'Mach c'? Scientists observe sound traveling faster than the speed of light

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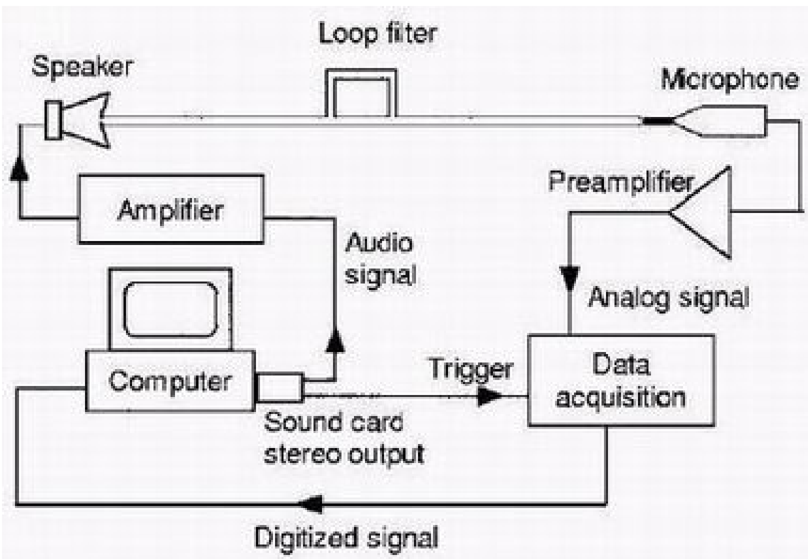

In this schematic of the acoustical test system, the scientists could create superluminal group velocity of sound waves, as well as negative group velocity. In the latter case, the peak of the output pulse traveling through the loop filter exited the filter before the peak of the input pulse had reached the beginning of the filter. Image credit: Bill Robertson, et al.

For the first time, scientists have experimentally demonstrated that sound pulses can travel at velocities faster than the speed of light, c. William Robertson's team from Middle Tennessee State University also showed that the group velocity of sound waves can become infinite, and even negative.

Past experiments have demonstrated that the group velocities of other materials' components—such as optical, microwave, and electrical pulses—can exceed the speed of light. But while the individual spectral components of these pulses have velocities very close to c, the components of sound waves are almost six orders of magnitude slower than light (compare 340 m/s to 300,000,000 m/s).

"All of the interest in fast (and slow) wave velocity for all types of waves (optical, electrical, and acoustic) was initially to gain a fundamental understanding of the characteristics of wave propagation," Robertson told *PhysOrg.com*. "Phase manipulation can change the phase relationship between these materials' components. Using sound to create a group velocity that exceeds the speed of light is significant here because it dramatically illustrates this point, due to the large difference between the speeds of sound and light."

The experiment was conducted by two undergrads, an area high school teacher and two high school students, who received funding by an NSF STEP (Science, technology, engineering, math Talent Enhancement Program) grant. The grant aims to increase recruitment and retention of students to these subjects.

In their experiment, the researchers achieved superluminal sound velocity by rephasing the spectral components of the sound pulses, which later recombine to form an identical-looking part of the pulse much further along within the pulse. So it's not the actual sound waves that exceed c, but the waves' "group velocity," or the "length of the sample divided by the time taken for the peak of a pulse to traverse the sample."

"The sound-faster-than-light result will not be a surprise to the folks who work closely in this area because they recognize that the group velocity (the velocity that the peak of a pulse moves) is not merely connected to the velocity of all of the frequencies that superpose to create that pulse," explained Robertson, “but rather to the manner in which a material or a filter changes the phase relationship between these components. By appropriate phase manipulation (rephasing) the group velocity can be increased or decreased.”

To rephase the spectral components, the sound waves were sent through an asymmetric loop filter on a waveguide of PVC pipe, about 8 m long. The 0.65-meter loop split the sound waves into two unequal path lengths, resulting in destructive interference and standing wave resonances that together created transmission dips at regular frequencies.

Due to anomalous dispersion (which changes the wave speed), sound pulses traveling through the loop filter arrived at the exit sooner than pulses traveling straight through the PVC. With this experiment, the group velocity could actually reach an infinitely small amount of time, although the individual spectral components still travel at the speed of sound.

“We also achieved what is known as a ‘negative group velocity,’ a situation in which the peak of the output pulse exits the filter before the peak of the input pulse has reached the beginning of the filter,” explained Robertson. “Using the definition for speed as being equal to distance divided by time, we measured a negative time and thus realized a negative velocity.”

It might not seem that a negative velocity would exceed the speed of light, but in this case, Robertson said, the speed of the pulse is actually much faster than c.

“Consider the pulse speed in a slightly less dramatic case,” Robertson said. “Say the peak of the output pulse exits the filter at exactly the same time as the input pulse reaches the beginning. In this less dramatic case, the transit time is zero and the speed (distance divided by zero) is infinite. So we were beyond infinite! ('To infinity and beyond,' to steal a line from *Toy Story*.) In our experiment, we measured a negative transit time corresponding to a negative group velocity of -52 m/s."

Although such results may at first appear to violate special relativity (Einstein's law that no material object can exceed the speed of light), the actual significance of these experiments is a little different. These types of superluminal phenomena, Robertson et al. explain, violate neither causality nor special relativity, nor do they enable information to travel faster than c. In fact, theoretical work had predicted that the superluminal speed of the group velocity of sound waves should exist.

"The key to understanding this seeming paradox is that no wave energy exceeded the speed of light," said Robertson. "Because we were passing the pulse through a filter, the sped-up pulse was much smaller (by more than a factor of 10) than the input pulse. Essentially, the pulse that made it through the filter was an exact (but smaller) replica of the input pulse. This replica is carved from the leading edge of the input pulse. At all times, the net energy of the wave crossing the filter region was equal to, or less than, the energy that would have arrived if the input pulse had been traveling in a straight pipe instead of through the filter."

Is this phenomenon simply the result of a clever set-up, or can it actually occur in the real world? According to the scientists, the interference that occurs in the loop filter is directly analogous to the "comb filtering" effect in architectural acoustics, where sound interference occurs between sound directly from a source and that reflected by a hard surface.

"The superluminal acoustic effect we have described is likely a ubiquitous but imperceptible phenomenon in the everyday world," the scientists conclude.

Citation: Robertson, W., Pappafotis, J., Flannigan, P., Cathey, J., Cathey, B., and Klaus, C. "Sound beyond the speed of light: Measurement of negative group velocity in an acoustic loop filter." *Applied Physics Letters* 90, 014102 (2007).

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