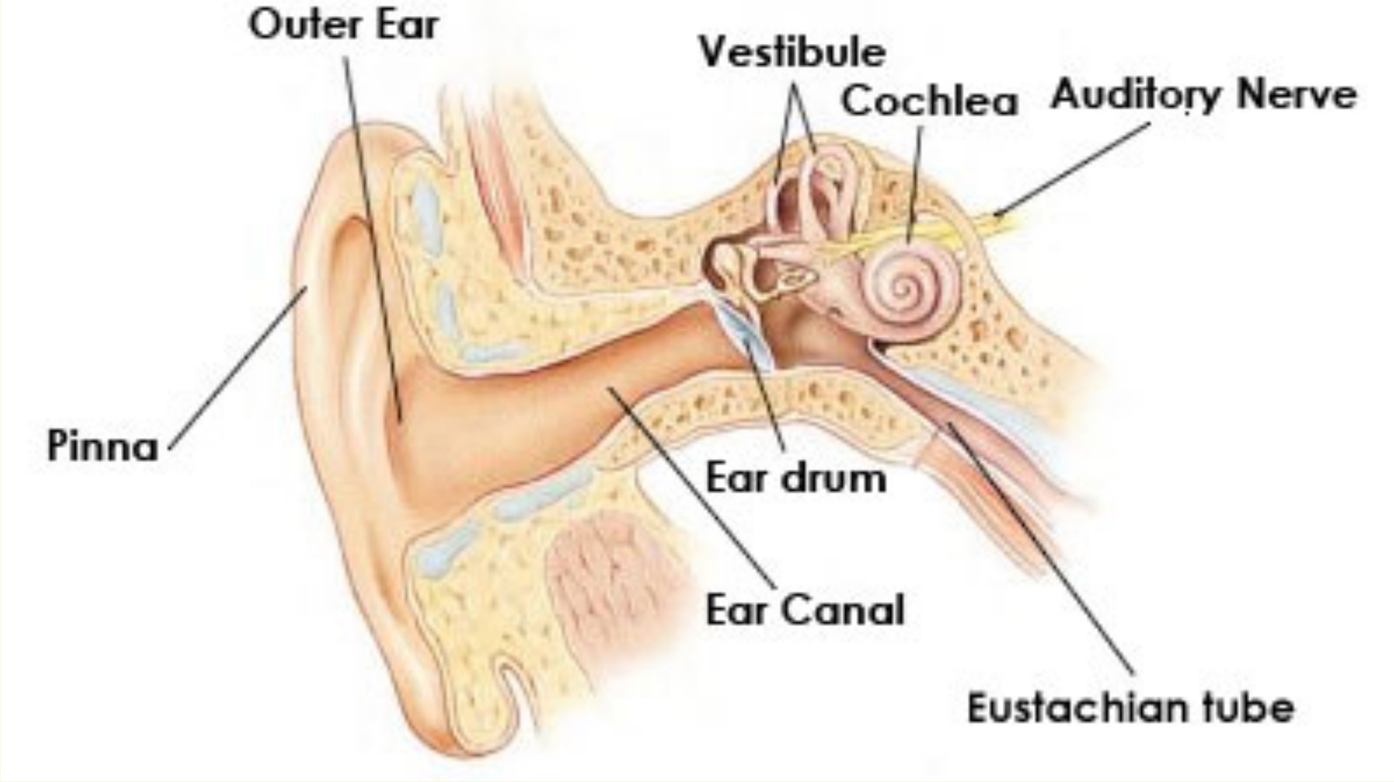
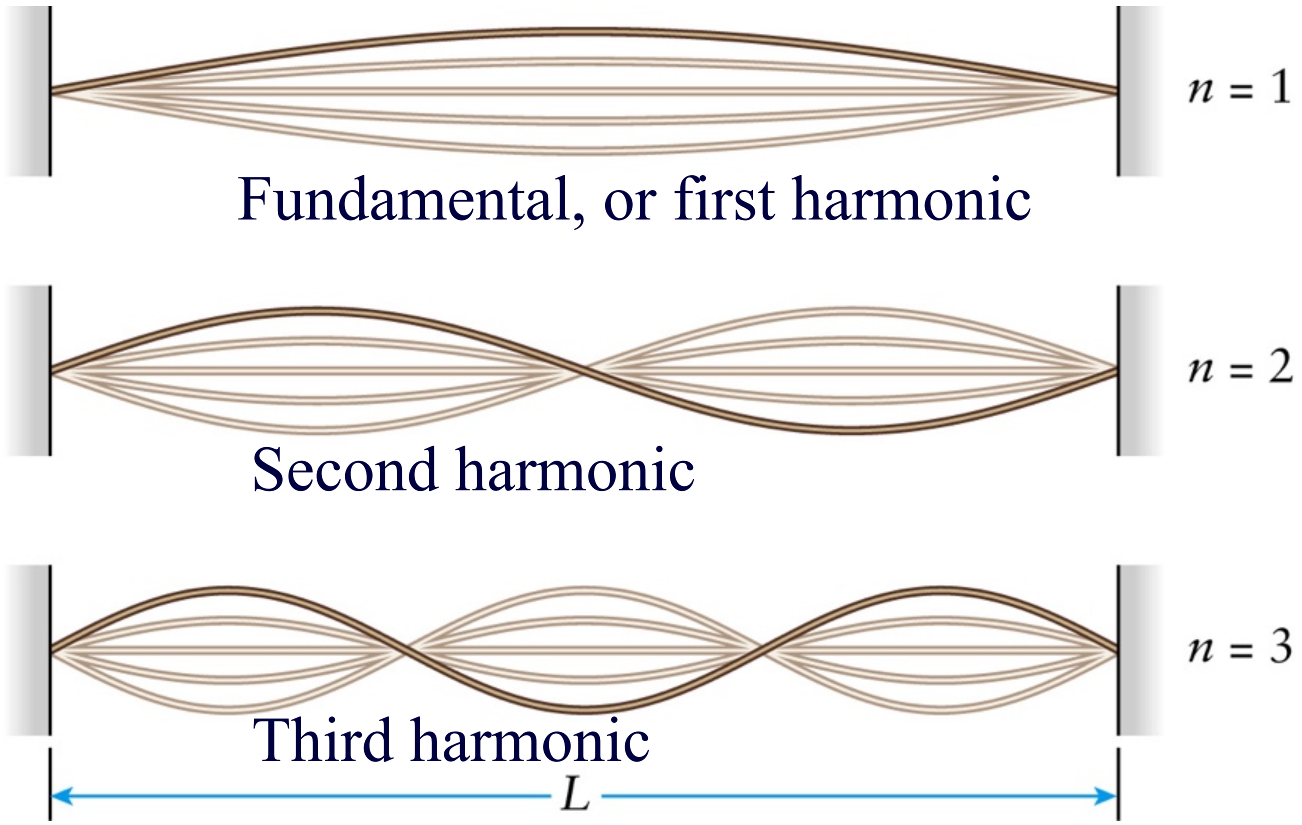
Physics 101: Lecture 23
Sound

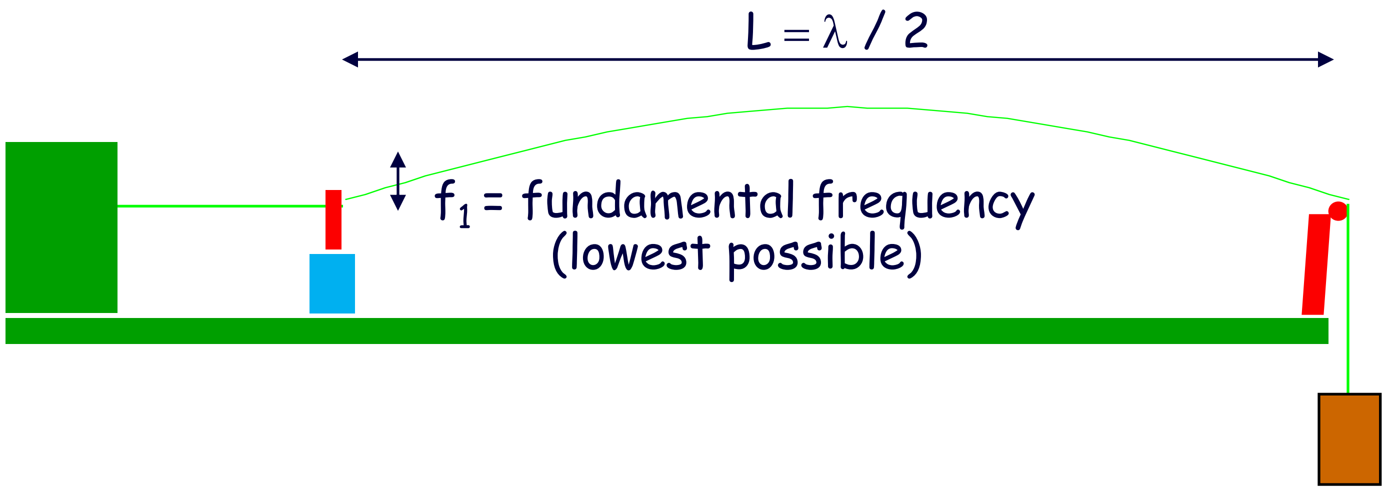


Standing Waves Fixed Endpoints

- Fundamental n=1 (2 nodes)
- $\lambda_n = 2L/n$
- $f_n = n\ v\ /\ (2L)$



Standing Waves Example



A guitar's E-string has a length of 65 cm and is stretched to a tension of 82N. If it vibrates with a fundamental frequency of 329.63 Hz, what is the mass of the string?

$$v = \sqrt{\frac{T}{\mu}}$$

f = v / λ tells us v if we know f (frequency) and λ (wavelength)

$v = \lambda\, f$
$= 2\ (0.65\ \text{m})\ (329.63\ \text{s}^{-1})$
$= 428.5\ \text{m/s}$

$v^2 = T / \mu$
$\mu = T / v^2$
$m = T\, L / v^2$
$= 82\ (0.65) / (428.5)^2$
$= 2.9 \times 10^{-4}\ \text{kg}$

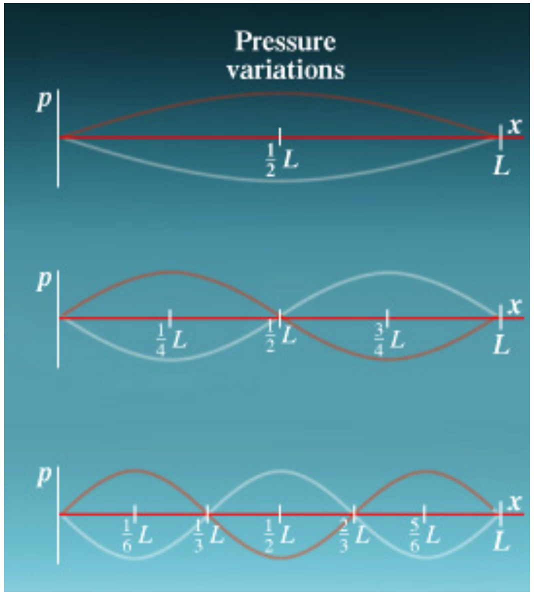
Standing Waves in Pipes

A pressure node is where pressure is normal (open to atmosphere)
NOTE: A pressure node corresponds to a displacement antinode and
A pressure antinode corresponds to a displacement node

Open at both ends:

Pressure Node at end

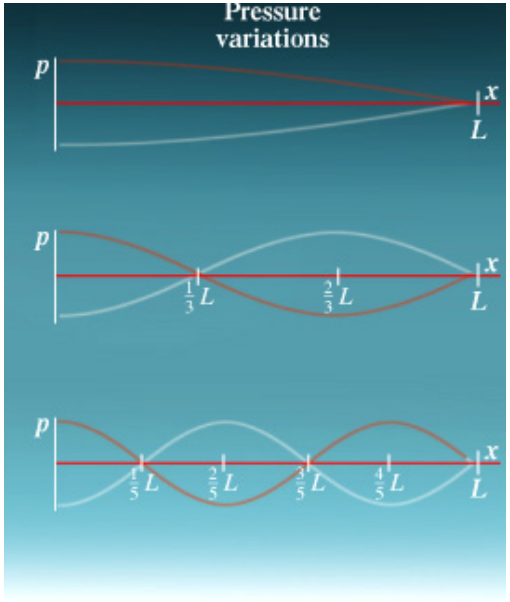
$\lambda = 2\,L / n \quad n=1,2,3..$



Open at one end:

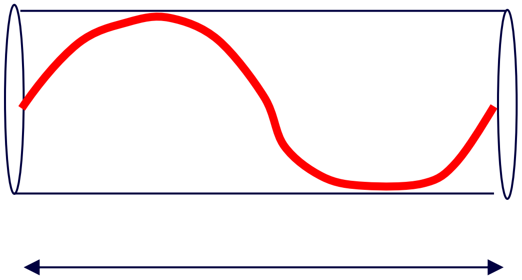
Pressure AntiNode at closed end : $\lambda = 4L/n$

n odd



Organ Pipe Standing Wave Example

A 0.9 m organ pipe (open at both ends) is measured to have its second harmonic at a frequency of 382 Hz. What is the speed of sound in the pipe?



Pressure Node at each end.

$\lambda = 2\ L / n \quad n=1,2,3..$

$\lambda = L$ for second harmonic ($n=2$)

$v = f\ \lambda = (382\ s^{-1})\ (0.9\ m)$

$= 343\ m/s$

Note: fundamental, n=1, has a wavelength of $\lambda = 2\ L$

Speed of Sound

- Recall for pulse on string: $v = \text{sqrt}(T/\mu)$
- For fluids: $v = \text{sqrt}(B/\rho)$

B = bulk modulus

Medium	Speed (m/s)
Air	343
Helium	972
Water	1500
Steel	5600

Intensity and Loudness

- Intensity is the power per unit area of a sound.
  - $I = Power / A$
  - Units: $(J/s)/m^2$ $(= Watts/m^2)$
- Loudness (Decibels): We hear "loudness" not intensity, and loudness is a logarithmic scale.
  - Loudness perception is logarithmic
  - Threshold for hearing $I_0 = 10^{-12}$ W/m^2 (corresponds to 0 dB)
  - Threshold for pain $I = 10^0$ $W/m^2 = 1$ W/m^2 (corresponds to 120 dB)

  This is a huge range of 12 orders of magnitude (12 powers of 10)
  - $\beta = (10 \text{ dB}) \log_{10} (I / I_0)$
  - $\beta_2 - \beta_1 = (10 \text{ dB}) \log_{10}(I_2/I_1)$

$\log_{10}$ Review

- $\log_{10}(1) = 0$
- $\log_{10}(10) = 1$
- $\log_{10}(100) = 2$
- $\log_{10}(1{,}000) = 3$
- $\log_{10}(10{,}000{,}000{,}000) = 10$
- $\log_{10}(2) = 0.3$

$\beta = (10\ \mathrm{dB}) \log_{10} (I / I_0)$

$\beta_2 - \beta_1 = (10\ \mathrm{dB}) \log_{10}(I_2/I_1)$

- $\log(ab) = \log(a) + \log(b)$
- $\log(a/b) = \log(a) - \log(b)$
- $\log_{10}(100) = \log_{10}(10) + \log_{10}(10) = 2$

Decibels Clicker Q

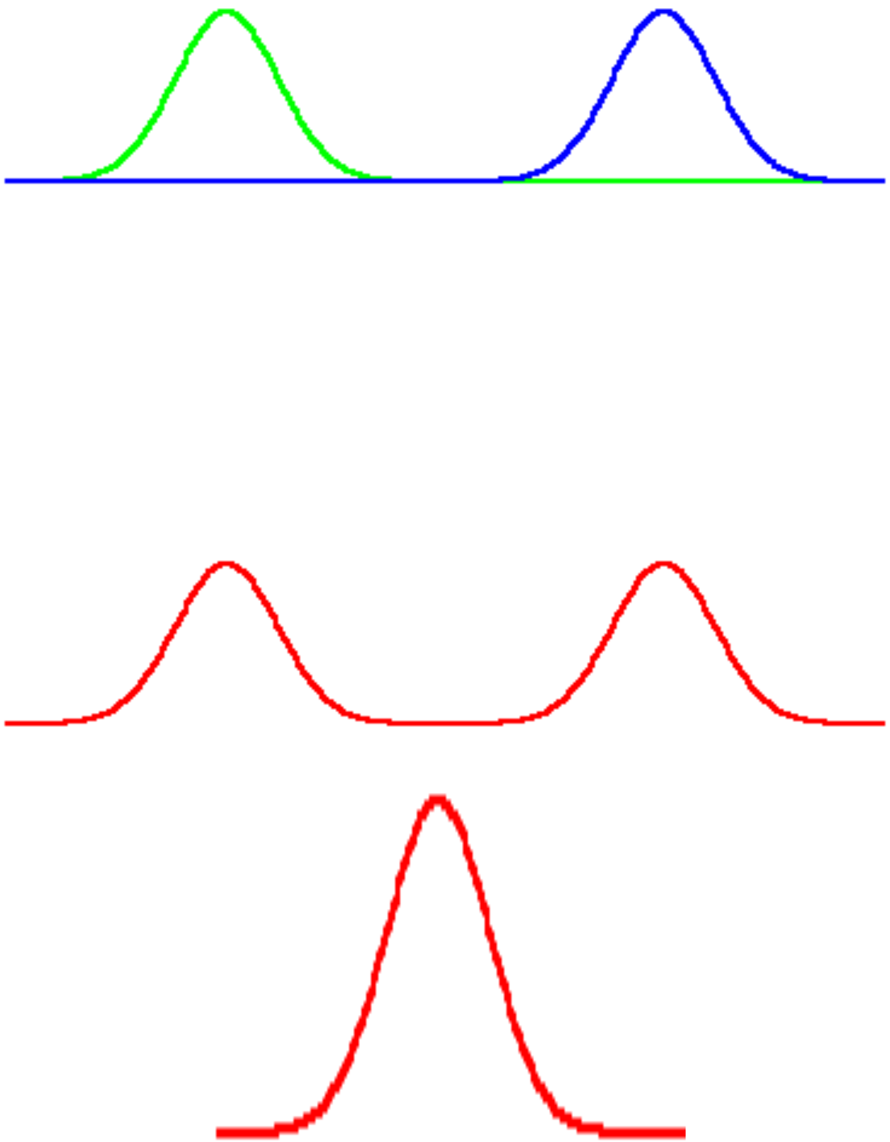
- If 1 person can shout with loudness 50 dB. How loud will it be when 100 people shout? Assume $I_{100} = 100I_1$

1) 52 dB 2) 70 dB 3) 150 dB

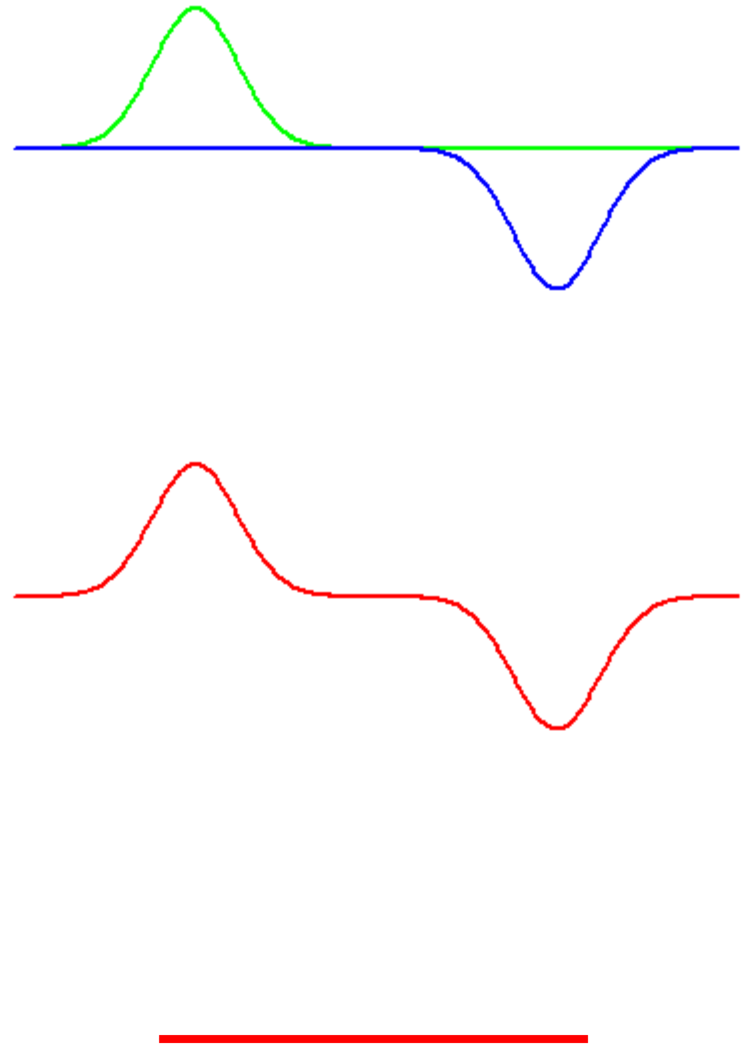
$$\beta_{100} - \beta_1 = (10\text{ dB}) \log_{10}(I_{100}/I_1)$$
$$= (10\text{ dB}) \log_{10}(100I_1/I_1)$$
$$\beta_{100} = \beta_1 + (10\text{ dB}) \log_{10}(100)$$
$$= 50\text{ dB} + (10\text{ dB})(2)$$
$$\beta_{100} = 50\text{ dB} + 20\text{ dB} = 70\text{ dB}$$

What if you had 2 shouters?

Interference and Superposition



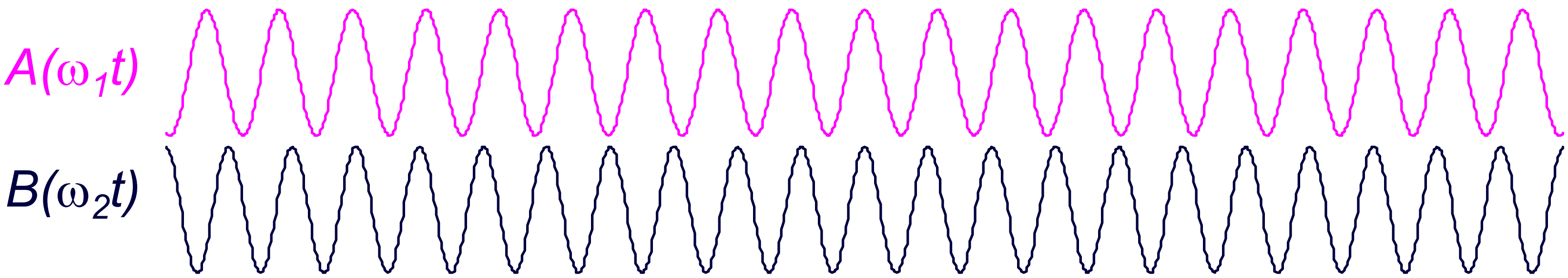
Constructive interference



Destructive interference

Superposition & Interference

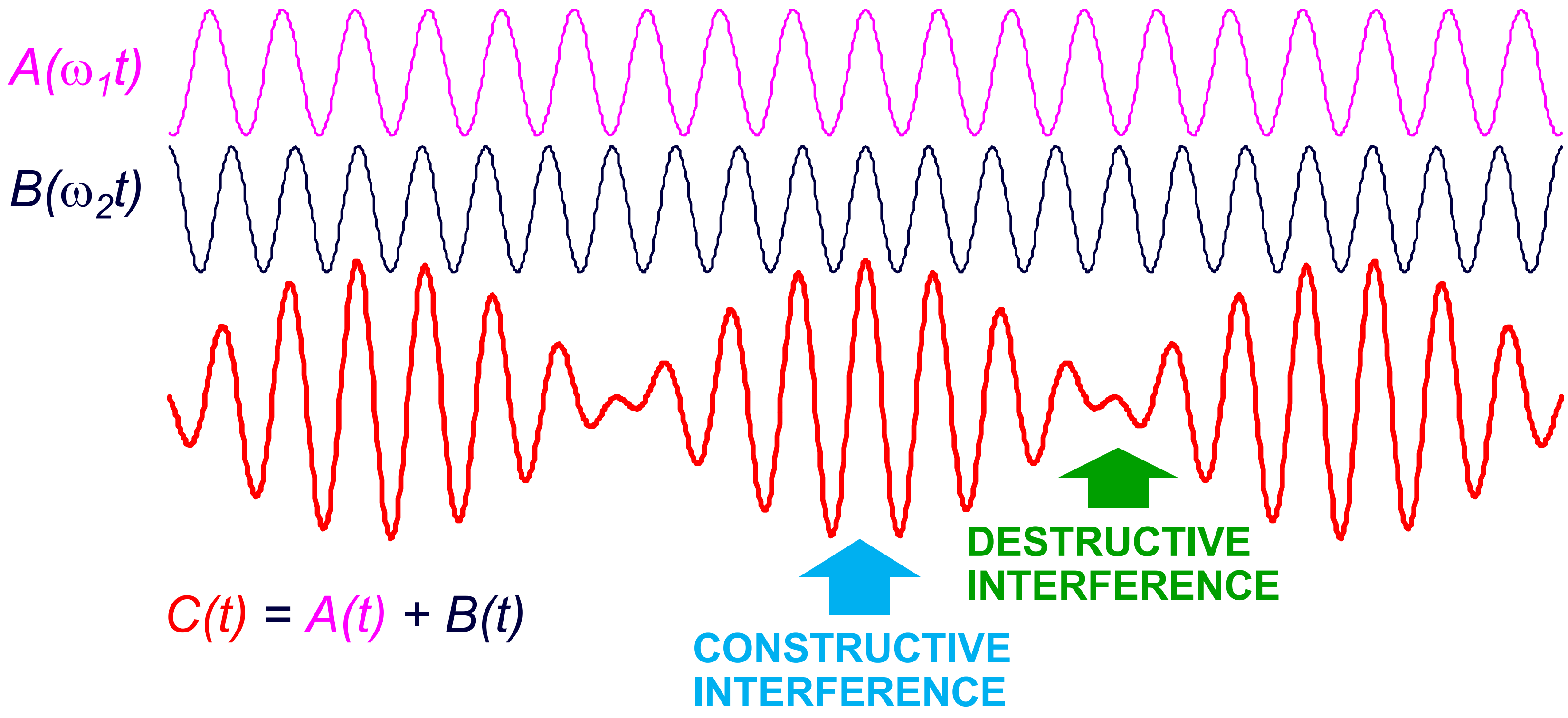
- Consider two harmonic waves *A* and *B* meeting at $x=0$.
  - ➡ Same amplitudes, but $\omega_2 = 1.15 \times \omega_1$.
- The displacement versus time for each is shown below:



What does $C(t) = A(t) + B(t)$ look like??

Superposition & Interference

- Consider two harmonic waves *A* and *B* meeting at $x=0$.
  - Same amplitudes, but $\omega_2 = 1.15 \times \omega_1$.
- The displacement versus time for each is shown below:

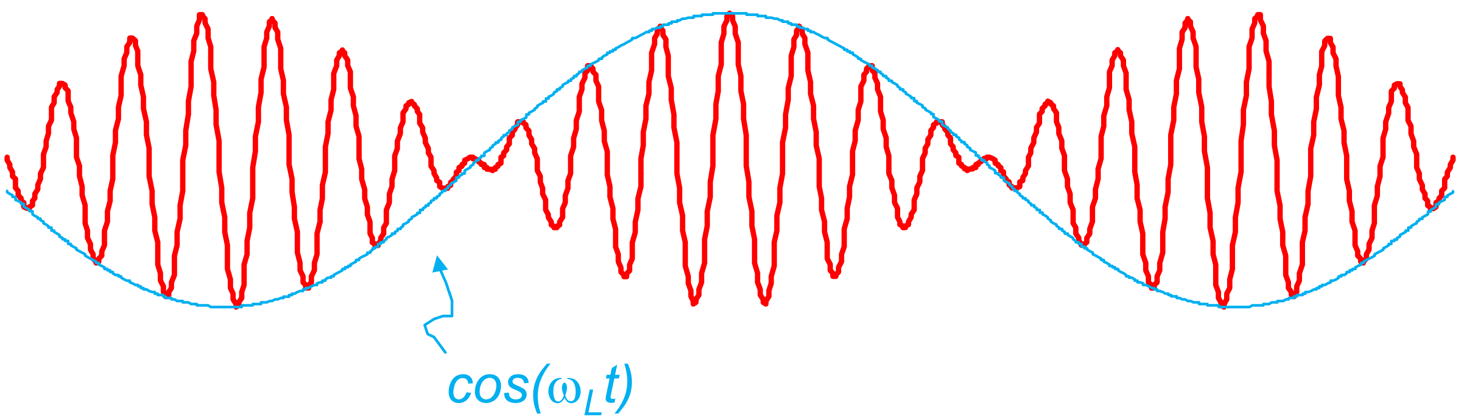


Beats

- Can we predict this pattern mathematically?
  - Of course!
- Just add two cosines and remember the identity:

$$A\cos(\omega_1 t) + A\cos(\omega_2 t) = 2A\cos(\omega_L t)\cos(\omega_H t)$$

where $\omega_L = \frac{1}{2}(\omega_1 - \omega_2)$ and $\omega_H = \frac{1}{2}(\omega_1 + \omega_2)$



Summary

- Speed of sound $v = \mathrm{sqrt}(B/\rho)$
- Intensity $\beta = (10\ \mathrm{dB})\ \log_{10}(I / I_0)$
- Standing Waves
- Beats $\omega_L = \frac{1}{2}(\omega_1 - \omega_2)$