



## Speed of Sound Pack

*(Product No. 3179)*

### Ranges

- Stethoscope  $\pm 100$  mV
- Stethoscope F  $\pm 100$  mV
- Sound  $\pm 1000$  mV
- Sound F  $\pm 1000$  mV

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**DS 090**

**No 4**

## Contents

Introduction .....	2
Connecting.....	3
Ranges .....	3
Which range to use.....	4
Limited warranty .....	5
Teacher's notes for Speed of Sound .....	6
01 Speed of Sound in Air.....	18
02 Speed of Sound through a Solid.....	21
03 Speed of Sound in Liquid .....	24
04 Speed of Sound in air by phase difference .....	28

## Introduction

The Speed of Sound pack contains 2 Stethoscope sensors (Product number 3176).

The Stethoscope sensor uses an electret microphone in a stethoscope chest piece to allow the heart (and other) sounds to be converted into an electrical signal. The signal can then be monitored with the EasySense software and an appropriate logger. In this application the sound will be recorded at two different distances from the point of creation. The difference in time of arrival of the sound at the two recording points will allow the calculation of the speed of sound (as long as the separation distance is known).

Recording and measuring sound in solids can be difficult. The large flat foot of the Stethoscope sensor provides a simple solution for recording sounds in solids. The foot of the Stethoscope sensor can be placed on the solid, the microphone within the bell of the sensor can then pick up sound transmitted through the solid surface. The diaphragm of the stethoscope needs to be removed; it acts as a high pass filter.

The Stethoscope sensor will rest with no additional equipment on a flat surface. It can easily be moved from one surface to another. The mobility of the apparatus allows the comparative measurement of the speed of sound in a variety of solids. The sensor can also be used to measure the speed of sound in air and water (provided protection is given for the sensor, see experiment notes for details).

The Stethoscope sensor has 4 ranges

- Stethoscope  $\pm 100$  mV
- Stethoscope F  $\pm 100$  mV
- Sound  $\pm 1000$  mV
- Sound F  $\pm 1000$  mV

The F ranges contain a low pass filter which allows the low frequency sounds to pass through to the logger and removes some high frequency sounds. It can be useful in removing ambient noise that may be triggering data collection or making the start point of a noise difficult to determine.

### Disclaimer

The Smart Q Stethoscope sensor is sold for the purpose of teaching and educational instruction. It is not, and has not been designed to be a diagnostic sensor. The results are illustrative only; any information gained from the use of this apparatus must not be used as the basis for any health and safety audit or diagnosis.

### Read the instructions before use.

The Stethoscope sensor has a diaphragm held onto the sounding bell by a screw ring. For the speed of sound experiments the diaphragm is not used.

Remove the diaphragm by unscrewing the screw ring; it is designed to be easily removed. In the sensors more conventional use as a device to listen to heart beats, information about the heart is gained by comparing the sounds at different locations on the chest and by comparing the sounds with and without the diaphragm. The diaphragm should remain in the ring; keep both parts safe it is not possible to purchase replacements.

Once the diaphragm is removed the microphone can be seen, it has been glued into place and it has a protective screen over the aperture but care should be taken to not damage the microphone.

## Connecting

- Push one end of the sensor cable (supplied with the **EASYSSENSE** unit) into the hooded socket on the adaptor with the locating arrow on the cable facing upwards.
- Connect the other end of the sensor cable to an input socket on the **EASYSSENSE** unit.
- The **EASYSSENSE** unit will detect that the Sensor is connected and display values using the currently selected range. If the range is not suitable for your investigation, set to the correct range.


## Ranges

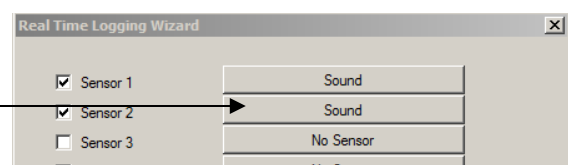
There are four ranges available to use:

1. **Stethoscope  $\pm 100$  mV**  
This is the most sensitive of the ranges and is for making recordings of the heart beat sound wave using the Stethoscope both with and without the diaphragm attached.
2. **Stethoscope F  $\pm 100$  mV**  
This range has a low pass filter. It reduces the effect of the higher frequency sounds that can be created by speech, movement of the sensor over the skin, clothing across the sensor, etc. It is for making recordings of the heart beat sound wave using the Stethoscope both with and without the diaphragm attached. It could be used where noise is a problem.
3. **Sound  $\pm 1000$  mV**  
This is a reduced sensitivity range for detection of sound in solids. The transmission of sound through a solid reduces attenuation of the original signal and more will reach the sensor. If the stethoscope range is used the sensor can be swamped by the volume of the noise.
4. **Sound F  $\pm 1000$  mV**  
This range contains a low pass filter to help reduce the effect of high frequency sound. It can be of use when moving the sensor while recording, the effect of high frequency will be attenuated, detail will be lost in the produced waveform and the waveform may appear to be slower forming. Not recommended for speed of sound measurements in solids unless the signal is very confused.

With some **EASYSSENSE** units it is possible to set the range from the unit. Please refer to the **EASYSSENSE** unit's user manual.

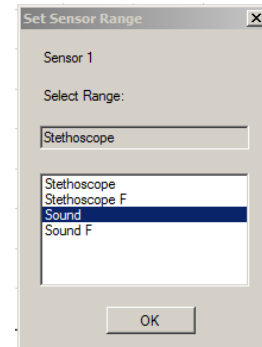
To alter the range in the EasySense software:

1. Select **EasyLog** from the Home screen.
2. Select the **New** recording wizard icon. 
3. Click on the sensor's name (it will be listed using its current range).
4. A set sensor range window will open. Select the required range, then OK.
5. Select Finish to exit the wizard.



Or

1. From the Home screen select **Sensor Config** (Settings menu).
2. Select the Sensor from the list and click on the **Change Range** button.
3. The current range will be highlighted. Select the required range and click on OK.
4. Close Sensor Config.

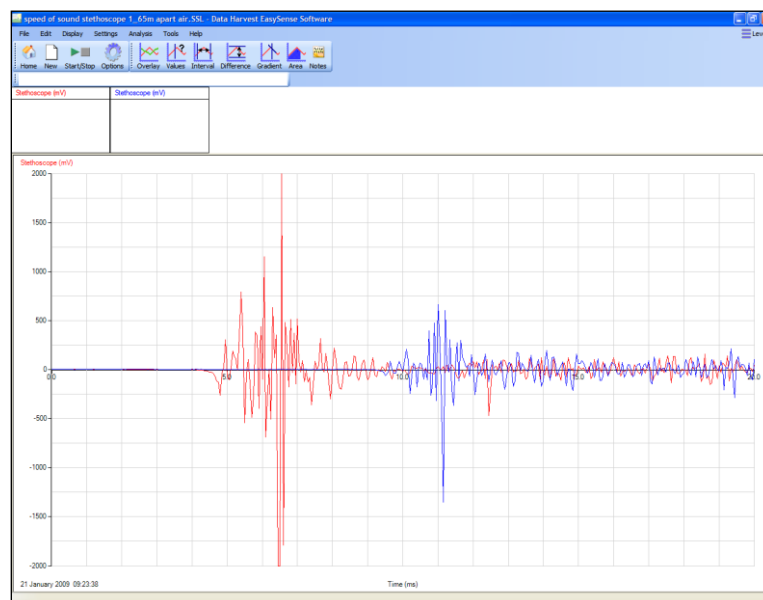


The range setting will be retained until changed by the user.

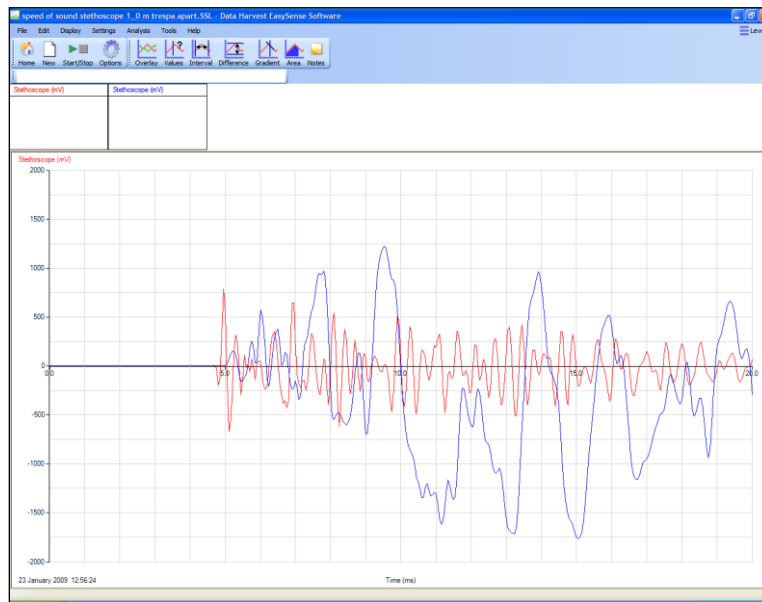
### Which range to use

For speed of sound measurements we would normally advise using the Sound range. If the recorded trace appears to have small peaks, try using Autoscale to make the graph data as big as possible, if this still fails to reveal the information required change the range to Stethoscope and repeat.

Material	Range	Suggested distance between sensors
Wooden bench top	Sound	At least 1 m
Aluminium	Sound	At least 1.5 m
Glass	Stethoscope	At least 1 m
Wood	Sound	At least 1 m
Concrete	Stethoscope	At least 3 m
Air	Stethoscope	At least 1.5 m



Recording of a sound detected by 2 Stethoscope sensors for a speed of sound in air calculation. Separation of sensors was approx. 1.5 m



Typical recording of sound through a solid (bench to) material using 2 Stethoscope sensors.

## Limited warranty

For information about the terms of the product warranty, see the Data Harvest website at: <https://data-harvest.co.uk/warranty>

**Note:** Data Harvest products are designed for **educational** use and are not intended for use in industrial, medical or commercial applications.



### WEEE (**W**aste **E**lectrical and **E**lectronic **E**quipment) Legislation

Data Harvest Group Ltd is fully compliant with WEEE legislation and is pleased to provide a disposal service for any of our products when their life expires. Simply return them to us clearly identified as 'life expired' and we will dispose of them for you.

## Teacher's notes for Speed of Sound

### Read

Sound is a vibration that travels through an elastic substance. The vibration causes areas of compression and rarefaction forming a longitudinal wave, which will show properties of reflection and diffraction. The speed of sound varies with the density of the material it travels through. As a general rule the greater the elastic properties of the material the faster the speed of sound. In air (a mixture of gases) at a temperature of 0°C sound travels at 331.1 metres per second, as temperature increases the speed also increases (by approximately 0.607 m/s per °C). The speed of sound in air is nearly independent of pressure and density.

Speed travels about 4 times faster in water than air; the exact multiple is temperature dependant. In solids additional waves to do with shear can be propagated. The presence of these additional waves can lead to widely varying speeds being quoted in tables of comparison. Many tables express the theoretical values while others use values calculated by experiment

The speed of sound  $c$  is given by  $c = \sqrt{\frac{B}{\rho}}$

$B$  is the elastic property; it is normally the bulk modulus in fluids and solids  
 $\rho$  is the density

This tells us that the speed of sound increases with the bulk modulus of the material, and decreases with the density.

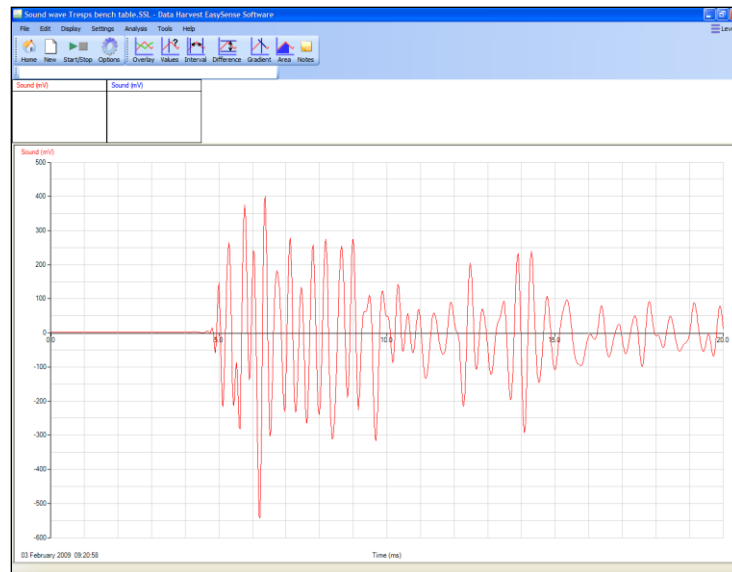
In a solid, transverse waves are also propagated, with a different velocity to the longitudinal waves. A flat surface, such as a bench top, will contain many different velocities and wave echoes. The cross section (and area) of the material being tested will also have an influence. If the solid is a rod, then the velocity of sound will be dependent upon the Young's modulus of the material.

The quoted speed of sound in air is often from calculated values rather than practical measurement. The formula used to calculate the speed of sound in air produces good results over a wide range of temperatures, but starts to fail at high temperatures. Good predictions of the speed in the atmosphere are possible, especially in the colder, drier, low pressure stratosphere. When the temperature inversion of the atmosphere is reached the predictions are increasingly less valid.

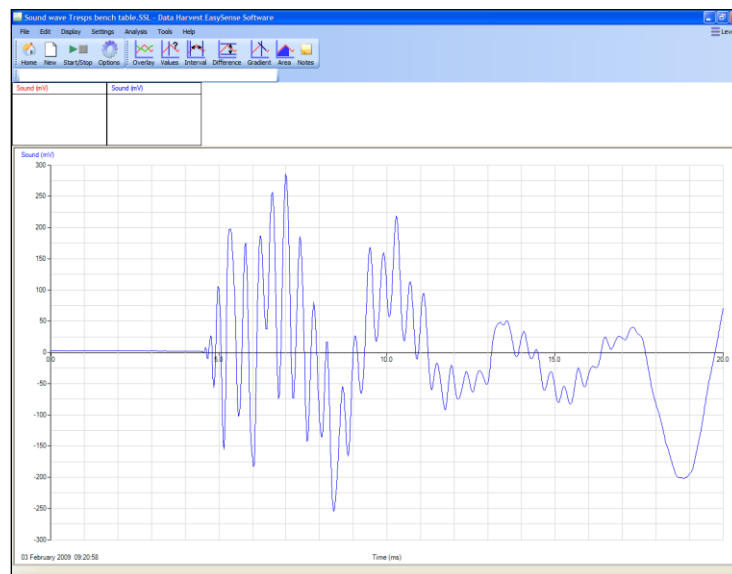
Changes in temperature and density associated with wind can create acoustic lenses which will alter the speed of sound, direction and distance of sound propagation. This will usually be misinterpreted as the wind "blowing" the sound.

Students may well have heard of the Mach number, this is a value quoted for the speed of aircraft; it is popular to assume the Mach number is the number of times faster than the speed of sound the aircraft is travelling. The Mach number is a ratio of the objects speed to the speed of sound of the medium through which it is passing. A value of Mach one is therefore when the object is travelling at the same speed as sound could travel through the medium. The Mach number is a relative value not an absolute value.

The way the material is mounted will affect the pattern of sound waves seen. E.g. the samples below show the wave pattern in piece of lab top (Trespa) mounted on base units and fixed to a wall and the same material mounted on a table frame.



Sound wave in Trespa mounted on a steel frame as a table / bench.



Sound wave in Trespa mounted on equipment cabinets.

The difference in the sound wave pattern from the same material mounted in different ways should not affect speed of sound measurements as we are looking for differences between times of arrival of the sound wave.

## Experiment(s)

The experiments described in the practical sheets use a method not dissimilar to the one used by William Derham in late 17<sup>th</sup> early 18<sup>th</sup> century. William Derham was the first recorded person to measure the speed of sound; he used a simple method of creating a sound and measuring how quickly it reached two far points. Knowing the distance separating the far points from the noise and the time taken to reach the points the speed was

calculated. In these experiments modern technology is used to reduce the distance between the listening points. Two microphones are placed a known distance apart, a noise is made and the time taken for the noise to travel between the two microphones is recorded. A simple calculation of distance / time gives the speed.

### Apparatus

For use in all experiments

1. An **EASYSense** logger capable of fast recording
2. 2 Smart Q Stethoscope sensors
3. Masking tape or modelling clay
4. An expandable measuring tape

### Additional apparatus for use in speed of sound in a liquid

1. A large container at least 1 m long.
2. Large leak proof polythene bag.

### Additional apparatus for use in speed of sound by phase difference

1. A Smart Q Voltage sensor  $\pm 12$  or 20 V.
2. A signal generator (sine wave, variable frequency).
3. A loudspeaker with matched impedance to the signal generator.
4. Patch leads.

### Set up of the software for experiments 1 to 3

When **Graph** is started a **New Recording Wizard** will start, enter the information below on the correct pages.

Recording mode	Length of recording	Intersample time	Trigger event	Pre trigger amount
Graph	50 ms	50 $\mu$ s	When Sound sensor 1 Rises above 100 mV	25%

Intersample time availability depends upon the logger being used and /or the number of sensors connected. You want the shortest available time.

The **Pre-trigger** value may need adjusting to account for ambient noise in and around the experiment location. To change this value click on **New**, and when the wizard starts click on **Next** until you are at the **Start Condition** page, enter the new value and **Finish**.

### Which range to use

For speed of sound measurements we would normally advise using the **Sound** range. If the recorded trace appears to have small peaks, try using **Autoscale** to make the graph data as big as possible. If this still fails to reveal the information required change the range to **Stethoscope** and repeat.



**Table 1 Ranges to use in speed of sound experiments**

Material	Sensor Range	Suggested distance between sensors
Wooden bench top	Sound	At least 1 m
Aluminium	Sound	At least 1.5 m
Glass	Stethoscope	At least 1 m
Wood	Sound	At least 1 m
Concrete	Stethoscope	At least 3 m
Air	Stethoscope	At least 1 m
Water	Sound	At least 1 m

**Note:** It is very difficult to verify the validity of the calculated speeds. Speed of sound in a solid will vary with the bulk modulus of the material, and decreases with the density. Small sections of materials give values which are close to published tables; there will however be differences between theoretical and experimental values. Showing that speed is significantly higher in dense materials will be easy to show.

**Table 2 Speed of sound in various solid materials**

Solids	$v$ (m/s)	Solids	$v$ (m/s)
aluminium	5100	rubber, butyl	1830
beryllium	12,890	rubber, vulcanized	54
brass	4700	silver	3650
brick	3650	steel, mild	5960
copper	4760	steel, stainless	5790
cork	500	titanium	6070
diamond	12000	wood, ash	4670
glass, crown	5100	wood, elm	4120
glass, flint	3980	wood, maple	4110
glass, pyrex	5640	wood, oak	3850
gold	3240	wood, pine	3313
granite (293 K)	5950		
iron	5950		
lead	2160		
lucite	2680		
marble	3810		
Neoprene	1600		

**Table 3 Speed of sound in various liquids and gases**

Liquids	$v$ (m/s)
alcohol, Ethanol	1207
alcohol, Methanol	1103
mercury	1450
water, distilled	1497
water, sea	1531
water vapour	494

Gases (STP)	$v$ (m/s)
air, 0°C	330
air, 20°C	343
argon	319
carbon dioxide (293 K)	259
helium (273 K)	965
hydrogen (H <sub>2</sub> ) (273 K)	1284
neon	435
nitrogen	334
nitrous oxide	263
oxygen (O <sub>2</sub> )	316
water vapour, 134°C	494

The values of some materials will vary widely in published literature. The speed of sound will depend upon the purity, cross sectional area and frequency used. Aluminium will have published values ranging from 5100 to 6240. In some cases the values are theoretical and others they have been calculated from practical measurement. The tables above are an amalgam of several sources. For some materials an average of published values is used.

### To get good values (in agreement) by experiment

1. Have at least 1 m between the sensors, the bigger the distance the better.
2. Measure the distance to the nearest mm. Errors in the distance measurement have a big effect in the calculation.
3. Use the fastest recording time possible.
4. Use a trigger.
5. When measuring a solid make sure the stethoscope is lying flat on it.
6. If you are using a non-flat or narrow object try to get as much of the bell of the stethoscope over the surface as possible. Make sure the microphone is over the surface and not displaced to one side.

You need to arrange the apparatus so that the point where you will create the noise is first, then the first sensor and then the second sensor.

Use a chalk line or a length of tape to mark out the expected path of the sound and the recording line.

To help with the maths try to get a separation of 'sensible' units e.g. 1.0 m, 1.2 m, 1.5 m, etc. Try to avoid distances like 1.25 m, 1.98 m if possible. It may be that you want the students to use more complex values, but for an introductory demonstration simple distances are better.

Students will need to use the following formulae,

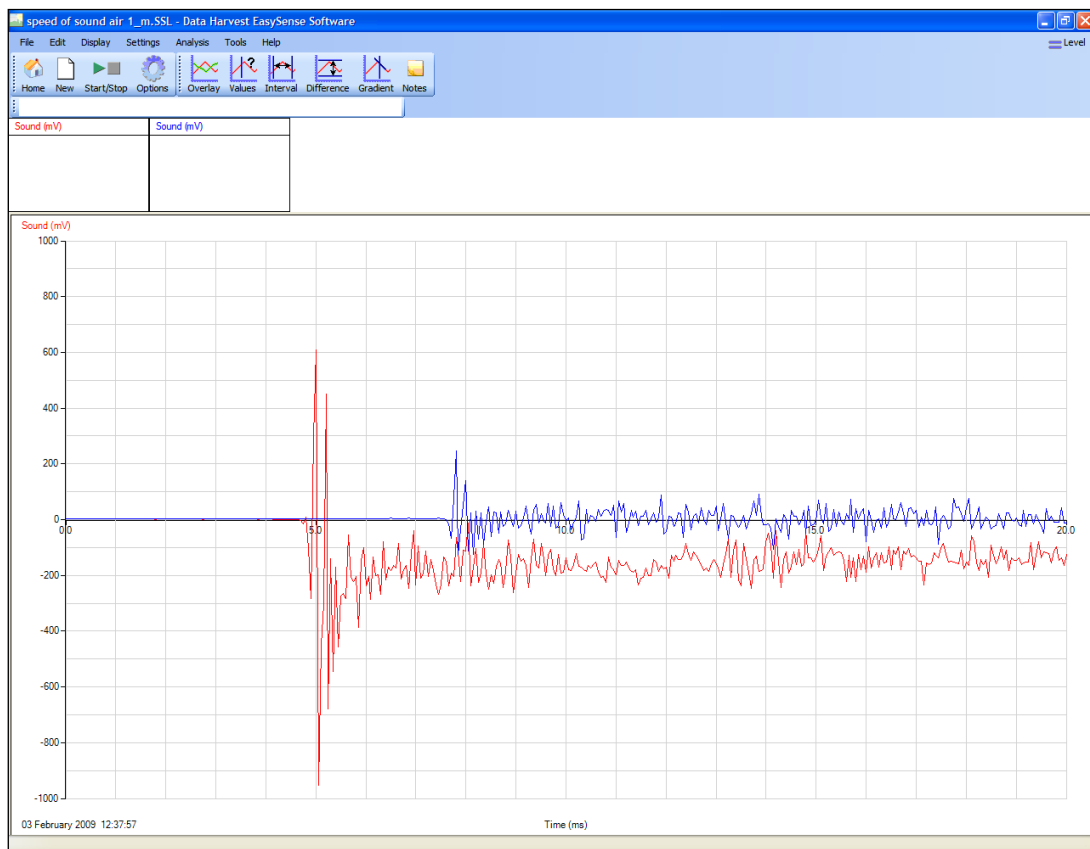
$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

$$\text{Wavelength} = \frac{\text{Velocity}}{\text{Frequency}}$$

The students should be confident to re-arrange the formulae to calculate the unknown value. A check to see that the students understand the terms velocity, speed, frequency and wavelength could also prevent difficulties in calculations.

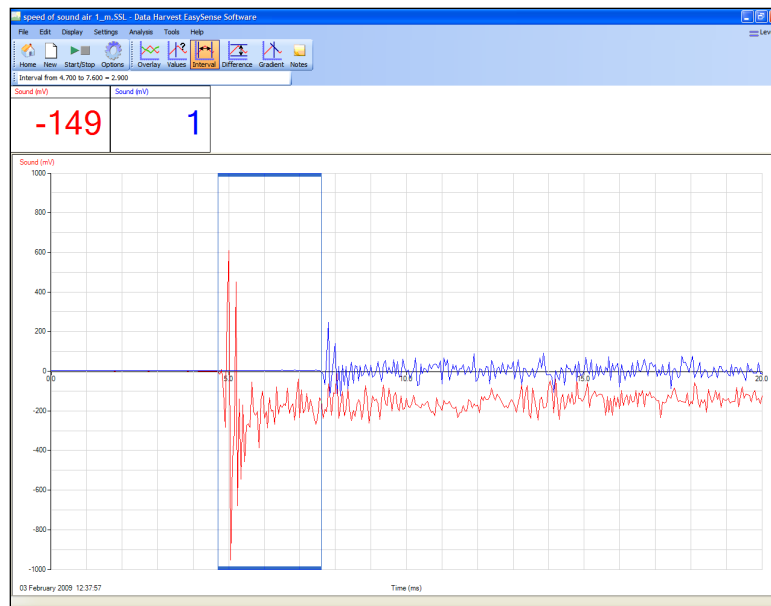
## Speed of Sound in Air

### Sample result



Separation of Stethoscope sensors of 1.0 m.

## Analysis



Use the **Interval** tool used to select the time from the first recording of the wave (sensor 1) to the second recording (sensor 2).

Interval = 2.90 seconds

Stethoscope sensor separation = 1.0 m

## Calculation

Speed of sound (calculated from sample results) =  $1.0 / 0.0029 = 344.8 \text{ m/s}$

Temperature of room =  $22^\circ\text{C}$ .

Correction for temperature =  $(0.607 \times 22) + 331.1 = 344.45$ .

(Speed of sound increases by 0.607 m/s per degree Celsius)

## Speed of Sound in Water

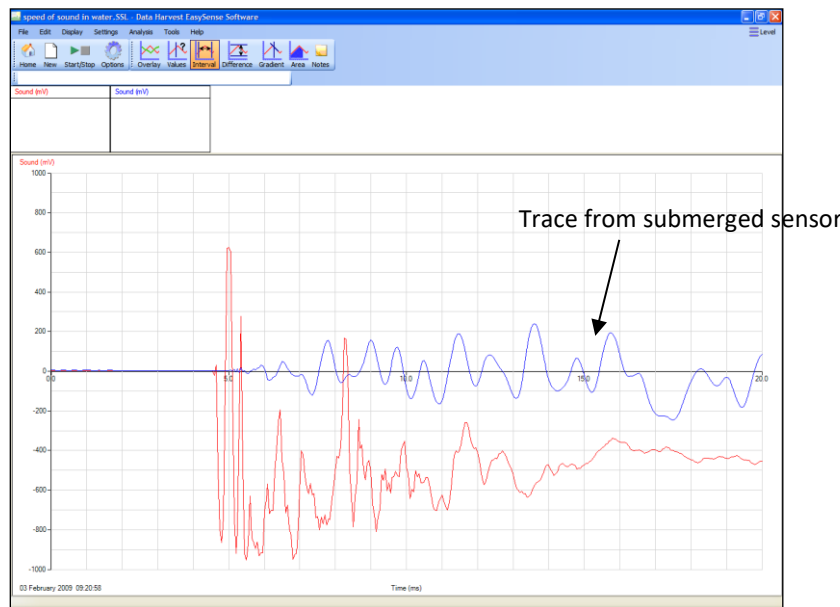
Note: You **must** use a polythene bag to contain the immersed sensor. The bag **must** be waterproof and leak proof.

1. While it should be possible to record the speed of sound in liquids other than water, the speed of the logging and size / volume of the container will normally mean that water is the only liquid used. You may want to compare fresh with salt water.
2. You will need a long container, the volume can be small. You only need enough depth of water to cover the immersed sensor.
3. A minimum of 0.5 m is required if you wish to simply show that speed is faster in water. If you wish to collect empirical data you need to be looking a distance of at least 1.5 m between sensors. The speed of sound in water is approximately 4 times faster than air. The time difference between the sensors will be small, the sample rate and the accuracy of the measurement of the distance separating the sensors will be introducing potentially large errors with a distance of 1 m or less.

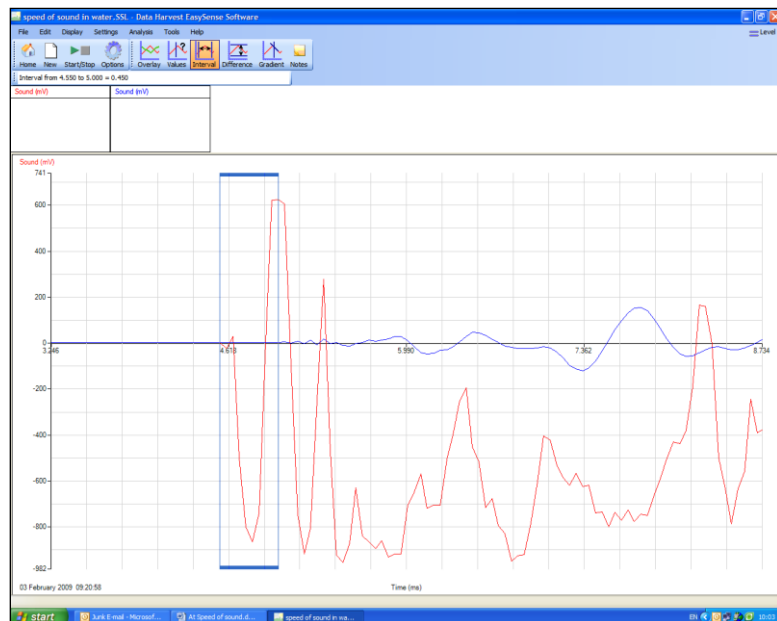
4. Take the temperature of the water, the speed of sound in water is temperature dependant. If you refer to published values you will need to compare values for the same temperature.
5. The container needs to be made of a stiff material. Polythene containers tend to dampen the noise and produce echoes. A polypropylene box was found to give easier to understand results compared to a similar length polyethylene container.

## Sample results and analysis

Path between stethoscope sensors was 0.6 m. Box made of polypropylene.



Note how the water smooths the waveform, this does make the difference between the two traces ambiguous. You may wish to use **Zoom** to help find the two start points of the sound.



**Zoom** applied to the first part of the data. **Interval** has been used to mark the beginning of the sound wave on each trace and reveal the time difference. With this data the time

resolution gave a value of 0.450 ms or 0.500 ms, use the mean of the two estimates for calculation i.e. 0.475 ms.

### Calculations

In this example the distance between the Stethoscope sensors was measured at 0.60 m.

The **Interval** tool revealed the time for the sound to reach the second sensor after reaching the first was 0.475 ms

$$\begin{aligned} \text{Speed of sound} &= \text{distance} / \text{time} \\ &= 0.6 / 0.000475 \text{ (time corrected from ms to s)} = 1263 \text{ m/s} \end{aligned}$$

This is considerably faster than the speed of sound in air. No correction has been made for temperature; the errors in the estimate of time are sufficiently large that we can only look at the gross idea of the sound travelling faster in water. If the container had been longer the time interval would have had greater certainty. In analysing the results there is always the danger of manipulating the values to produce the result required, this is good opportunity to raise the issue of the impartial observer.

Speed of sound in water is normally quoted as 4 x faster than in air. Air value = 331.1,  $\times 4 = 1325$ . The results are not far off.

### Speed of Sound by phase difference

The student's notes show how to conduct the experiment using a Voltage sensor to record the output of the signal generator. The experiment can be done using a pair of Stethoscope sensors. When using a pair of sensors have one as a fixed sensor close to the loud speaker, this will record the reference wave form. Move the second sensor slowly away from the fixed sensor, pause every 10 cm or so to check the phasing.

The experiment works well; ideally you need a short wavelength to reduce the effects of volume attenuation distorting the produced wave from the moving speaker. Which frequency you use will depend upon the frequency response of the loudspeaker, the response of the loudspeaker and the irritation factor of the audible tone. Do be careful when picking the tone / frequency, some are particularly distressing (especially with a younger audience) and have the potential to cause hearing damage. (Check with local safety guidelines for any frequencies to avoid). In testing, a frequency of about 460 Hz was used this gave a theoretical wavelength of approx. 0.76 m.

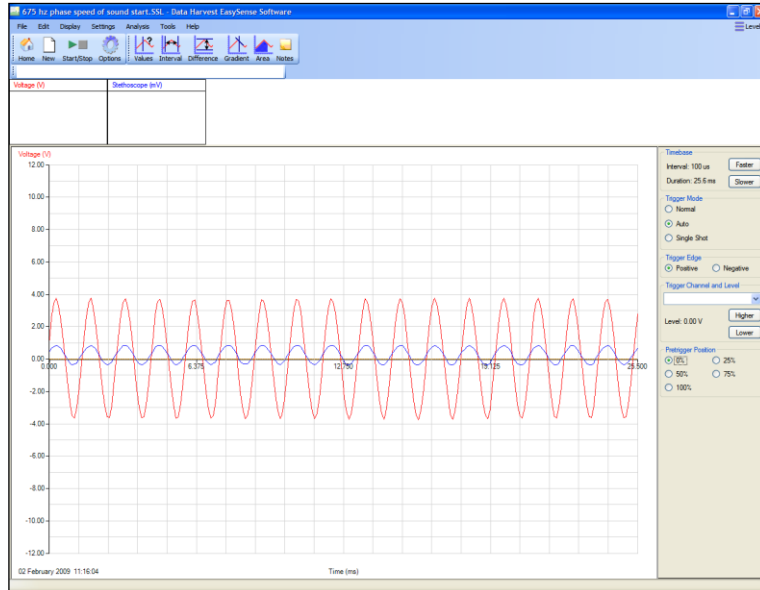
It is an idea to calculate the theoretical wavelength of the frequency chosen, for practical reasons (attenuation of signal, restrictions of work area) avoid anything with a wavelength of over 80 cm and under 30 cm. At the shorter wavelengths it can become more difficult to find the in phase node with accuracy.

Frequency	Wavelength (m) at 23°C	Wavelength (m) at 0°C
400	0.86	0.82
450	0.77	0.74
500	0.69	0.66
550	0.62	0.60
600	0.58	0.55

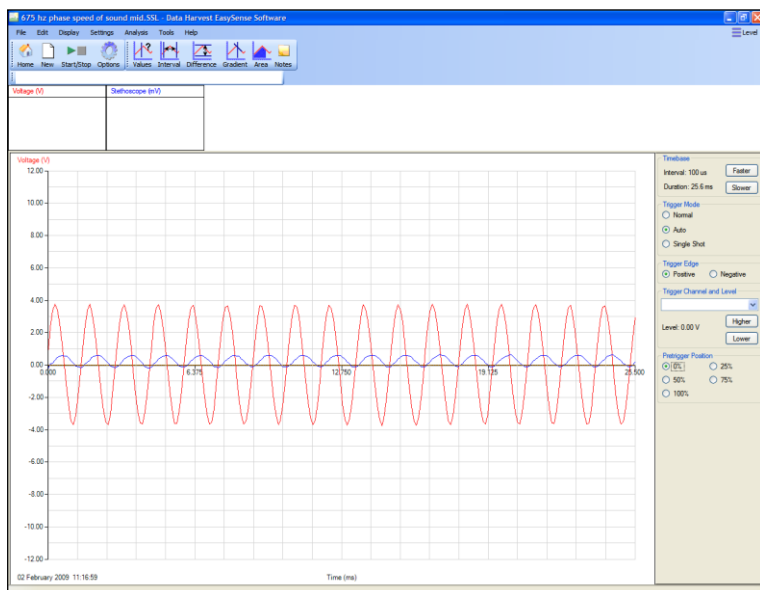
Wavelength at frequencies in the range 400 - 600 Hz at 23 and 0°C.

## Sample data

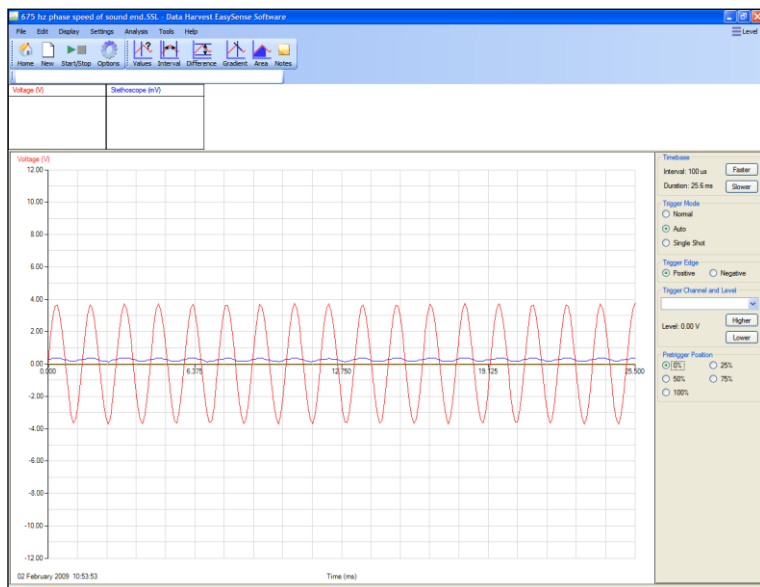
Voltage and sound in phase with Stethoscope at its closest point to the speaker in the experiment.



Sound and voltage out of phase, as the Stethoscope is moved away from the loud speaker.

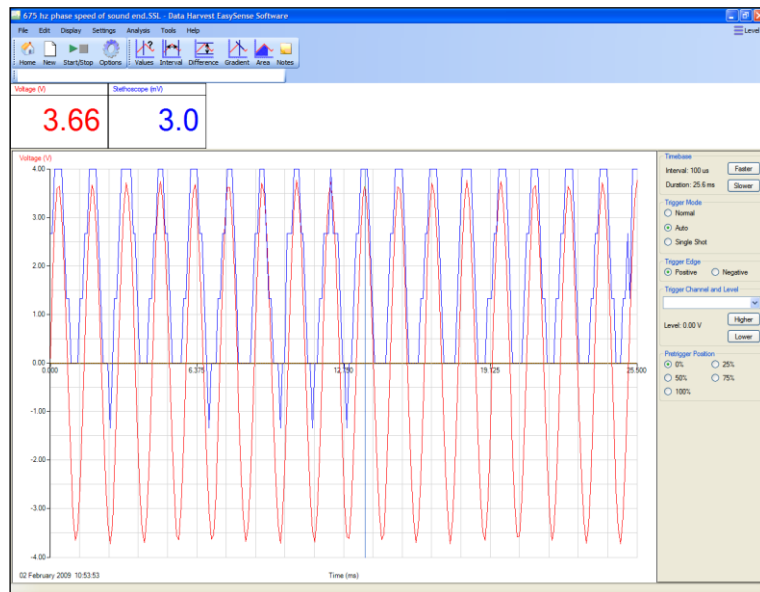


Sound and Voltage back in phase when the Stethoscope is at its most distant from the speaker in this experiment.



You will need to use **Autoscale** at this point to check the phase difference.

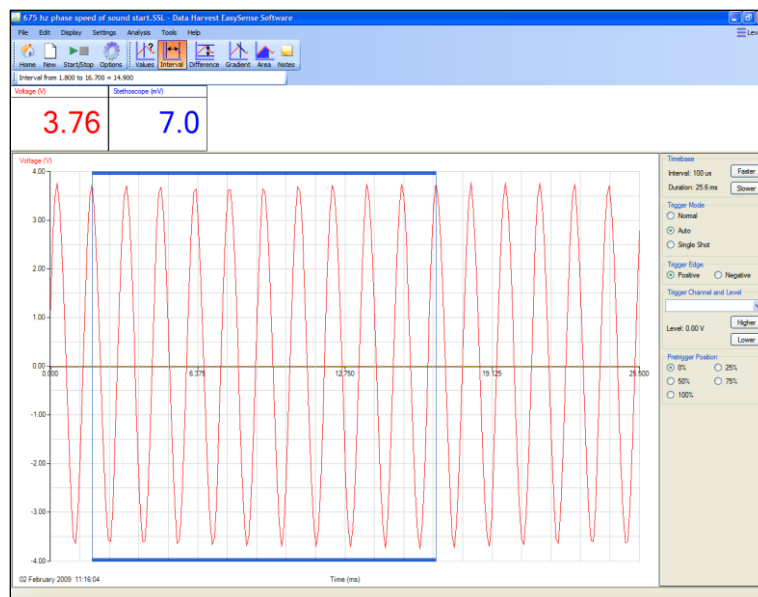
Using **Autoscale** on the data to see if the waves are in phase. Use the **Values** tool to check the alignment.



## Calculations

Frequency from voltage wave.

- Taking a single wave. Use the **Interval** tool to find the interval between two adjacent peaks.
- Calculate  $1/\text{interval (in seconds)} = \text{frequency in Hz}$ . Take several peaks and produce an average.



Selecting 10 peaks to calculate frequency.

In the sample data the interval was 1.5 ms, this gave a calculated frequency of 666.66 Hz. Using several peaks allowed an average to be calculated. A frequency meter confirmed the frequency was 675 Hz. Using 10 peaks to find the time gave a value of 672 (14.8 ms over 10 peaks) suggesting that this was a more accurate method of determining the frequency.

- Using multiple waves.
  - Use the Interval tool to find the time interval for 10 peaks.



- b. Divide the time interval by the number of peaks to find the time for one cycle
2. Calculate  $1/\text{interval (in seconds)} = \text{frequency in Hz}$

### Calculate the speed of sound

Values taken from a recorded practical.

1.  $f = 672 \text{ Hz}$
2.  $L = 0.525 \text{ m}$  (initial in phase distance 23 cm - final in phase distance 75.5 cm)
3.  $f/l = 352 \text{ m/s}$

Temperature of the room =  $25^{\circ}\text{C}$ , correction =  $0.607 \text{ m/s per } 1^{\circ}\text{C} = 25 \times 0.607 = 15.2$ .

Expected value =  $331.3$  (speed at standard pressure and  $0^{\circ}\text{C}$ ) +  $15.2 = 346.5$ .

Experimental value =  $352$ . (2% error over theory)

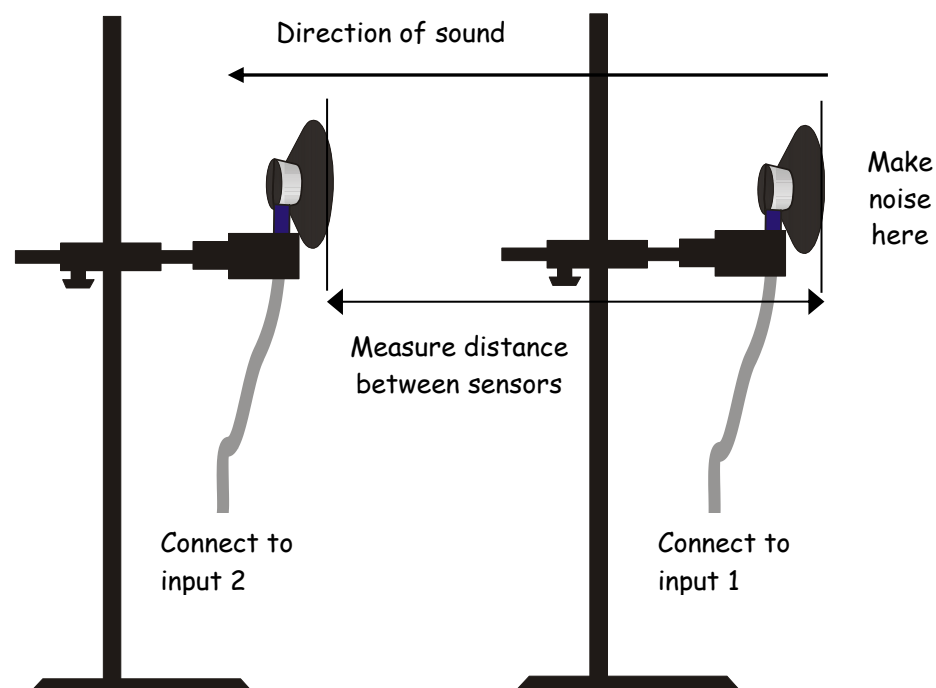
**Note.** With the speaker being used the first "in phase" was 23 cm in front of the speaker at this frequency. This is due to a lagging phase shift between the sound wave and the changing voltage frequency driving the speaker. The lag is created by impedance within the coil magnet system driving the speaker cone. The lag can be up to 45 degrees, producing a phase difference of  $45/360 = 12.5\%$ .

## 01 Speed of Sound in Air

### Read

Sound is a vibration that travels through an elastic substance. The stiffness of the material will affect the attenuation of the sound and the speed at which it travels through the material. Reference sources will give a value of 333.1 to 331.6 m/s at 0°C for the speed of sound in air, temperature has a significant effect.

In the experiment you arrange a pair of microphones to receive a sound from a point source, but at different distances from the source.



Use clamps to hold the sensors at the same height above the bench top. Check by sight that they are in line. The sensors should be at right angles to the bench top, parallel to each other and facing the noise. A clap of the hands is usually sufficient to produce a measurable sound.

### What you need

1. An EASYSense logger capable of fast logging
2. 2 x Smart Q Stethoscopes set to the Sound range
3. 2 x long sensor cables
4. 1 x measuring tape
5. Stands and clamps

### What you need to do

1. Remove the diaphragms from the Stethoscope sensors and place them in a safe place.

2. Use stands and clamps to position the sensors as shown in the diagram. Try to get at least a 1 metre separation between the sensors.
3. Measure the distance (in metres) between the two sensors. Make sure you measure between the same points on the sensors (e.g. centre to centre or front edge to front edge). Make a note of the distance, this reading should be accurate to a millimetre (mm).
4. Start the **EASYSense** software and select **Graph** from the Home screen.
5. Use the set up table below to set the recording parameters.
6. Select **Start**.
7. When ready, make a sharp noise in front of the sensor connected to input 1.
8. If the sound was of the correct intensity logging will be triggered and you will see 2 traces. The red trace is the sound recorded by the Stethoscope sensor closest to the noise and the blue trace for the Stethoscope sensor furthest from the noise source.
9. You should notice the peaks on the red trace appear before the peaks on the blue trace. You need to measure the distance between the first red peaks and the first blue peaks, using the **Interval** tool (see below for details).

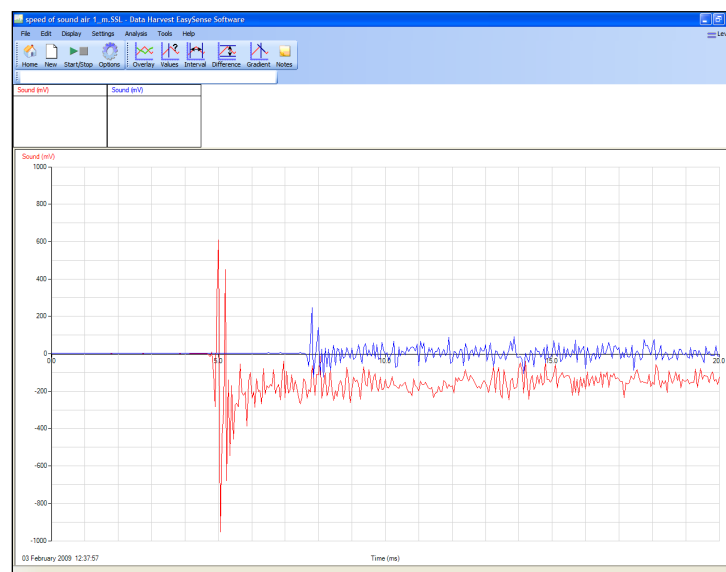
### Set up of the software

The following set up is based upon a separation of 1 m.

Recording mode	Length of recording	Intersample time	Trigger event	Pre trigger
Graph	50 ms	50 $\mu$ s	When sound sensor 1 rises above 100 mV	25%

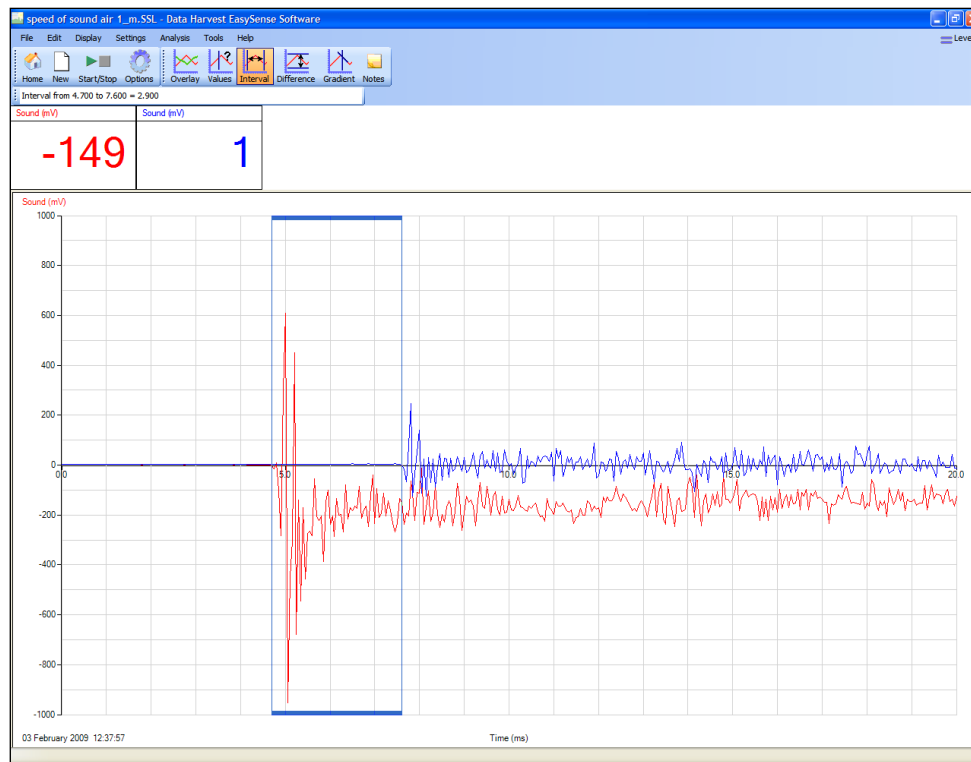
Set the length & intersample time to the shortest available. Logger type and number of sensors may lead to a variation in choice.

### Sample result



Separation of Stethoscope sensors of 1.0 m

## Analysis



Use the **Interval** tool to find the time difference between the sound reaching sensor 1 and sensor 2.

Interval = 2.90 milliseconds

Stethoscope sensor separation = 1.0 m

### Calculation

Speed of sound = distance / time

Speed of sound =  $1.0 / 0.0029 = 344.8 \text{ m/s}$

Temperature of room =  $22^\circ\text{C}$ .

Correction for temperature =  $(0.607 \times 22) + 331.1 = 344.45$ .

(Speed of sound increases by 0.607 m/s per degree Celsius).

### Extension

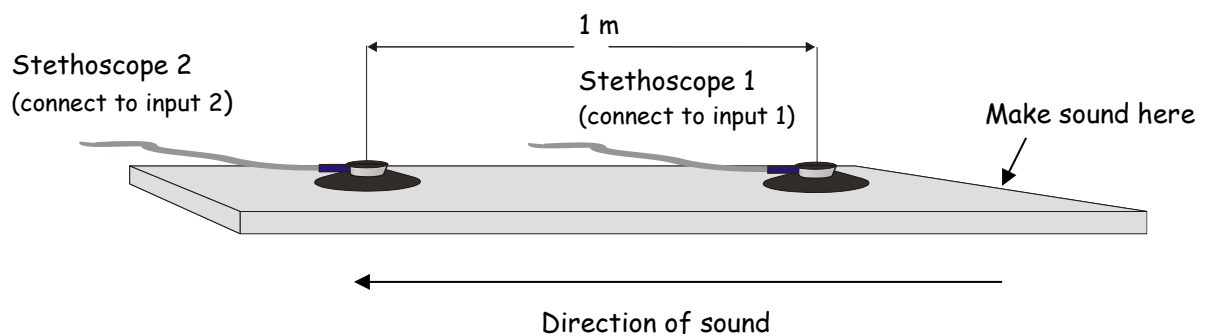
Try placing a heater under and between the two sensors to heat the air between them, does it alter the speed of sound?

## 02 Speed of Sound through a Solid

### Read

Sound is a vibration that travels through an elastic substance. The stiffness of the material will affect the attenuation of the sound and the speed at which it travels through the material. Sound travels much faster in a solid than in air. Reference sources will give a value of 333.1 to 331.6 m/s at 0°C for the speed of sound in air.

In this experiment you arrange a pair of microphones to receive a sound from a point source.



### To get the best values:

1. Have at least 1 m between the Stethoscope sensors.
2. Measure the distance between the sensors as accurately as possible.
3. Use the fastest recording time possible.
4. Use a trigger.
5. Make sure the stethoscope is lying flat on the solid.
6. Use something like a pencil or ball point pen to make the noise, you shouldn't need to use a large force to make a sound the sensors can detect. If the noise is too large you may end up with a pattern containing a large quantity of confusing, irrelevant data.

By placing the 2 sensors in line on a bench you can record the time taken for the sound to reach sensor one and then pass onto sensor 2. Arrange the apparatus so that the point where you will create the noise is first, then the sensor 1 and then sensor 2.

To help with the math try to get a separation of "sensible" units e.g. 1.0 m, 1.2 m, 1.5 m, etc. Try to avoid distances like 1.25 m, 1.98 m if possible. You must measure the distance between the sensors to the nearest mm.

### What you need

1. An **EASYSense** logger capable of fast logging
2. 2 x Smart Q Stethoscope sensors set to the Sound range
3. 2 x Long sensor cables
4. 1 x measuring tape
5. 2 x small masses, modelling clay or masking tape.

### What you need to do

1. Remove the diaphragm from the Stethoscope sensors and place them in a safe place.
2. Place the Stethoscope sensors onto the bench with the bell / microphone facing down onto the bench top (as in diagram).  
Make sure that the sensor connected to input 1 has space between it and the edge of the bench. You will tap on the bench in this space to make the sound.  
The sensor should stay in place, if the wire connecting to the sensor is making the sensor lift off the table, or move around, place a small mass on the sensor to hold it in place. Alternatively you could use masking tape or modelling clay to secure the sensor in place.
3. Measure the distance (in metres) between the two sensors. Make sure you measure between the same points on the sensors (e.g. centre to centre or front edge to front edge). Make a note of the distance
4. Start the **EASYSense** software and select **Graph** from the Home page.
5. Use the table below to set up the recording parameters.
6. Select **Start**.
7. When ready, make a noise on the bench top by striking it with an object, something metal gives a sharper sound. There is no need to strike the bench with a large force; a slight tap may be all that is required.
8. If the sound was of the correct intensity logging will be triggered and you will see 2 traces. The red trace is the sound recorded by the Stethoscope sensor closest to the noise and the blue trace for the Stethoscope sensor furthest from the noise source.
9. You should notice the peaks on the red trace appear before the peaks on the blue trace. You need to measure the distance between the first red peaks and the first blue peaks, using the **Interval** tool (see below for details).

### Set up of the software

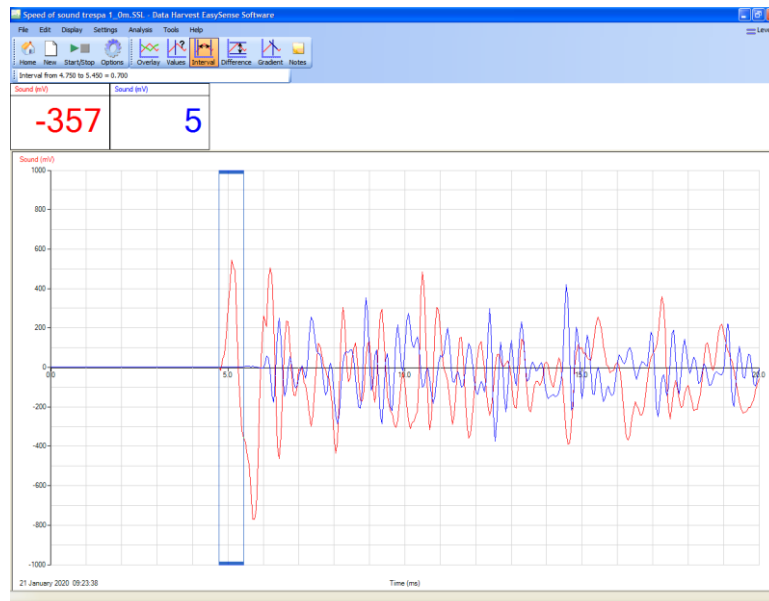
The following set up is based upon a separation of 1 m using a wood bench surface.

Recording mode	Length of recording	Intersample time	Trigger event	Pre trigger
Graph	50 ms	50us	When sound sensor 1 rises above 100 mV	25%

Set the length & intersample time to the shortest available. Logger type and number of sensors may lead to a variation in choices.

## Sample result and Analysis

Sensors placed on a school work bench topped with Trespa



Use the **Interval** tool to find the time difference between the sound reaching sensor 1 and sensor 2.

Interval = 0.70 ms

Separation between sensors = 1.0 m.

Speed of sound in the Trespa =  $1.0 / 0.0007$   
 = 1428 m/s

## Extension

Repeat the work but use different materials.

Note: If testing glass be very careful to only tap the glass and do not use a heavy object with a point, this will only concentrate the force and increase the chance of shattering the glass. Tapping on the glass with pencil or ball point should give enough sound.

Use masking tape (a low tack tape) to hold the Stethoscope to the glass, this prevents the glass from being marked after the work is completed.

If you are using shaped materials, e.g. iron tube, aluminium extrusions, try to get the microphone over the largest area of material possible.

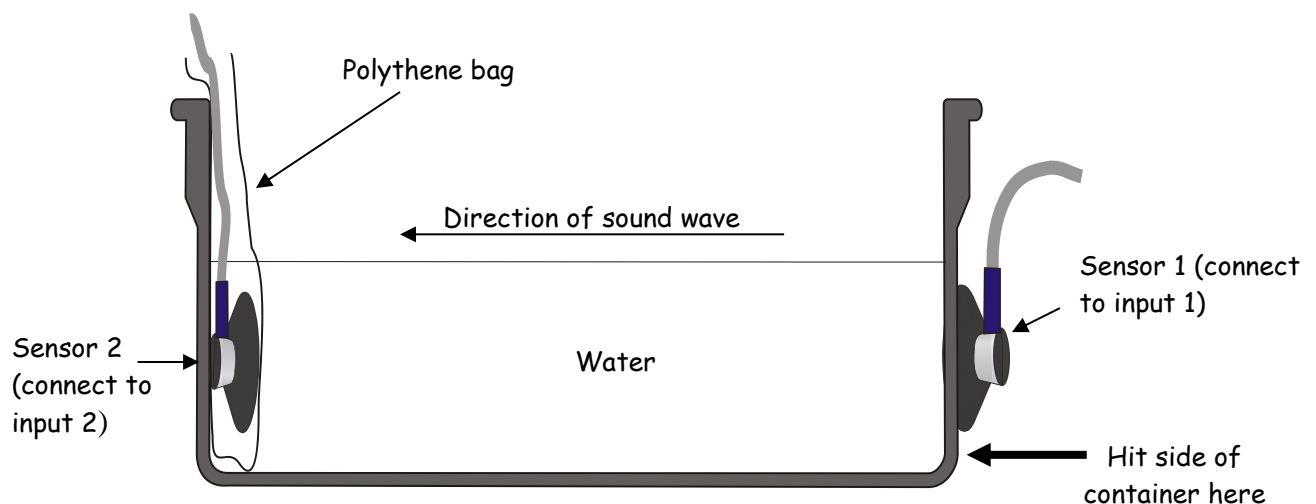
When using concrete (flooring) use extension leads to increase the separation of the sensors and check the area being used to make sure there are no joins in concrete between the sound source and or the sensors.

## 03 Speed of Sound in Liquid

### Read

Sound travels faster through water than air. In this experiment you will try to measure the speed of sound in water.

The experiment uses a simple container part filled with water. The method used is essentially the same as that used to determine the speed of sound in air, i.e. two microphones separated by a known distance. For convenience, one sensor is mounted on the outside surface of the container. The second sensor is placed in a water (and leak) proof bag which can be attached to the internal opposite facing surface of the container. With care, the second sensor can be positioned very close to the wall of the container, when the water is added to the apparatus the pressure of the water will help hold the sensor against the side of the container and press the enclosing bag against the sensor and microphone.



### Warning

The experiment works well and will show the speed of sound in water. The Stethoscope sensor is not water proof. It is the responsibility of the user to ensure that water does not come into contact with the sensor or logger. No liability can be accepted by Data Harvest for failure to take note of this warning.

### What you need

1. An **EASYSense** logger capable of fast logging
2. 2 x Smart Q Stethoscope sensors set to Sound range with diaphragm removed.
3. 1 x Smart Q Temperature sensor or thermometer.
4. Large container at least 0.5 m long.
5. Polythene bag (without holes or damage i.e. both leak and water proof).
6. 2 x long sensor cables.
7. Masking tape, modelling clay or sticky tape (to attach bag and sensors to walls of containers).



### What you need to do

1. Set up the apparatus as shown in the diagram. Fix sensor one to the outside of the container with the bell in contact with the outside wall of the container. Make sure the sensor is not touching the bench. To help when filling the container keep the sensor as low down on the container wall as possible, this will reduce the volume of water required.
2. Place the second sensor into a large polythene bag and fix the bag to the opposite inner wall of the container. The bell of the stethoscope should be facing the opposite wall of the container.
3. Check the bag is secured to the container, and that the opening of the bag is above the projected water level inside the container.
4. Fill the container with water, use enough to give a level of water above both of the sensors only. Check that as the water is added, the bag is not leaking and that the bag is pressing against the sensor. If a leak is noticed remove the bag at once, the sensor is not waterproof.
5. Start the **EASySENSE** software and select **Graph** from the Home screen.
6. Use the set up table below to set the recording parameters. (Note: The value of the trigger may need adjusting).
7. Select **Start** and then tap on the wall of the container close to sensor 1 (the external sensor). A clear sharp sound is best; experience will show the best sound and how loud it needs to be.
8. If the sound was of the correct intensity logging will be triggered and you will see 2 traces. The red trace is the sound recorded by the sensor closest to the noise and the blue trace for the sensor furthest from the noise source.
9. You should notice the peaks on the red trace appear before the peaks on the blue trace. You need to measure the distance between the first red peaks and the first blue peaks, using the **Interval** tool (see below for details).

### Set up of the software

The following set up should give good results for water tank 0.75 m long.

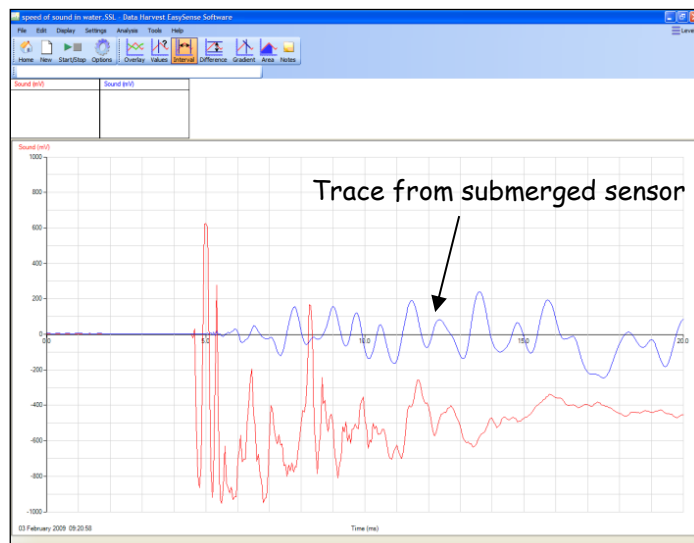
Recording mode	Length of recording	Intersample time	Trigger event	Pre trigger
Graph	50 ms	50 $\mu$ s	When sound sensor 1 rises above 100 mV	25%

Set the length & intersample time to the shortest available. Logger type and number of sensors may lead to a variation in choice. The trigger value may need adjusting down depending on the type of container used.

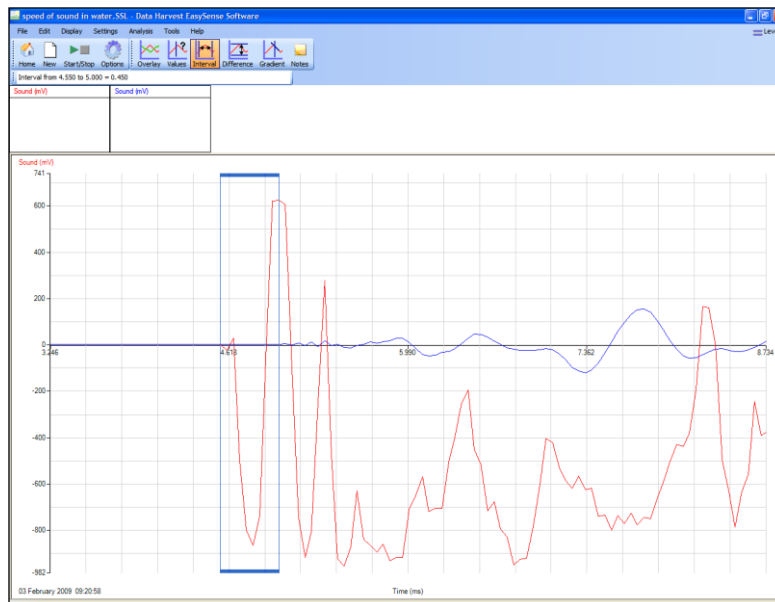
## Sample result

Path between Stethoscope sensors was 0.6 m.

Note how the water smooths the waveform, this does make the difference between the two traces ambiguous. Use **Zoom** to help find the two start points



## Analysis



**Zoom** applied to the first part of the data. The **Interval** tool has been used to mark the beginning of the sound wave on each trace and reveal the time difference. With this data the time resolution gave a value of 0.450 ms or 0.500 ms, use the mean of the two estimates for calculation i.e. 0.475 ms

## Calculations

In this example the distance between the Stethoscope sensors was measured at 0.60 m.

The **Interval** tool revealed the time for the sound to reach the second sensor after reaching the first was 0.475 ms

Speed of sound = distance / time

= 0.6 / 0.000475 (time corrected from ms to s).

= 1263 m/s

This is considerably faster than the speed of sound in air. No correction has been made for temperature. Use the Temperature sensor to find the water temperature and apply any correction factor as required.

Speed of sound in water is normally quoted as 4 x faster than in air. You can use this as a quick check to see how good your results were. Speed of sound in air is 331.1 m/s

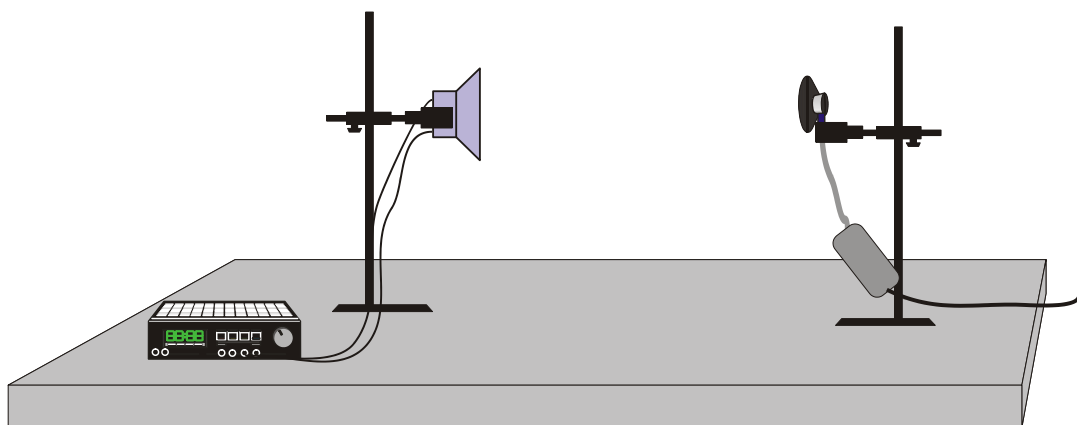
1. If your result showed a big difference what were the sources of error that created this difference?
2. How could you control the experiment better on a repeat experiment?
3. What would be the effect of adding salt to the water (making artificial sea water)?
4. Does the depth of the water have an effect on the speed of sound?

## 04 Speed of Sound in Air by phase difference

### Read

When you have a loudspeaker connected to a signal generator the tone being produced by the generator can be made audible (assuming the tone is within the audible range and the speaker's response range). If you place a microphone in front of the loudspeaker you will (with the aid of a suitable logger or an oscilloscope) show the waveform of the tone. With a pair of microphones together (side by side) the wave signals from each microphone will be in phase (peaks and troughs of the waves will line up). If you keep one microphone fixed, and move the other to be more distant from the loudspeaker the displayed waves will move out of phase (the peaks and troughs will no longer line up). If you keep moving the second microphone, you will eventually reach a point where the waves come back in phase. The distance between the points from when the waves are in phase and back in phase again, is one wavelength of the original tone being produced by the signal generator.

We can show this using either a pair of Stethoscope sensors or a single Stethoscope sensor and a Voltage sensor. For convenience in this experiment you will use a Voltage sensor connected across the output of the signal generator and a single moving Stethoscope sensor.



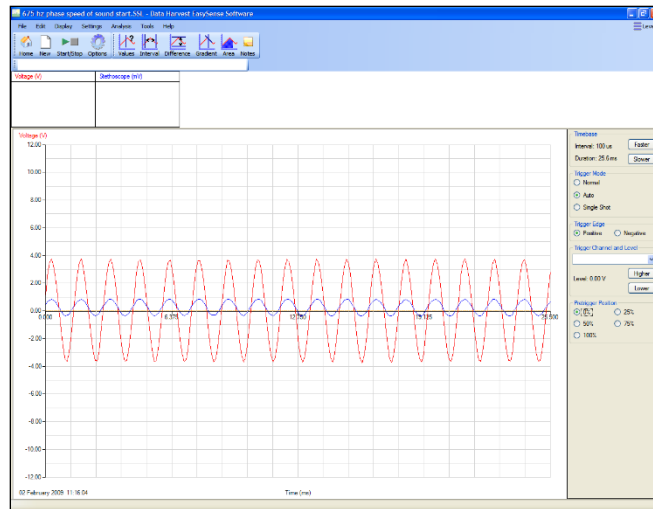
### What you need

1. An EASYSense logger capable of fast logging
2. 1 x Smart Q Stethoscope sensor set to Stethoscope range with the diaphragm removed
3. 1 x Smart Q Voltage sensor  $\pm 12$  or 20 V
4. Signal generator
5. Loudspeaker matched to signal generator's output
6. Patch leads
7. Retort stands and clamps

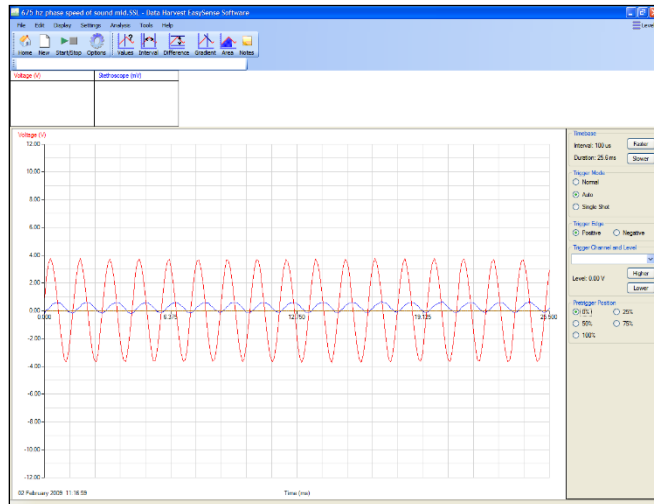
### What you need to do

1. Set up the apparatus as shown in the diagram. Don't worry too much about the separation of the Stethoscope sensor to loudspeaker at present.
2. Select a frequency of about 400 - 600 Hz, this gives a reasonable wavelength.
3. Place the Stethoscope sensor as close to the loudspeaker as possible.
4. Start the **EASYSense** software and select **Scope** from the Home page. No further set up of the software is required.
5. Turn on the signal generator and verify that a tone is being generated at the loudspeaker, adjust the amplitude / volume control to give an acceptable volume (pure tones, as generated by signal generators are especially invasive).
6. Select **Start**. Check the signal from the Voltage and Stethoscope sensors are approximately in phase (see note below). If not reverse the cables to the Voltage sensor.
7. Once you are happy the signals from both the Voltage and Stethoscope sensors are showing the same approximate phase start to move the Stethoscope sensor away from the loudspeaker, you should notice the relative position of the waves starts to move. Move the sensor until the wave from the signal generator (as measured by the Voltage sensor) is in phase with the wave being shown by the Stethoscope sensor. Mark this position or measure the position of the Stethoscope sensor from a reference point e.g. the frame of the speaker. You may need to right click and select **Autoscale**.
8. Once this in phase position has been marked, move the Stethoscope sensor until the waves go out of phase and then come back in phase with each other. Mark the bench / position of the Stethoscope sensor at the point when the waves are back in phase and measure the distance. You may need to repeatedly stop and restart logging so that you can use the **Values** tool to check how well the waves are phased. As distance increase you may need to increase the volume, try not to use maximum volume.
9. Repeat to collect enough data for an average.
10. On the last run select **Stop** and Save the data, use the Voltage waveform data in the saved file to calculate or verify the frequency (displays of frequency are not always accurate).

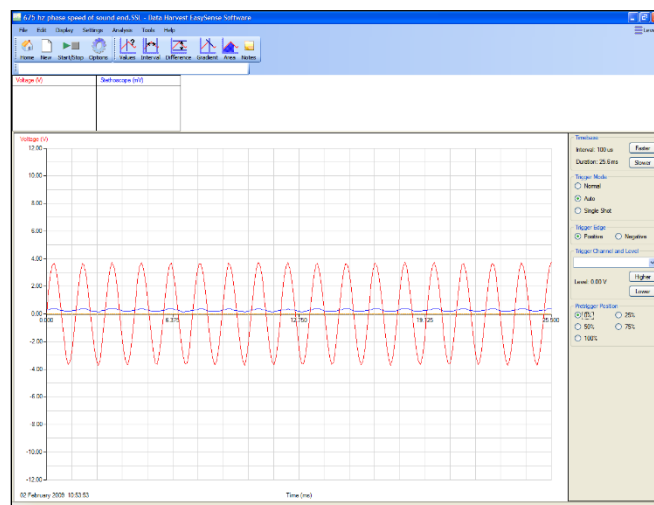
## Sample data



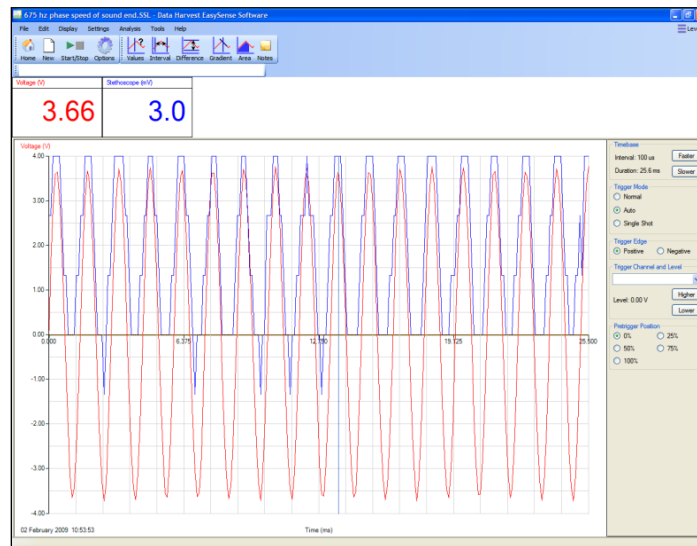
Voltage and Sound in phase with Stethoscope at its closest point to the speaker.



Sound and Voltage out of phase, as the Stethoscope is moved away from the loud speaker.



Sound and Voltage back in phase when the Stethoscope sensor is at its most distant from the speaker. You will need to use **Autoscale** at this point to check the phase difference.



Using **Autoscale** on the data to see if the waves are in phase. Use the **Values** tool to check alignment.

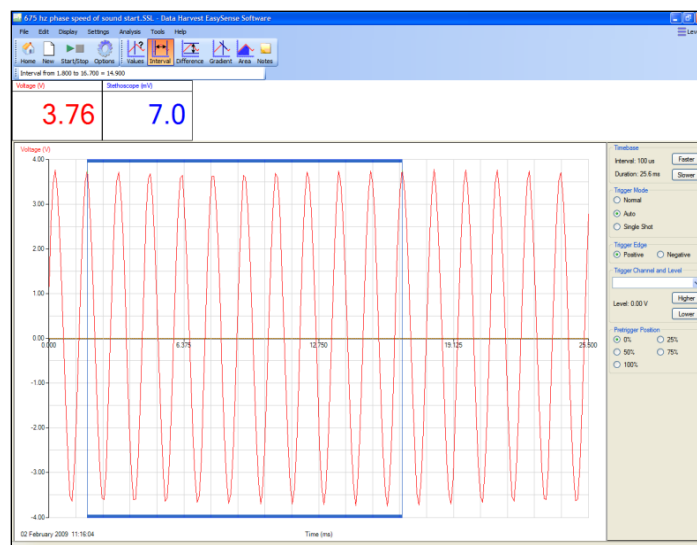
## Calculations

Find the frequency from the voltage wave.

1. Taking a single wave. Use the **Interval** tool to find the interval between two adjacent peaks.
2. Calculate  $1 / \text{interval (in seconds)} = \text{frequency in Hz}$ . Take several peaks and produce an average.

Selecting 10 peaks to calculate frequency.

3. Using multiple waves.
  - a. Use the **Interval** tool to find the time interval for 10 peaks.
  - b. Divide the time interval by the number of peaks to find the time for one cycle.
4. Calculate  $1 / \text{interval (in seconds)} = \text{frequency in Hz}$



In the sample data the interval between adjacent peaks was 1.5 ms; this gave a calculated frequency of 666.66 Hz. Using several peaks allowed an average to be calculated. A frequency meter confirmed the frequency was 675 Hz. Using 10 peaks to calculate frequency gave a value of 672 (14.8 ms over 10 peaks) suggesting that this was a more accurate method of determining the frequency.

### Calculate the speed of sound

Values taken from a recorded practical.

1.  $f = 672 \text{ Hz}$
2.  $L = 0.525 \text{ m}$  (initial in phase distance 23 cm - final in phase distance 75.5 cm)
3.  $f / L = 352 \text{ m/s}$

Temperature of the room =  $25^\circ\text{C}$ , correction =  $0.607 \text{ m/s per } 1^\circ\text{C} = 25 \times 0.607 = 15.2$ .

Expected value =  $331.3$  (speed at standard pressure and  $0^\circ\text{C}$ ) +  $15.2 = 346.5$ .

Experimental value =  $352$ . (2% error over theory)

Note: With the speaker and frequency being used, the first "in phase" was 23 cm in front of the speaker. This is due to a lagging phase shift between the sound wave and the changing voltage driving the speaker. The lag is created by impedance within the coil magnet system driving the speaker cone. The lag can be up to 45 degrees of phase difference or  $45 / 360 = 12.5\%$ .