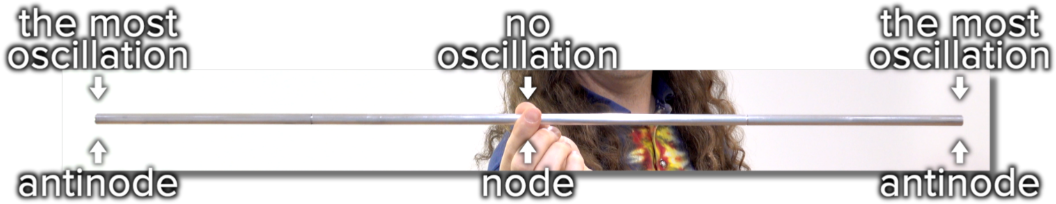
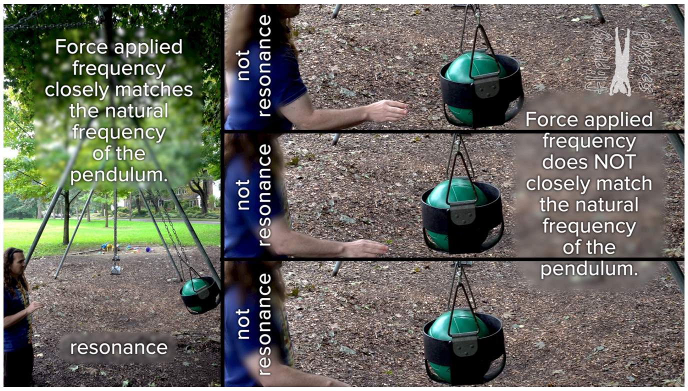
Flipping Physics Lecture Notes:
Resonance Introduction using 9 Demonstrations
https://www.flippingphysics.com/resonance.html
(really, you need to see and hear these demonstrations)

Resonance involves standing wave patterns. So, if you have not learned about standing waves, please enjoy my video about standing waves.[1]

The first example is called a "Singing Rod". The vibration of the friction between my fingers and the aluminum rod set up a standing wave in the rod at its "resonance frequency" or its "natural frequency". My fingers in the middle force a node at that point, and the two ends have their maximum amplitude vibration and are therefore antinodes.

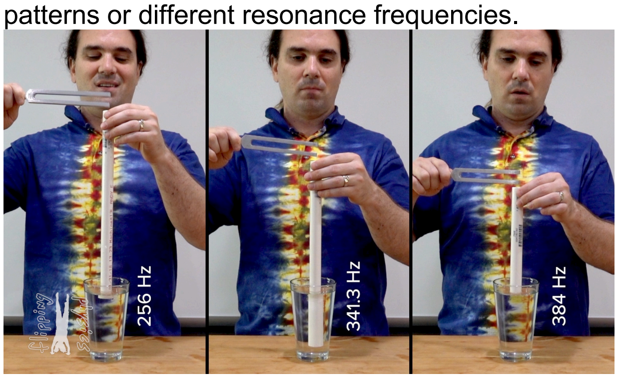


The second example is a swing. A swing is a pendulum which has a natural frequency of oscillation. If I apply a force to the swing at a frequency which closely matches the natural frequency of the pendulum, the force will amplify the oscillations. If I apply a force to the swing at a frequency which **does not** closely match the natural frequency of the pendulum, the force will **not** amplify the oscillations.



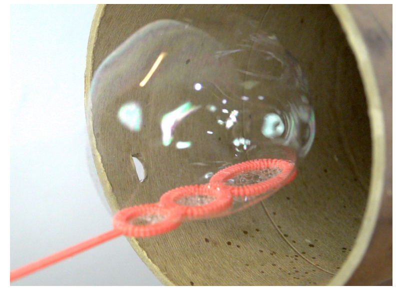
The third example is a goblet. Rubbing a damp finger along the rim of a goblet will cause standing wave patterns in the goblet which is the goblet vibrating at its resonance frequency. Adjusting the amount of water in the goblet will change the resonance frequency of the goblet.

The fourth example uses a tuning fork to oscillate a column of air inside a hollow tube. The water at the bottom of the hollow tube seals of that end of the tube. Therefore, moving the tube up and down adjusts the amount of the tube which is out of the water and therefore adjust the length of the air column inside the tube. Different air column lengths will have standing wave patterns or different resonance frequencies.



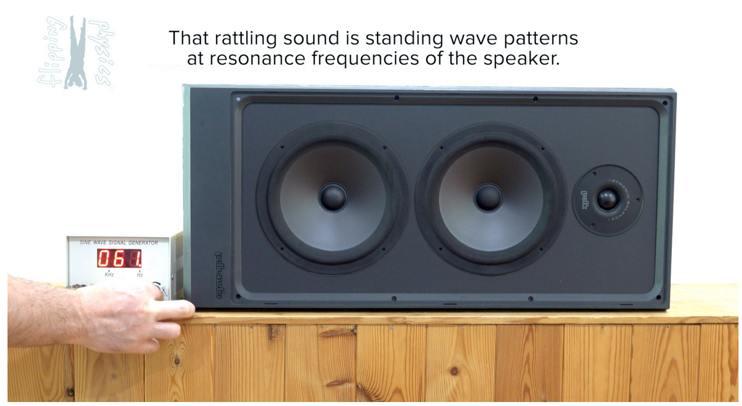
[1] "Standing Waves" video from Flipping Physics: https://www.flippingphysics.com/standing-waves.html

The fifth example uses a fixed length hollow tube which is open at both ends and speaker to adjust the sinusoidal frequency at which the speaker oscillates. At 68 hertz, a standing wave pattern is setup in the air column in the hollow tube which is a resonance frequency for this length hollow tube open at both ends. A soap bubble is used to show that the air is oscillating at the end of the tube.



The sixth example is a seashell. When you listen to a seashell, what you hear is various frequencies from the ambient noise setting up standing waves in the seashell at resonance frequencies for the air column inside the seashell. And the frequencies which do not match the resonance frequencies in the air column in the seashell are dampened. That results in an echoey sound some people call “The sound of the sea”.

The seventh example is a speaker which was dropped too many times and now has unidentified items which are loose and causing resonance in the speaker. This is not ideal for a speaker. This particular speaker has resonance frequencies below roughly 120 Hz. Above that frequency there appear to be no resonance frequencies in the speaker. In other words, do not drop your speakers, duh!



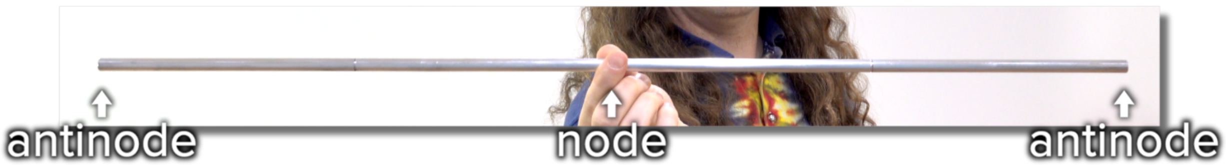
The eighth example is of resonance of the human body using a key fob. When I hold the key fob away from my body and I press the button, it sends out radio waves, and those radio waves should reach the car to lock and unlock the car, but unfortunately I am just a little bit too far away for that to work. What I can do instead is I can hold the key fob to my body, when I do so I can now lock and unlock the car. The radio waves which are sent out by the key fob have a wavelength and frequency which approximately match a resonance frequency and wavelength of my body, and therefore set up a standing wave pattern in my body which amplifies the signal and makes it so the signal can reach the car. The frequency used by key fobs for North American made vehicles is:

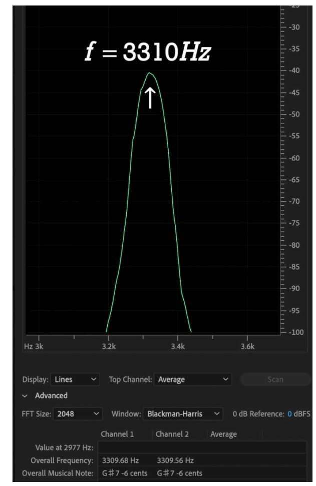
$$f_{fob} = 315MHz = 315\times10^{6}Hz$$

And radio waves are electromagnetic radiation which move at the speed of light: $v_{radiowaves} = c = 3.0\times10^{8}\frac{m}{s}$

Therefore, the wavelength of key fob radio waves is:

$$v = f\lambda \Rightarrow \lambda = \frac{v}{f} = \frac{3.0\times10^{8}}{315\times10^{6}} = 0.95238 \approx 0.95\text{m}$$





The last thing we do is return to the very first example and perform some calculations. Because the rode has two antinodes and one node, half a wavelength fits on the rod. The length of the rod is 0.750 m and audio analysis gives 3310 Hz for the frequency emanating from the resonating rod:

$$L=\frac{\lambda}{2}\Rightarrow\lambda=2L\ \&\ v=f\lambda=f\left(2L\right)\ \&\ L=0.750m;\ f=3310Hz$$

$$\lambda=2L=\left(2\right)\left(0.75\right)=1.50m\Rightarrow v=f\lambda=\left(3310\right)\left(1.5\right)=4965\approx4960\frac{m}{s}$$

Therefore, the speed of sound in the rod is 4960 meters per second.

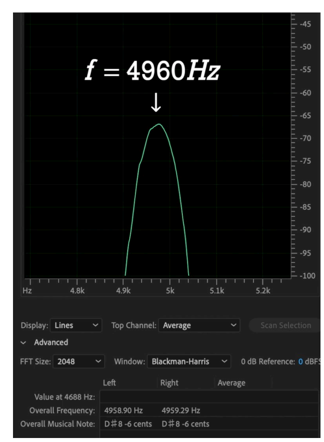
According to EngineeringToolbox.com[2], the speed of sound in rolled, extensional Aluminum, which is what this rod is made of, equals 5000 meters per second.

The ninth example decreases the length of the rod, however, the material is the same so the speed of sound in the rod should be the same. We can predict that a shorter rod should give a higher frequency:

$$L_2<L_1\Rightarrow\lambda_2<\lambda_1\ \&\ \lambda=\frac{v}{f}\Rightarrow f_2>f_1$$

We can also predict the frequency which should come from the resonating shorter rod:

$$L_1=0.750m\Rightarrow\lambda_1=1.50m\ \&\ f_1=3310Hz\Rightarrow v_1=4960\frac{m}{s}\ \&\ L_2=0.500m\Rightarrow f_2=?$$



$$L_2=\frac{\lambda_2}{2}\Rightarrow\lambda_2=2L_2=\left(2\right)\left(0.5\right)=1.00m$$

$$v_1=4960\frac{m}{s}=v_2=v=f\lambda\Rightarrow f_2=\frac{v}{\lambda_2}=\frac{4960}{1}=4960Hz$$

And audio analysis of the sound gives 4960 Hz because, the physics works!

[2] https://www.engineeringtoolbox.com/sound-speed-solids-d_713.html