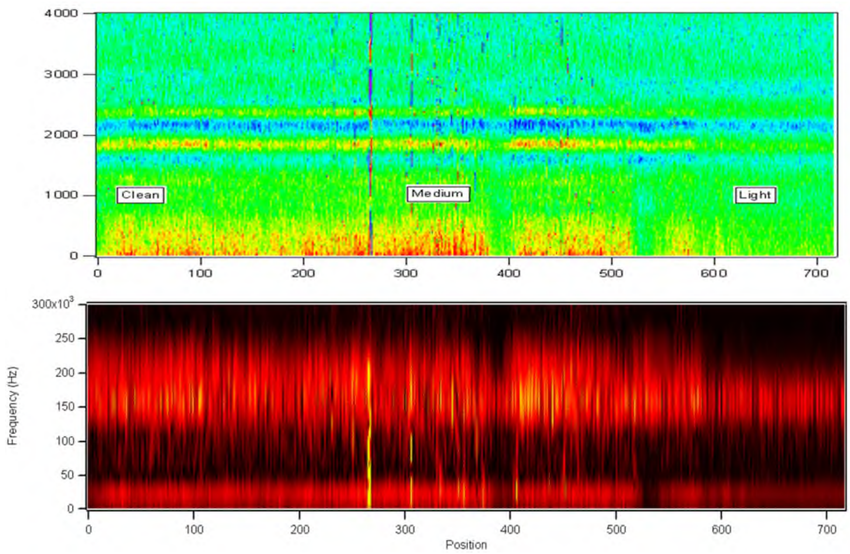


# Non-destructive testing




# Ultrasound in the environment

# Ultrasound in the environment




# Adding reverb

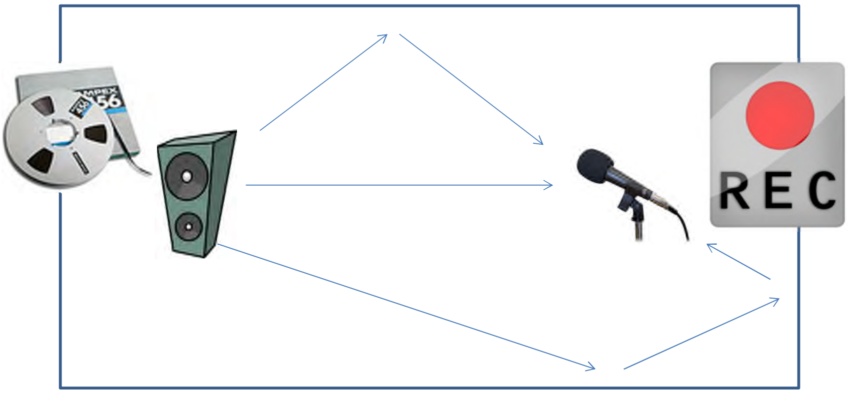
**Live (amplified) performance: example…**

- Laura Moody @ the concert
- Song: Satellite
- Request: *"Can I have the reverb we discussed please!"*

**Studio recording:**

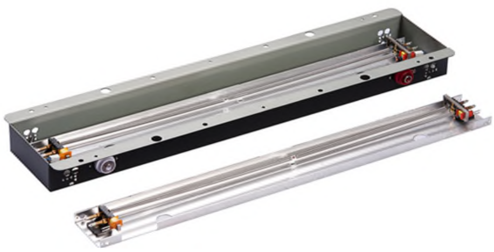
- Record "dry" (but not "flat", in my experience).
- Add reverb in a controlled way.
- Often a necessity rather than a choice, e.g. overdubs, small studio spaces.
- Rock band vs. string quartet?

# Adding reverb: rooms




Nice speaker, nice microphone, nice room…

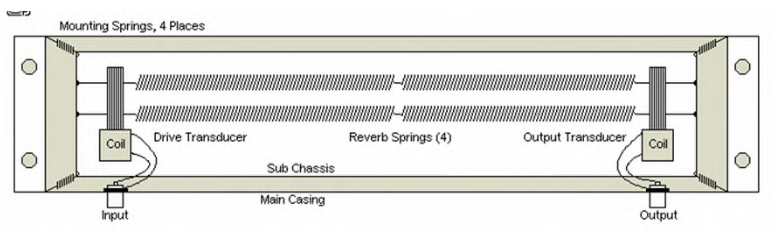
# Adding reverb: springs



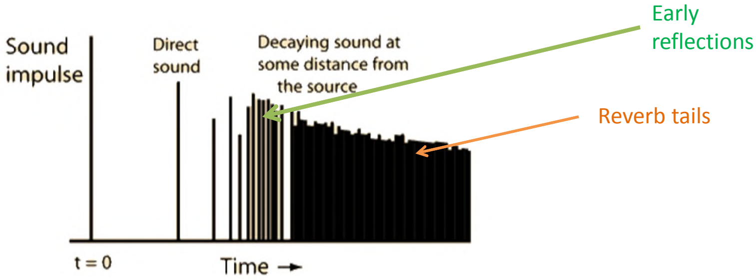
Speaker → transducer

Room → springs and plate

Microphone → transducer



# Adding reverb: digital




Easy: copy sound and add a little later → early reflections
But: reflections of reflections of reflections….
Computationally horrible! Algorithms to approximate tails.

# Adding reverb: convolution

Measure the *impulse response* of an **actual** acoustic space.

Microphones and sudden sound in a real space, e.g. Sydney Opera House or BandSoc Room.

Then “mix” the impulse response with dry sound source. Mathematical operation: **convolution**.