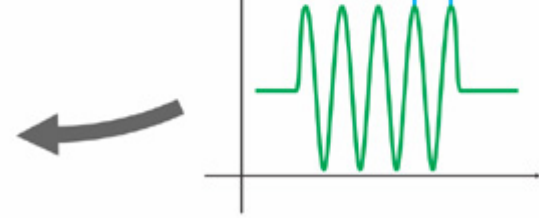

EXHIBIT 2007

The frequency of the sinusoid is measured (usually by FFT). The fringe spacing is known (from calibration), thus the speed of the particle can be calculated.

$$\text{speed} = \text{fringe spacing} \times f$$



[Click image to view larger](#)

Probe Volume Characteristics

The two beams must be focused at the probe volume to 1) create the smallest possible intersection (increasing the “brightness” of the light reflected by the particles), and 2) to ensure that the spacing of the fringes does not change much inside the probe volume. This critical alignment is easily maintained in the design of the miniLDV because both arms of the interferometer go through the same individual lens.

There is always some “fringe divergence” as it is physically impossible to build a system in which the fringe spacing is absolutely constant within the probe volume. This is because the wavefront radius of curvature (according to beam propagation theory) is only zero at the waist, which is the exact focal point of the beams. The design of MSE’s LDV products are built to achieve the minimum possible fringe divergence.

Fundamentally an LDV or LDA uses the same Doppler effect that causes the siren from an ambulance to change pitch—except that here the Doppler effect is with light, not sound. However, there are many ways to interpret how an LDV or LDA is able to measure the speed of an object. The more intuitive explanation (figure) goes as follows.

How Speed is Measured

The fringes formed by the interference of the beams is a pattern of light and dark regions in space. When a particle passes through the probe volume, it goes through the light and dark regions, so if its reflected light is measured over time, the intensity versus time curve looks like a sinusoid with a Gaussian envelope. The envelope comes from the fact that the intensity of the beams is Gaussian in nature. The sinusoid is the result of the physical travel of the particle through the fringes. The physical distance between the fringes is known from calibration which is performed with every probe. So the frequency of the intensity signal is directly proportional to the velocity of the particle: velocity = fringe spacing x intensity frequency.

Although perhaps less intuitive, the measurement still works if the object passing through the probe volume is a continuous surface. This is because the probe volumes are so small that any microscopic feature on the surface will reflect different amount of light and behave almost as if the surface were a stream of particles.

To measure the velocity of fluids like air or water, there must be something in the fluid to reflect the light. For air the particles can be as small as the smoke particles of an incense stick; for water, sometimes a small amount of dye gives enough signal straight out of the tap.

“D” is for Doppler

The second explanation reveals how the “Doppler” in LDV/LDA comes about.

Frequency Shifting and the Determination of Direction

When two beams are crossed in space as in a classical LDV/LDA, the interference pattern is static in space. This means that 1) it is impossible to know if the particle was traveling from left to right or right to left and 2) it is impossible to measure very low velocities, because it will take too long for the particle to travel through a bright and dark region (alternatively, the beat frequency is too low).

The trick is to add a Doppler shift to the beams themselves. When an LDV has “frequency shifting” already have a frequency difference when they are in space, so if a particle has velocity zero, the signal will have the same frequency as the difference in frequency between the two beams.

The effective frequency of the signal is the sum of the frequency due to the particle and the shift frequency. When a particle is going one way, it will add to the shift frequency; going the other way it will subtract. If a particle has velocity zero it does not change the shift frequency at all. Viewed another way, the fringes are moving through space, so the actual measurement is the velocity of the particle relative to the velocity of the fringes. miniLDV can be ordered with or without frequency shifting. For ultra-stable frequency shifting applications (to measure extremely low velocities), MSE offers the ultraLDV line.

It should be noted that any LDV or LDA measures only the component of velocity along the direction of the interference pattern—so the instrument must be aligned to the flow (or some known direction so that corrections/adjustments to the results can be made). MSE also offers multi-component systems: the 2D miniLDV.