

More on phase cancellation

## The equations again

- Wavelength of a given frequency

$$\text{wavelength} = \frac{\text{velocity}}{\text{frequency}} \quad \lambda = \frac{v}{f} \quad ft = \frac{ft/sec}{\text{waves/sec}} \quad ft = \frac{ft/sec}{Hz}$$

- Frequency of a given wavelength

$$f = \frac{v}{\lambda} \quad \text{frequency} = \frac{\text{velocity}}{\text{wavelength}} \quad Hz = \frac{ft/sec}{ft} = \frac{1}{sec}$$

- These are all equivalent statements – just rearrangements of the same basic equation. When frequency increases, wavelength decreases, and vice versa.

## More equations

- The relationship between frequency and period (the time it takes for one wave cycle to complete)

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

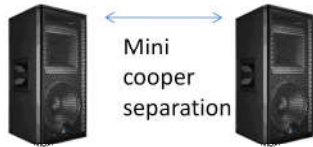
$$\text{period} = \frac{1}{\text{frequency}}$$

$$\text{sec} = \frac{1}{\text{sec}^{-1}} = \frac{1}{\text{Hz}}$$

- More waves per unit time means less time per wave.

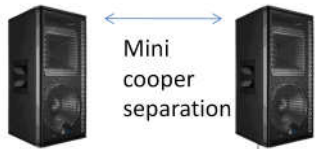
Period is important when calculating delays. If two speakers are offset by a mini cooper, they are offset by 10 milliseconds (thousandths of a second). 20 milliseconds is the period of 50 Hz, which is where the first 180 degree offset occurs in the following example, causing complete cancellation. In the example, if we wanted to fix the comb filter, we would apply a 10 millisecond (ms) delay to the second speaker, making it produce sound 10 ms after the first speaker. That way, when the sound from the first speaker arrives at the second speaker, it starts bumpin'. The two speakers now fire in time with each other, and the comb filter goes away.

## Example 1 – finding the first $180^\circ$ phase cancellation in a comb filter

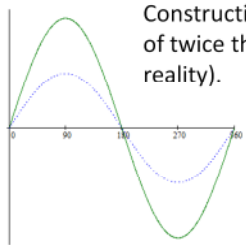
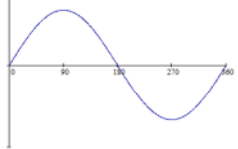
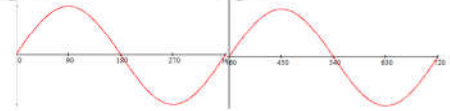


Two speakers are separated by 11 feet.  
They are transmitting identical sound waves.

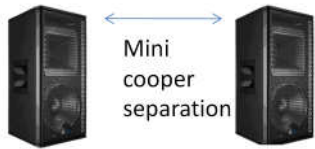
11 feet is about 360 degrees of a 100 Hz wave.



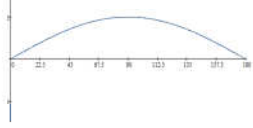
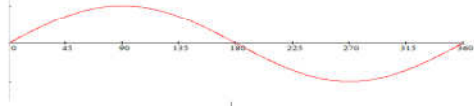
The wave from the first speaker will meet the wave from the second speaker at the same point in the 100 HZ wave cycle.



Constructive interference gives us a wave of twice the amplitude (somewhat less in reality).

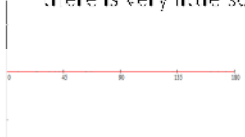


11 feet represents only 180 degrees of a 50 Hz wave (which has a wavelength of about 22 feet)

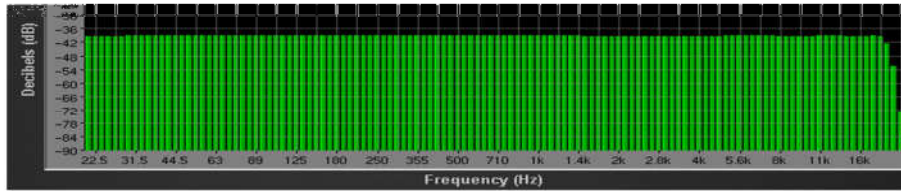


The wave from the second speaker is 180 degrees out of phase with the first speaker, which has the same effect of a polarity reversal (but only at this frequency).

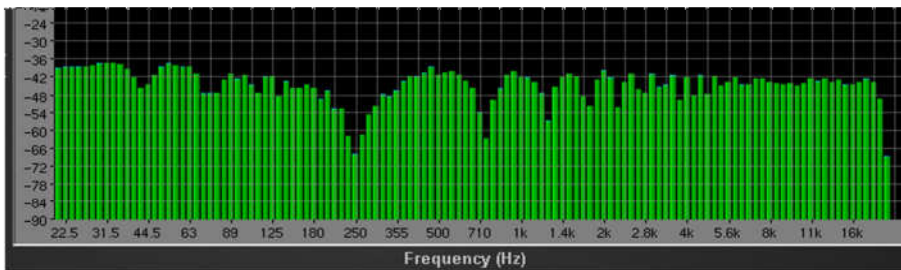
Destructive interference takes place and there is very little sound at 50 Hz



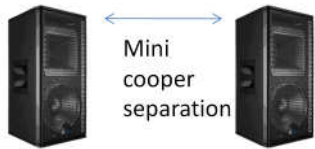
## Interference at higher frequencies in a comb filter



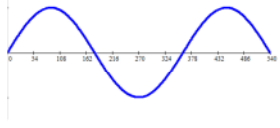
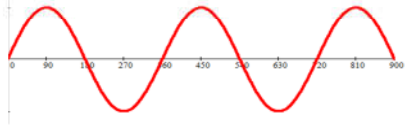
Obviously the frequency where the first 180-degree shift isn't the only frequency with cancellation. Why?



This isn't the spectrum that would result from the example above; my trial license on the measurement software has just run out and I made this for a different scenario – The first 180 degree cancellation occurs at 250 Hz in this example. Can you tell me how far apart the speakers are (assuming 1100 ft/sec sound speed)? Can you tell me how far apart they are in time?



Destructive interference takes place when two waves are 540 degrees out of phase.



Destructive interference takes place and there is very little sound at 150 Hz as well

## The final result

- Frequencies that are multiples of the lowest frequency where a single complete wavelength is equal to the separation add.
- So 100 Hz, 200 Hz, 300, 400 Hz and so on add
- Frequencies that are multiples of the lowest frequency with 180 degrees of offset (half the frequency of the first constructive interference) subtract.
- 50, 150, 250, 350, 450, ... Hz will cancel

My apologies – I had the stuff in red wrong during the lecture – wrong multiples.

## What happens in between?

- Refer to your phase wheel handouts. I'll check with Meyer and see if they're ok with me posting it online. You're welcome to use this handout on the quizzes and final.
- As you move higher in frequency, due to the logarithmic frequency perception of your hearing, the dips and peaks happen closer together.

The stuff in red was added just before posting. We're going to cover logarithmic scales on Monday, but the take-home message is this: the further apart your sound sources are (or the longer your delay), the more severely your sound is affected.