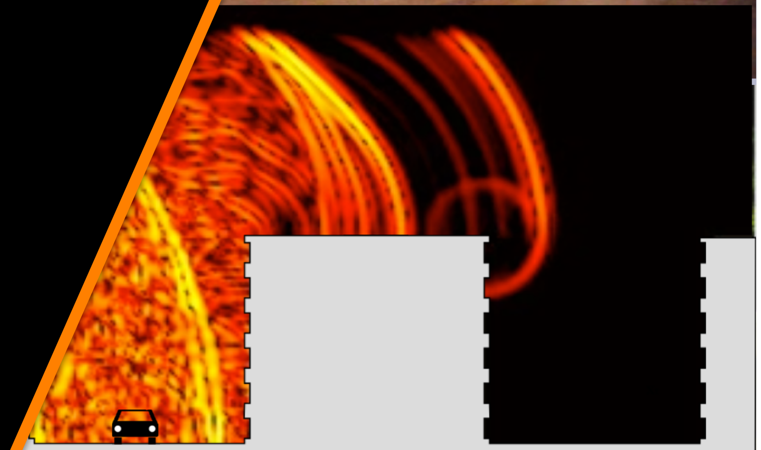
# Architectural Acoustics

**Week 1:** Fundamentals of Acoustics
Lecture F.1

prof.dr.ir. Maarten Hornikx



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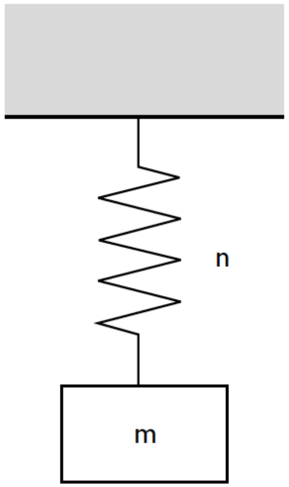
http://metaist.com

# Harmonic motion: example



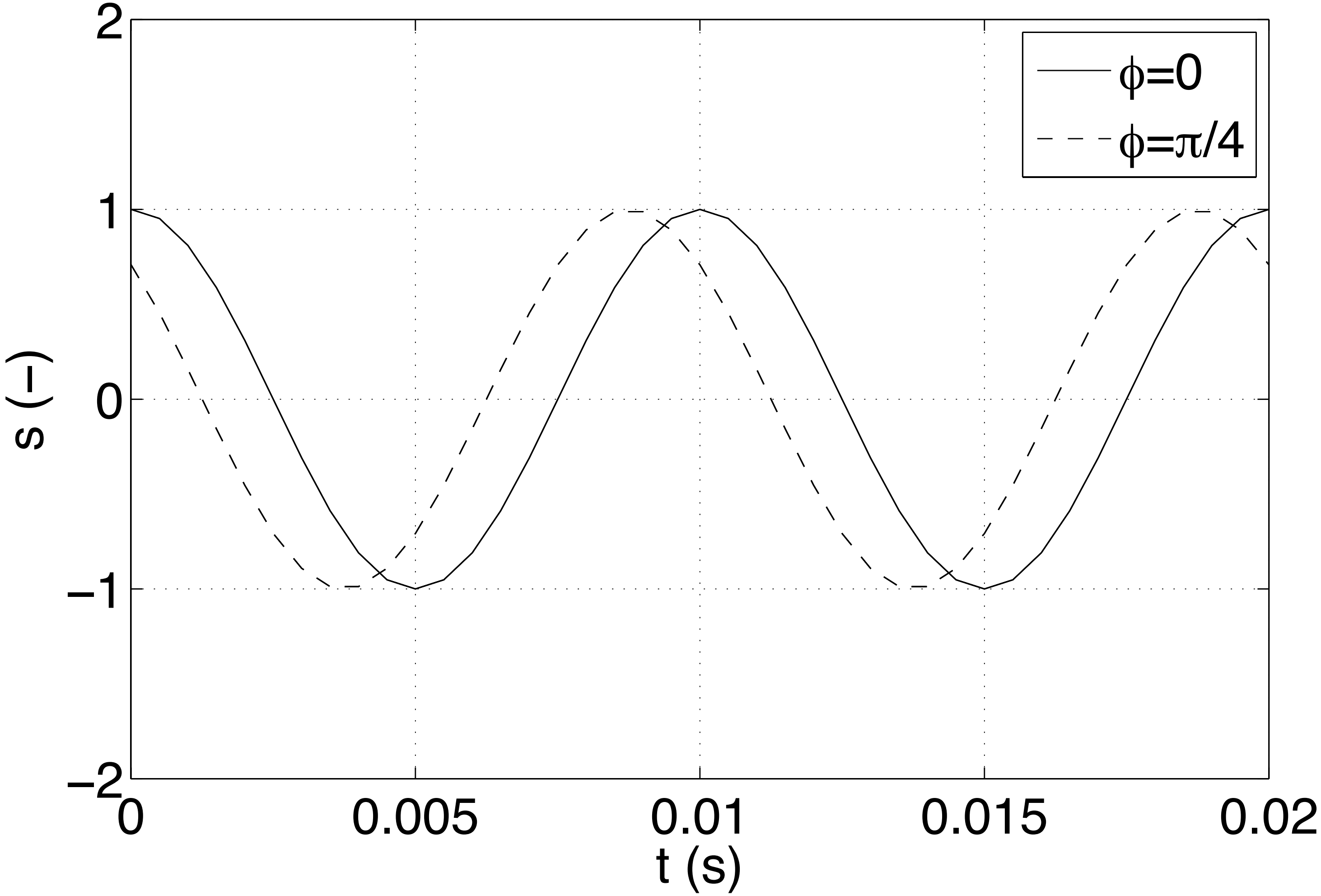

http://www.melfoamacoustics.com

# Harmonic motion

$$s(t) \quad = \quad \hat{s}\cos(\omega t + \phi)$$

| | |
|---|---|
| $s(t)$ | Displacement (m) |
| $\hat{s}$ | Displacement amplitude |
| $\omega$ | Angular frequency $\quad = \quad 2\pi f$ |
| $\phi$ | Phase shift |

# Harmonic motion



# Harmonic motion: time averaged signal

$$\langle s^2 \rangle = \frac{1}{t_0}\int_0^{t_0} [s(t)]^2 dt = \tilde{s}^2$$

$$\langle s^2 \rangle = \tilde{s}^2$$ Effective value

$$\tilde{s} = \hat{s}/\sqrt{2}$$ For harmonic signals

# Complex numbers

Easy way to compute amplitude (effective value) and phase of a harmonic signal

$$
\begin{aligned}
s(t) &= \hat{s}e^{j(\omega t+\phi)} \\
e^{jz} &= \cos(z) + j\sin(z)
\end{aligned}
$$

Physical signal is the real value of the complex signal, thus

$$\hat{s}\cos(\omega t + \phi)$$

# Complex numbers

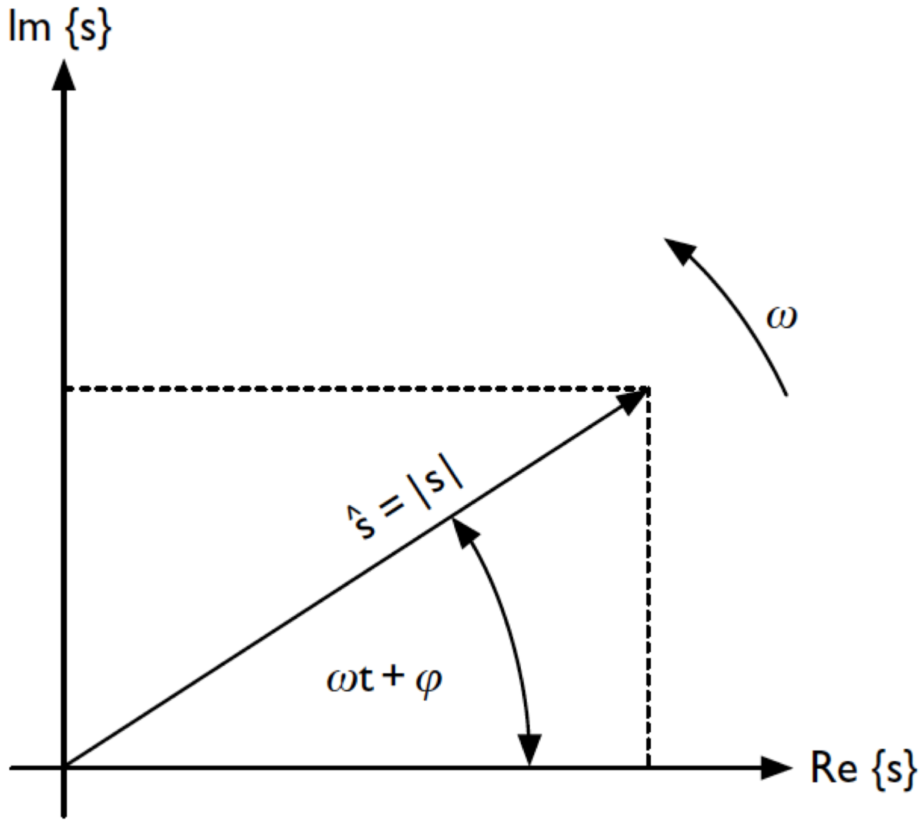



*Figure 2.4* Phasor representation of a harmonic oscillation.

Animation

Kuttruff, H. (2007). *Acoustics: an introduction*. CRC Press.

# Complex numbers

Absolute value of s (displacement amplitude)

$$
\begin{aligned}
|s(t)| &= \sqrt{Re\{s(t)\}^2 + Im\{s(t)\})^2} \\
&= \sqrt{Re\{\cos(\omega t + \phi)\}^2 + Im\{\sin(\omega t + \phi)\})^2}
\end{aligned}
$$

Argument of s

$$
\begin{aligned}
\angle s &= \operatorname{atan}\left(\frac{Im\{s(t)\}}{Re\{s(t)\}}\right) \qquad \text{for Im } \{s(t)\} > 0 \\
&= \pi + \operatorname{atan}\left(\frac{Im\{s(t)\}}{Re\{s(t)\}}\right) \qquad \text{for Im } \{s(t)\} < 0,\ Re\{s(t)\} > 0 \\
&= -\pi + \operatorname{atan}\left(\frac{Im\{s(t)\}}{Re\{s(t)\}}\right) \qquad \text{for Im } \{s(t)\} < 0,\ Re\{s(t)\} < 0
\end{aligned}
$$

# Beats

Example of calculating with complex numbers

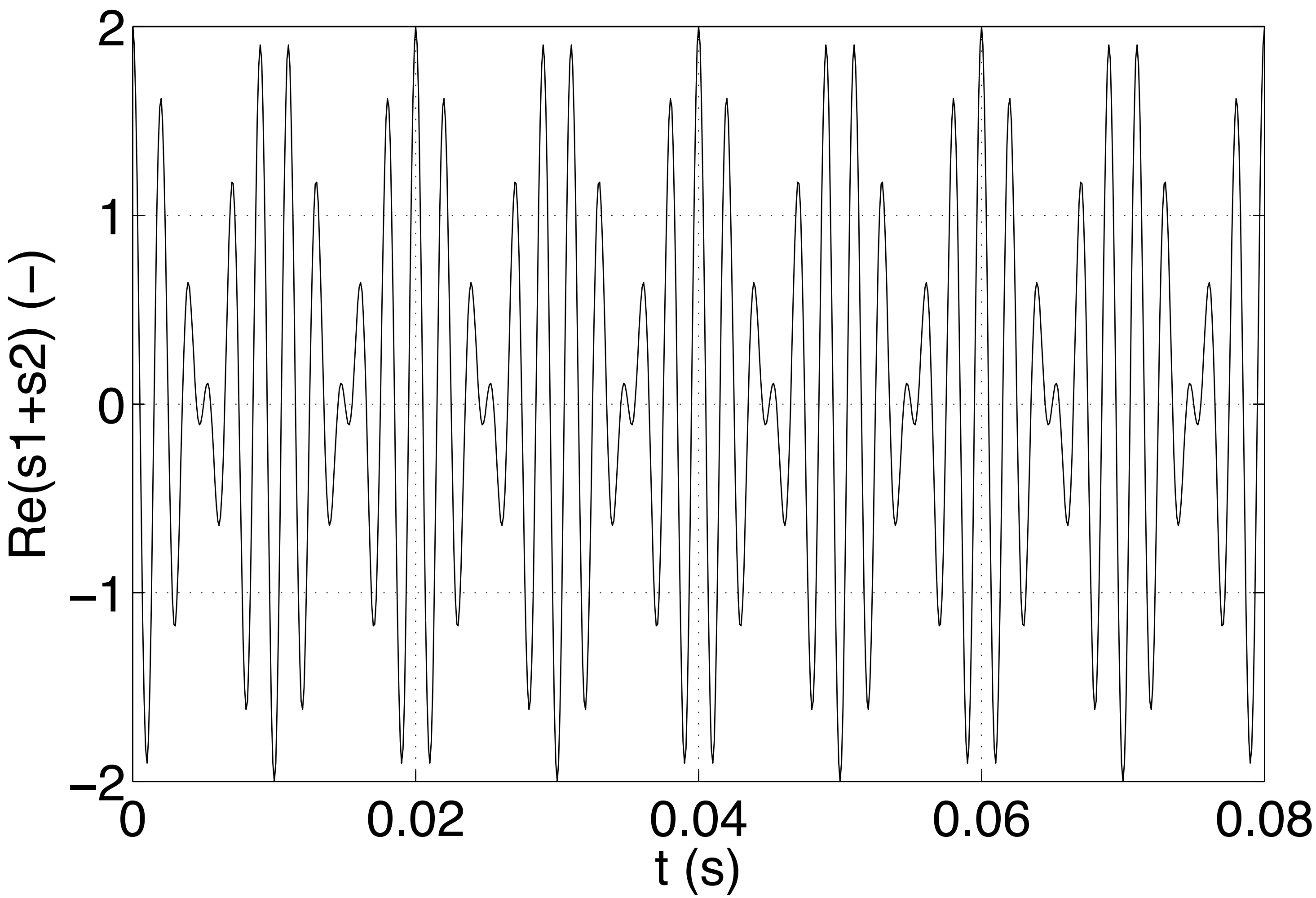
$$
\begin{aligned}
s_1(t) &= \hat{s}e^{j(\omega+\Delta\omega)t} \\
s_2(t) &= \hat{s}e^{j(\omega-\Delta\omega)t} \\
s_1 + s_2 &= \hat{s}\left(e^{-j\Delta\omega t} + e^{j\Delta\omega t}\right)e^{j\omega t} = 2\hat{s}\cos(\Delta\omega t)e^{j\omega t} \\
Re\{s_1 + s_2\} &= 2\hat{s}\cos(\Delta\omega t)\cos(\omega t)
\end{aligned}
$$

# Beats

S1 

S2 

S1+S2 



# Impedance

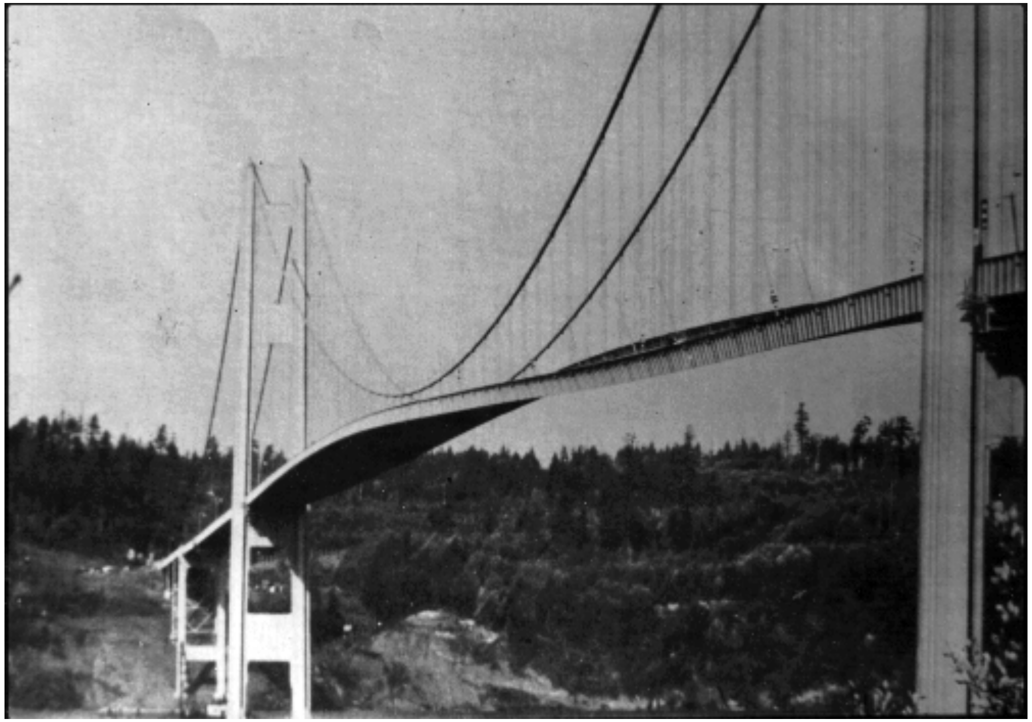
Resistance of a material against setting it into motion

$$
\begin{aligned}
Z &= \frac{F}{v} = \frac{\hat{F}}{\hat{v}} e^{j\phi} \\
F &= \hat{F} e^{j\omega t} \\
v &= \hat{v} e^{j(\omega t - \phi)}
\end{aligned}
$$

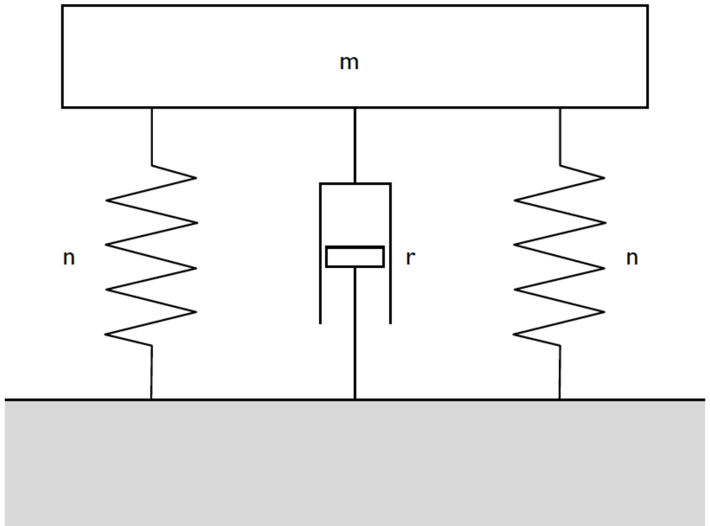
https://pediaa.com/difference-between-hardness-and-toughness/

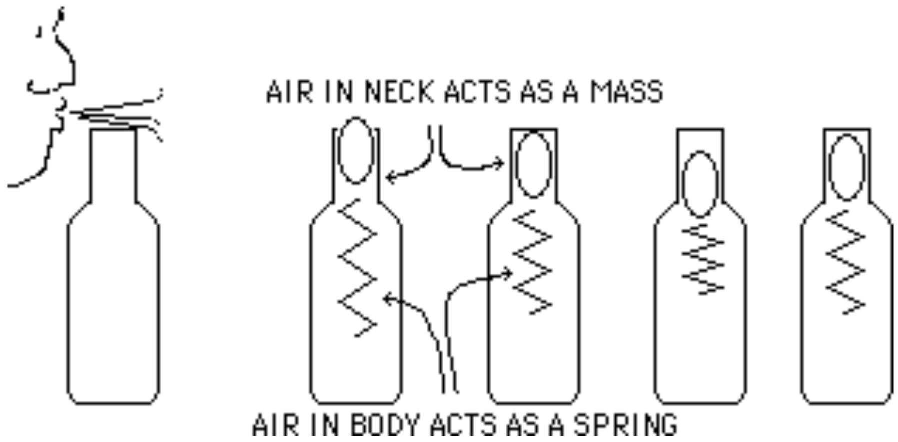
# Resonance

https://www.youtube.com/watch?v=XggxeuFDaDU



# Resonance




http://artsites.ucsc.edu

*Figure 2.6* Simple resonance system (m: mass, n: spring, r: mechanical resistance).

# Resonance

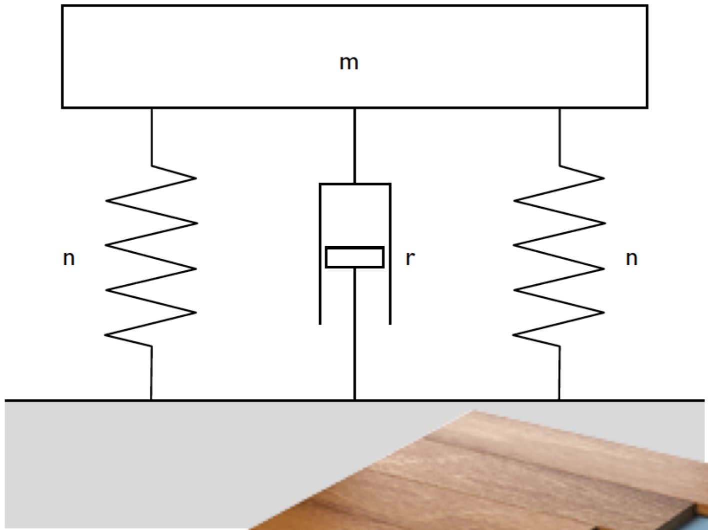
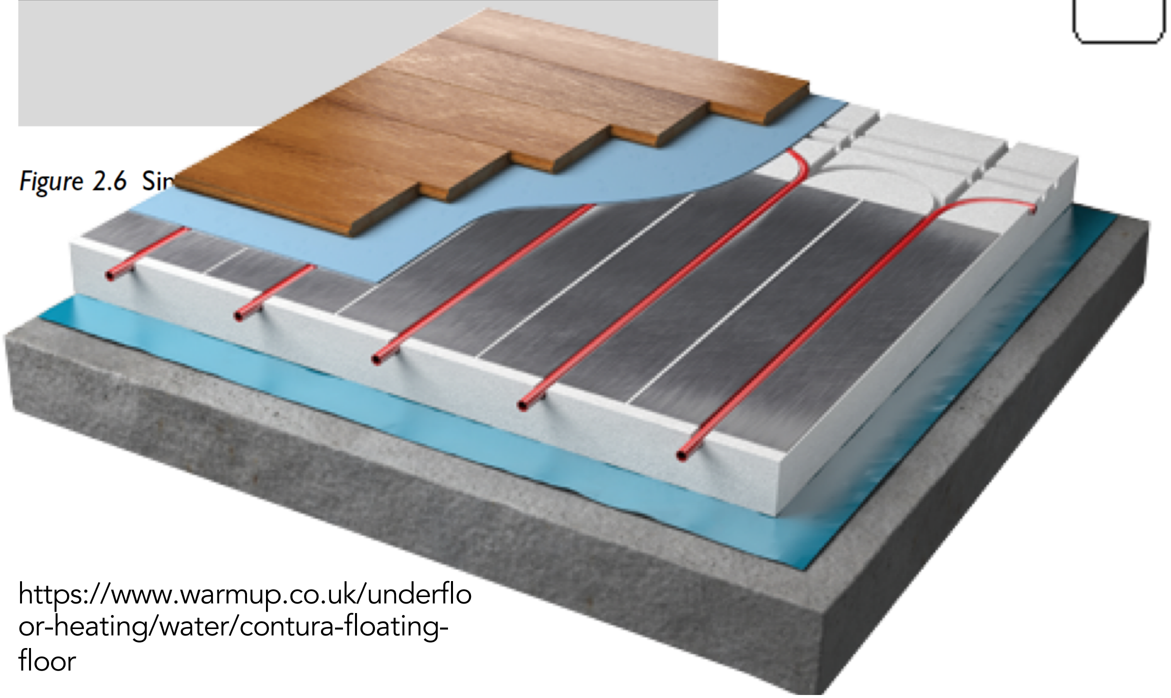
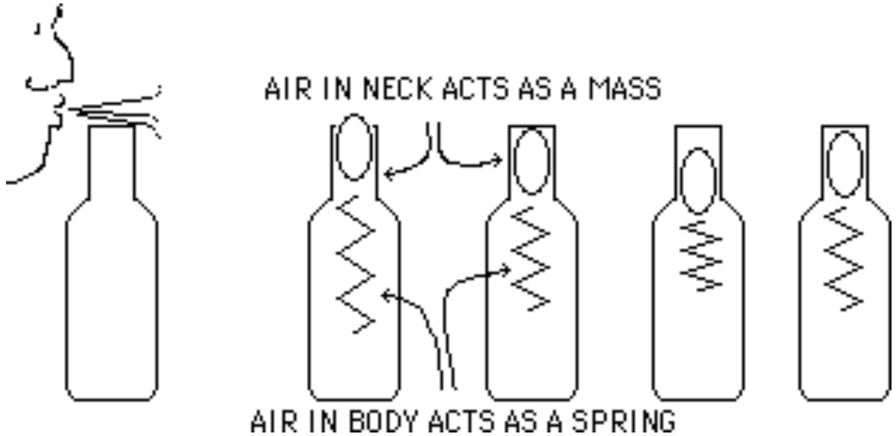



Figure 2.6 Si



https://www.warmup.co.uk/underfloor-heating/water/contura-floating-floor




http://artsites.ucsc.edu

# Resonance

$$Z_{mass-spring} = j\omega m + r + \frac{1}{j\omega n}$$

$$f_0 = \frac{1}{2\pi\sqrt{mn}}$$ Mass-spring resonance frequency