Phys 111: Lecture 29

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The 29th Day: "Penultimate"

Today's Topics

1. Principle of Linear Superposition
2. Beats (not the Apple kind)
3. Complex Waves
4. Example Problems

Intensity Equations Recap

$$I = \frac{P}{A}$$

$$\beta = (10\ dB)\log\left(\frac{I}{I_o}\right)$$

$$I = I_o 10^b$$

$$b = \frac{\beta}{10\ dB}$$

Exercise #1

C&J 16.67 A listener doubles his distance from a source that emits sound uniformly in all directions. There are no reflections. By how many decibels does the sound intensity level change?

Exercise #1 Need to Know

C&J 16.67 Source emits sound spherically with no reflections so we can say

$$I = \frac{P}{4\pi r^2}$$

and we are going to want to use intensity level

$$\beta = (10\ dB)\log\left(\frac{I}{I_o}\right)$$

Exercise #1 Work

C&J 16.67 A listener doubles his distance from a source that emits sound uniformly in all directions. There are no reflections. By how many decibels does the sound intensity level change?

If distance doubles, then $r_1 = 2r_o$ is the only change that causes the change in intensity so

$$\frac{I_1}{I_o} = \frac{A_o}{A_1}$$

$$\frac{I_1}{I_o} = \frac{\pi r_o^2}{\pi (2r)^2}$$

$$\frac{I_1}{I_o} = \frac{1}{4}$$

Exercise #1 Answers

C&J 16.67 Therefore

$$\beta_1 = (10\ dB)\log\left(\frac{1}{4}\right)$$

Since I chose the initial intensity to be my reference then

$$\beta_o = 0.$$

Regardless of the choice of reference the difference in intensity level will be equal to

$$\beta = -6.00\ dB.$$

Doppler Effect Summary

Summary for simple cases

- Moving towards then frequency observed higher
- Moving away then frequency observed lower

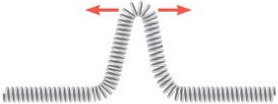
Both effects apply when both move and all cases equations can be summarized with

$$f_o = f_s\left(\frac{1 \pm \frac{v_o}{v}}{1 \mp \frac{v_s}{v}}\right)$$

Slinky Example of Linear Superposition 1

Consider the two constructive input waves traveling through one medium.

(a) Overlap begins



(b) Total overlap; the Slinky has twice the height of either pulse

(c) The receding pulses

Figure: 28.9 Linear wave inputs[9]

[9] C&J Figure 17.01

Slinky Example of Linear Superposition 2

Now consider the two destructive input waves traveling.

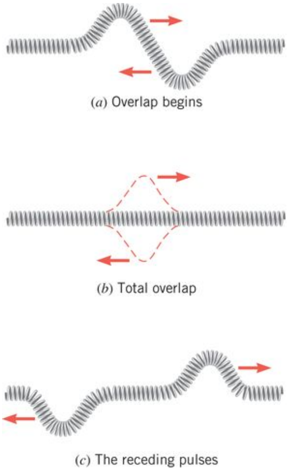


Figure: 28.10 Superpositional combination[10]

[10] C&J Figure 17.02

Formal Statement about Superposition

Principle of Linear Superposition: When two or more waves are present simultaneously at the same place, the resultant disturbance is the sum of the disturbances from the individual waves.

This principle can be applied to all types of waves.

Constructive Interference

When the waves superpose to solely increase an effect, we say they constructively interfere.

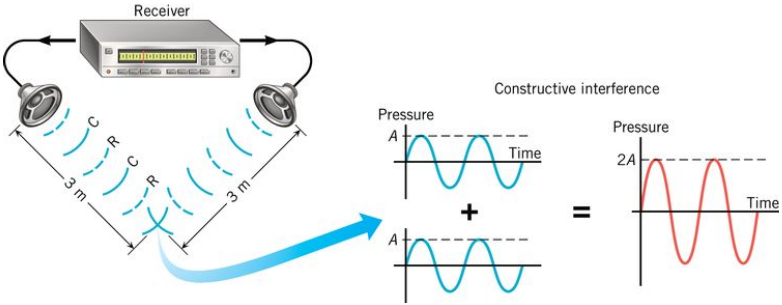


Figure: 28.11 Constructively interfering sound[11]

[11] C&J Figure 17.03

Destructive Interference

When the waves superpose to completely cancel, we say they destructively interfere.

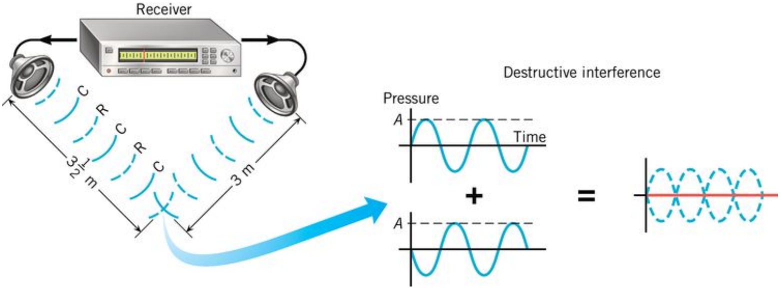


Figure: 28.12 Constructively interfering sound[12]

[12] C&J Figure 17.04

Special Case of Interference: Beats[15]

No, not the headphone company Apple acquired a few years ago!

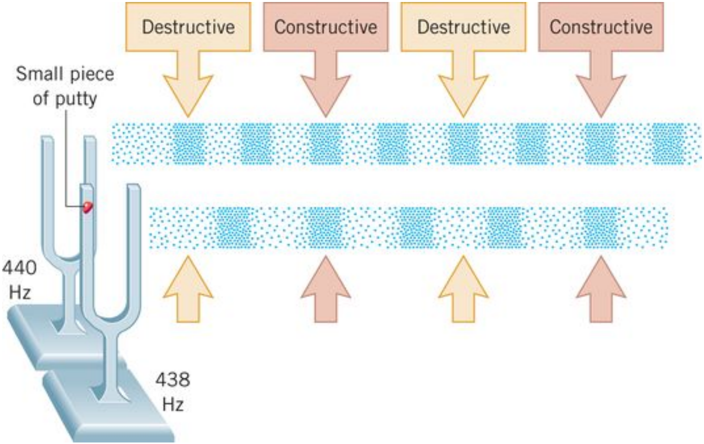


Figure: 28.14 Beats by tuning fork[14]

[14] C&J Figure 17.13

[15] https://www.youtube.com/watch?v=V8W4Djz6jnY

Beats Graphs & Examples

Ideal data for beats and another link[17].

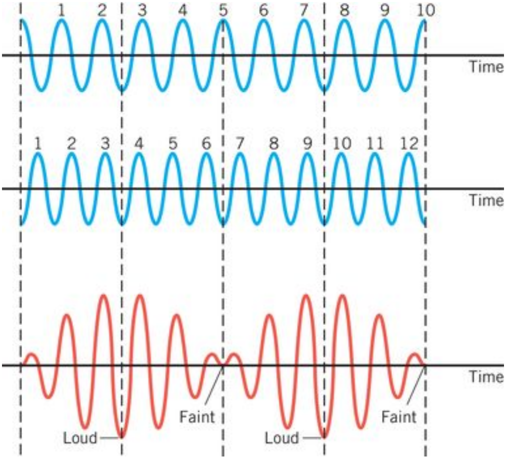


Figure: 28.16 Beats by tuning fork[16]

[16] C&J Figure 17.14

[17] `https://www.youtube.com/watch?v=I9f6bP3x_yo`

Exercise #2

C&J 17.21 A $440.0\ Hz$ tuning fork is sounded together with an out-of-tune guitar string, and a beat frequency of $3\ Hz$ is heard. When the string is tightened, the frequency at which it vibrates increases, and the beat frequency is heard to decrease. What was the original frequency of the guitar string?

C&J 17.21 A $440.0\ Hz$ tuning fork is sounded together with an out-of-tune guitar string, and a beat frequency of $3\ Hz$ is heard.

When the frequency of the guitar increases and the beat frequency decreases that must mean that the string's frequency was $3\ Hz$ less than the frequency of the tuning fork, not higher.

$$f_o = 437.0\ Hz$$

C&J 17.19 Two pure tones are sounded together. The drawing shows the pressure variations of the two sound waves, measured with respect to atmospheric pressure. What is the beat frequency?

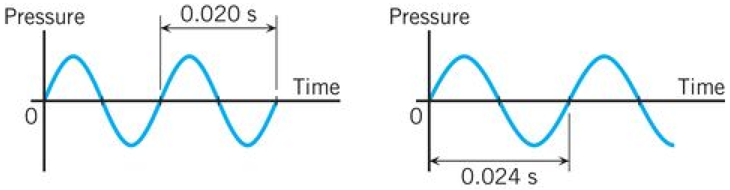


Figure: 29.0 Data for problem 17.04.19[0]

[0]C&J Fig 17.04.19

Exercise #3 Explanation

C&J 17.19 Beats or beat frequencies are based on the difference in **frequency** of the interacting source waves so it's important that we calculate individual frequencies first and then subtract them!

$$f = \frac{1}{T}$$

Therefore our data can be reexpressed as

$$f_1 = 42\ Hz$$

$$f_2 = 50\ Hz$$

Now it's clear that the beat frequency is

$$f_b = 8\ Hz.$$

Summary

Sound

- Intensity level β rated in decibels dB
- Doppler effect has equations shown in previous slides
- Beats used to tune musical instruments

All Waves

- Intensity I is power P passing perpendicularly through an area A
- Intensity often compared to a reference
- Different Doppler effects for wave types and conditions
- Beats used for calibration and other measurements
- have interference patterns based on many factors

Please read[18] C&J 17.5-7 and prepare for the final exam.

[18] http://hyperphysics.phy-astr.gsu.edu/hbase/Audio/fourier.html

Let's discuss part of what a spectrum analyzer does!

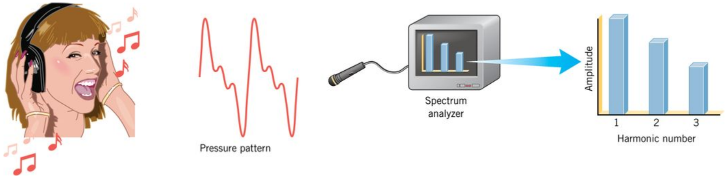


Figure: 29.1 Wave Spectrum Analysis Intro[1]

[1] C&J Fig 17.24

3 Wave Combination

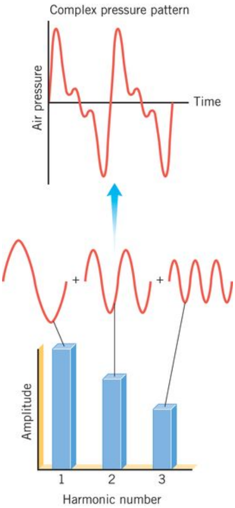


Figure: 29.2 Wave Analysis with 3 frequencies[2]

[2] C&J Fig 17.23

3 Hz Sawtooth Wave

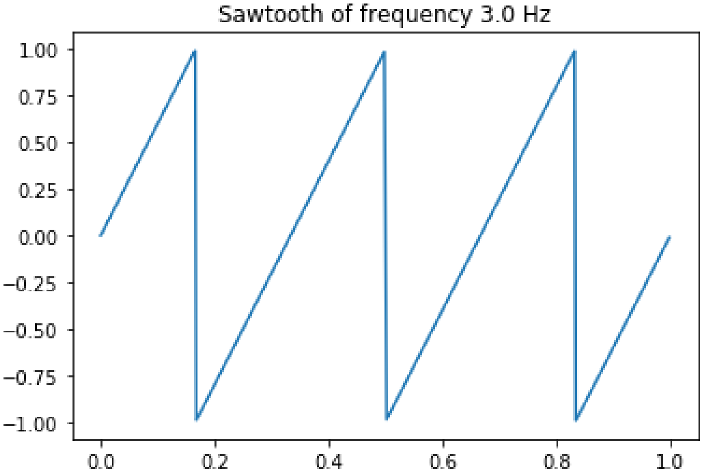


Figure: 29.3 3 Hz Sawtooth Wave Approximation

First Harmonic

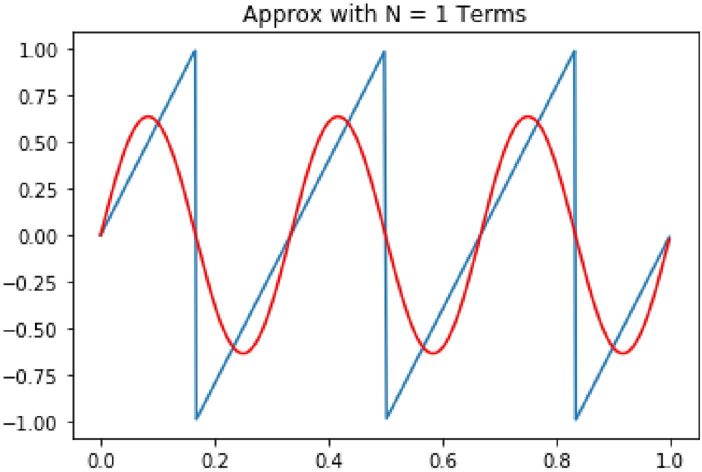


Figure: 29.4 3 Hz sawtooth wave first harmonic

Second Harmonic Added

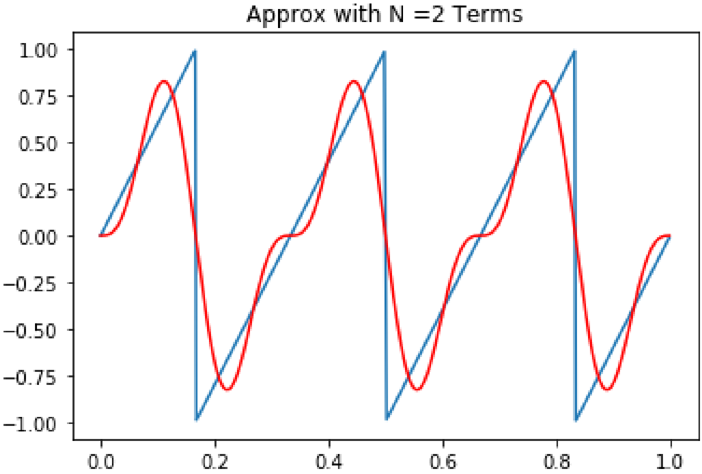


Figure: 29.5 3 Hz sawtooth wave second harmonic

Third Harmonic Added

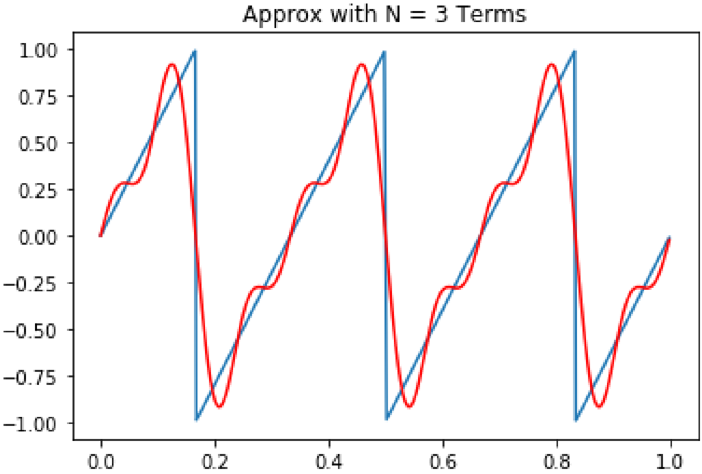


Figure: 29.6 3 Hz sawtooth wave second harmonic

Fourier's Sum

How did I make those plots?

Well it turns out that any wave can be approximated by a linear superposition of harmonic waves!

Fourier Series:

$$y(x) \approx \frac{a_o}{2} + \sum_{n=1}^{N} \left[a_n \cos\left(2\pi(nf)x\right) + b_n \sin\left(2\pi(nf)x\right) \right]$$

a_o and the a_n and b_n must be generated for the particular function y that quantifies the total wave being analyzed and nf signifies a multiple of the harmonic frequency f.