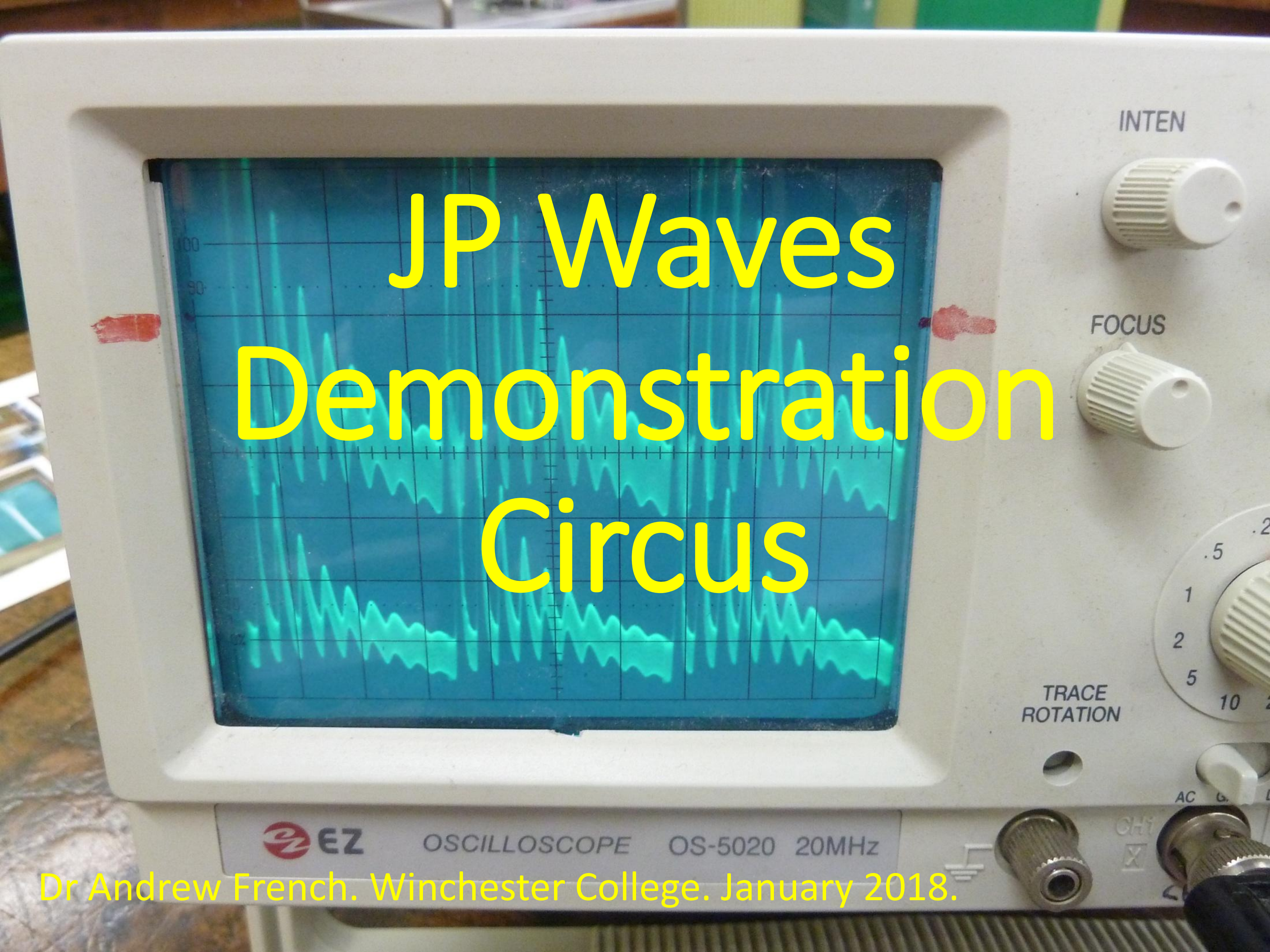
JP Waves Demonstration Circus



Dr Andrew French. Winchester College. January 2018.

JP Waves Circus Demonstrations

1. Slinkies
2. Tuning forks, a microphone and an oscilloscope
3. Measuring the speed of sound
4. Measuring the speed of light in a conductive cable
5. Kundt’s tube
6. Rubens’ tube
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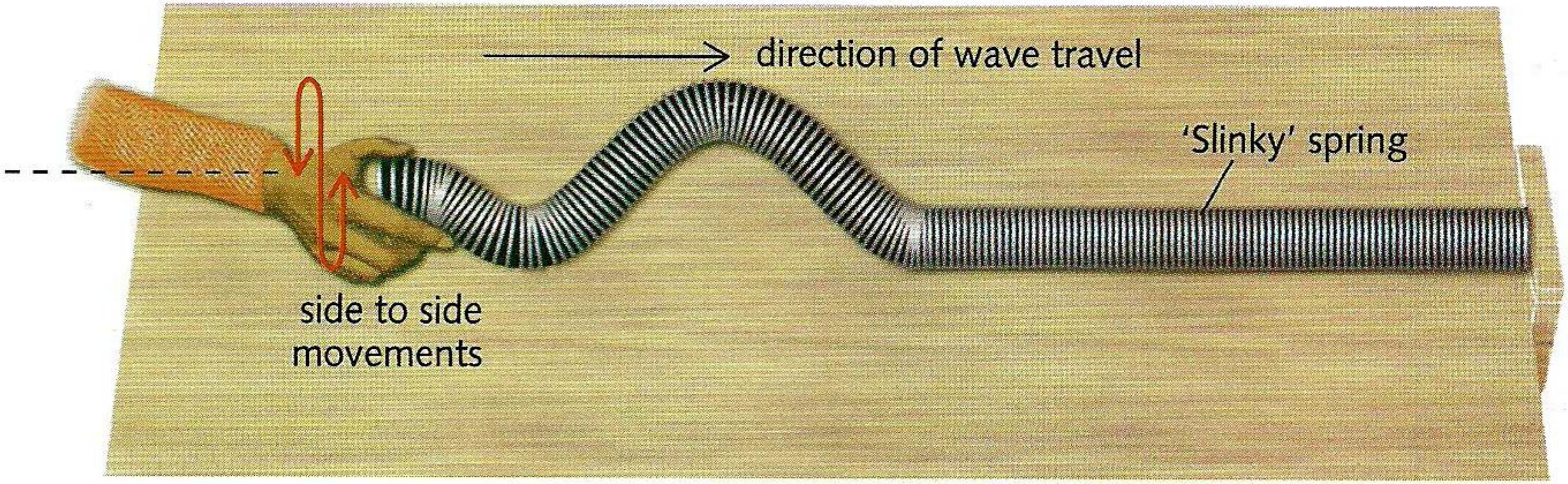
8. Signal generator and two-speaker sound interference recorded using a CRO + microphone
9. Diffraction of water waves using a ripple tank

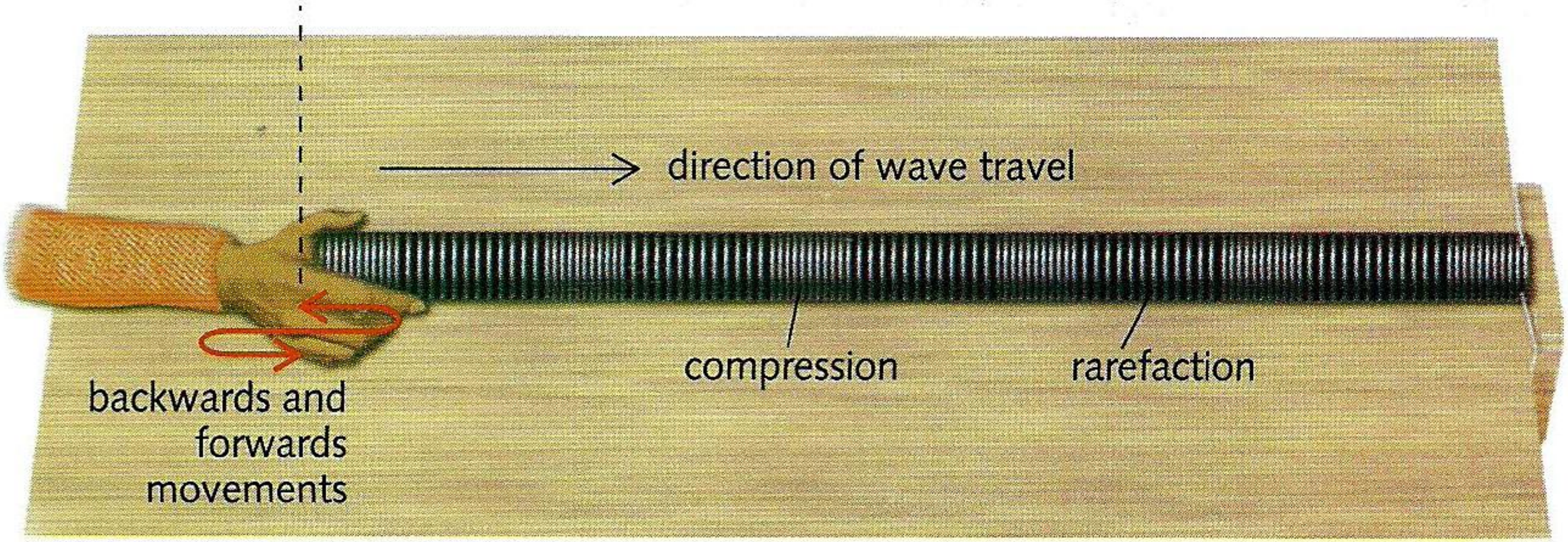
JP Waves Circus Demonstrations
Slinkies

- Idea of wave being a *disturbance*
- Longitudinal vs transverse waves
- Speed of waves varies with slinky tension
- 180^{o} phase change on reflection from fixed end
- Idea of standing waves – *nodes* and *antinodes*

Transverse waves

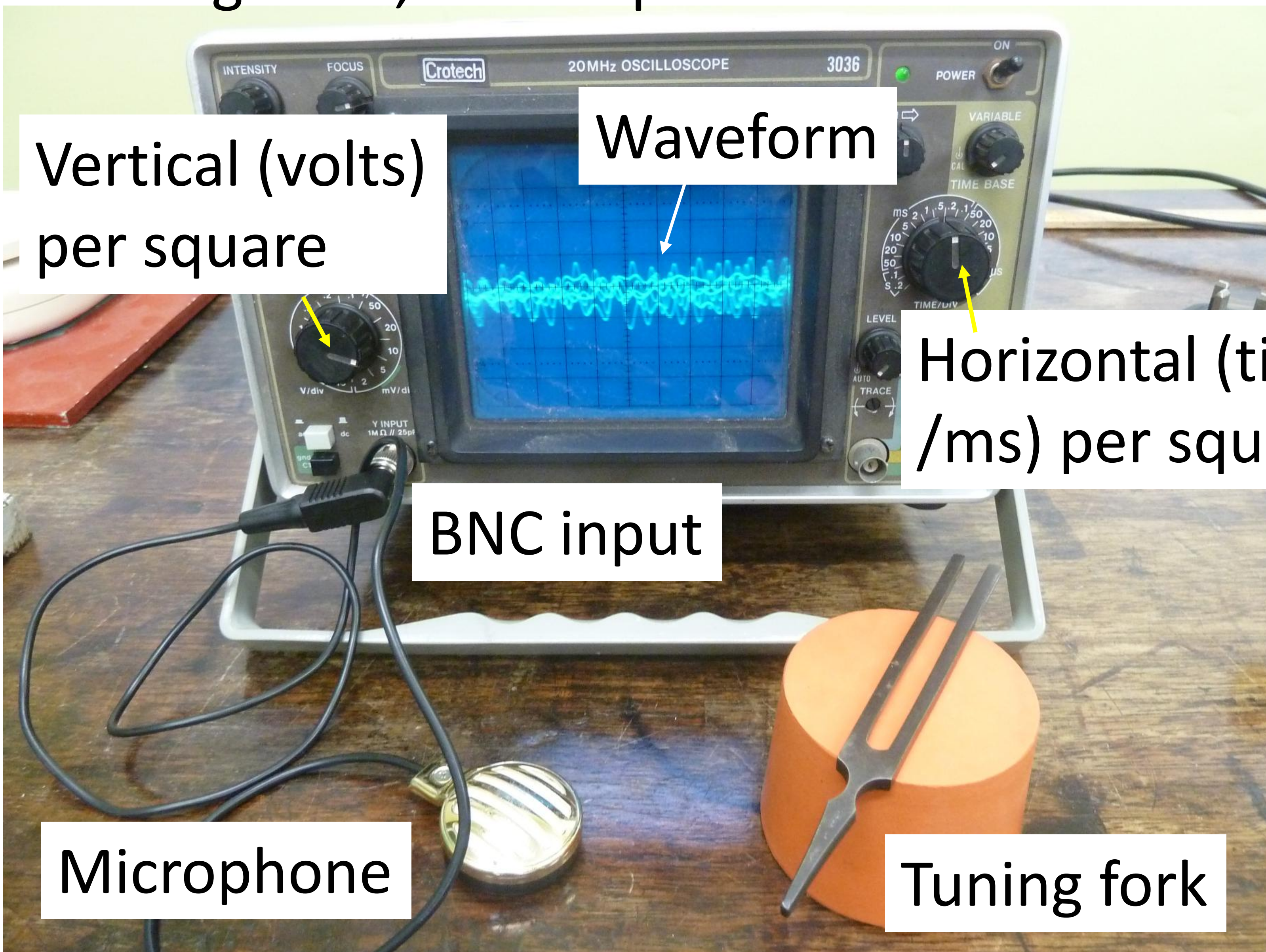


Longitudinal waves



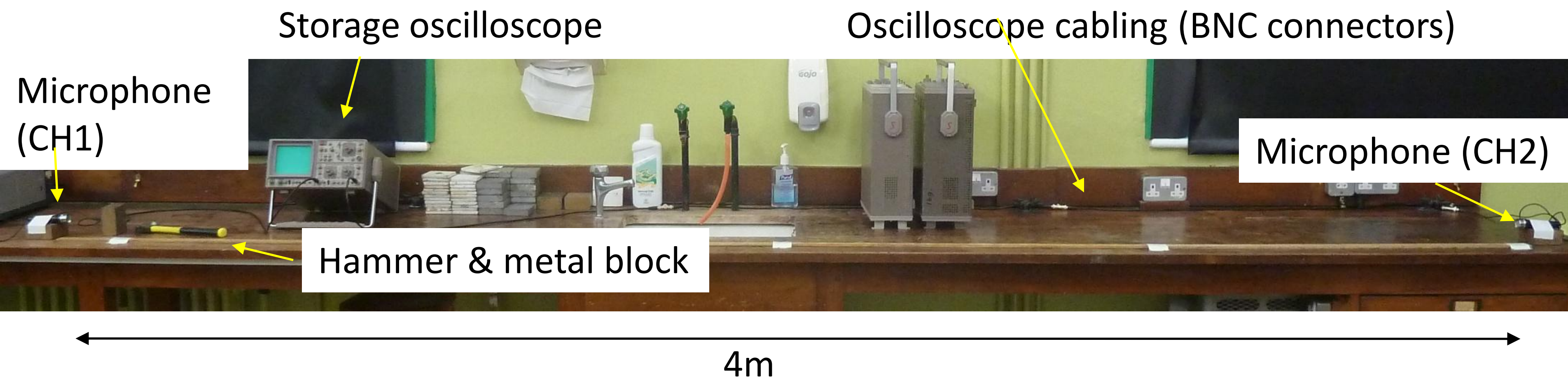
JP Waves Circus Demonstrations

#2 Tuning forks, a microphone and an oscilloscope



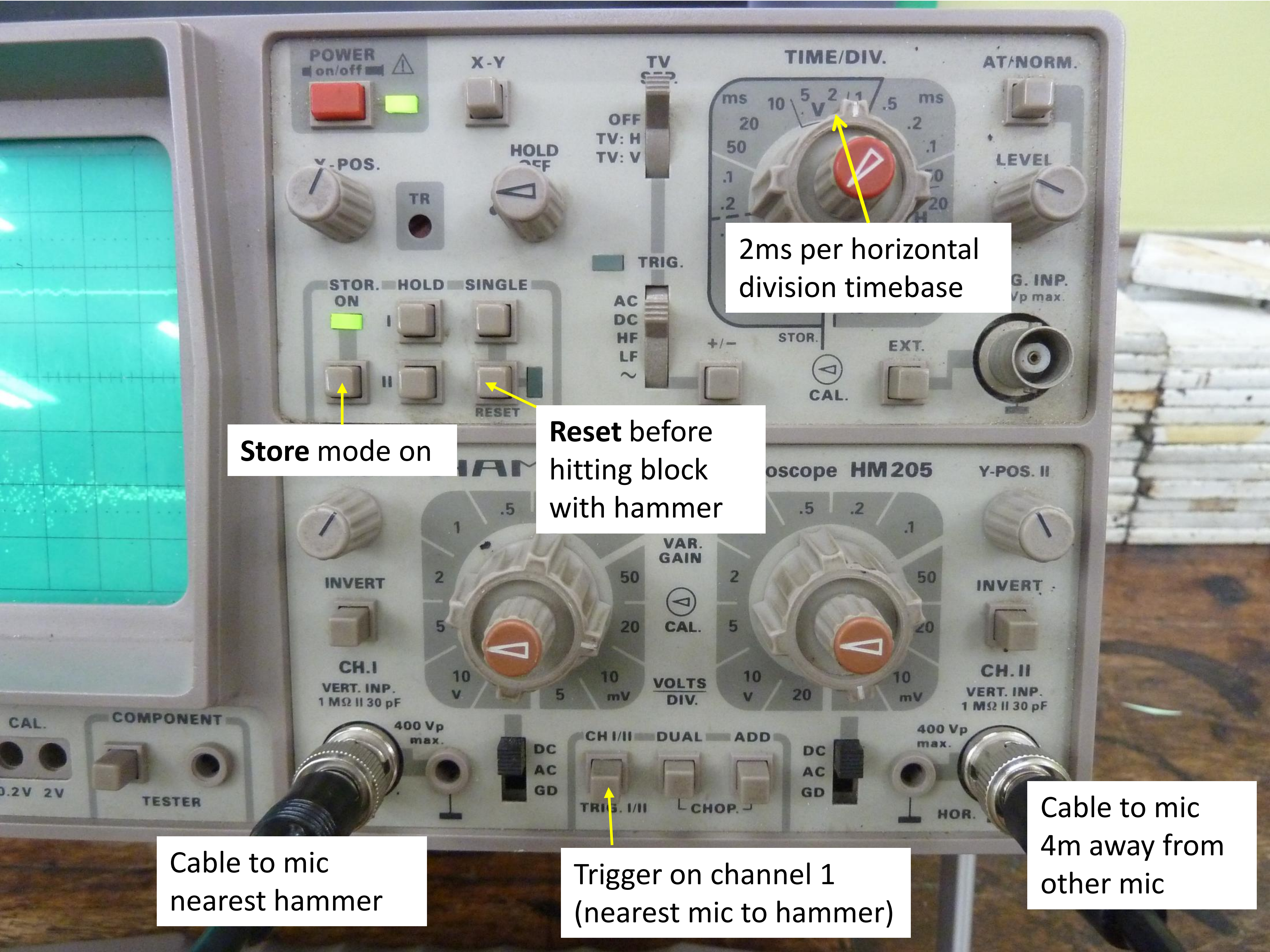
JP Waves Circus Demonstrations

#3 Measuring the speed of sound

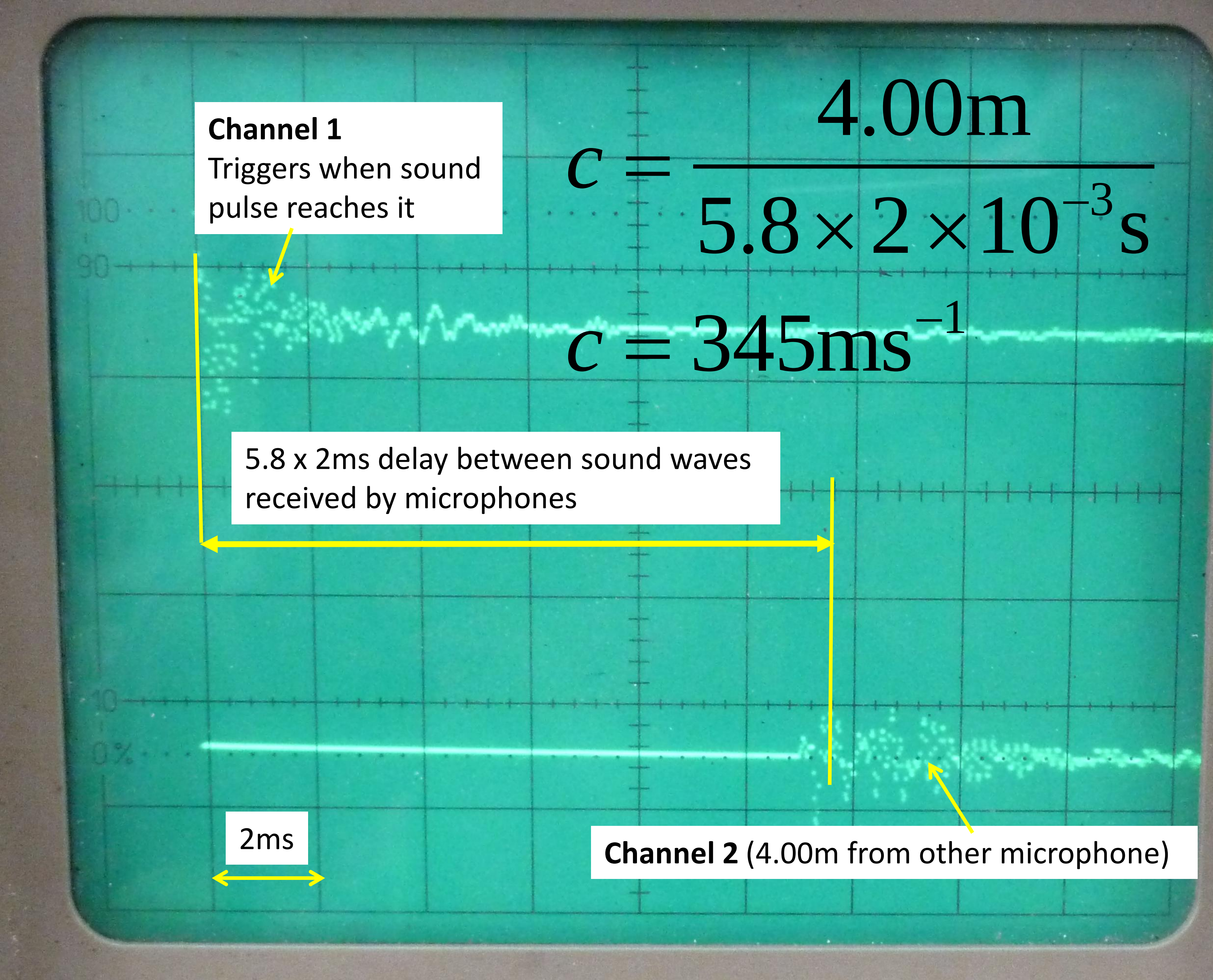


Pick up block and strike with hammer to produce a sound pulse. Pick up block to avoid bench vibration.

Strike *behind* mic so CRO triggers when sound wave reaches this mic. The recorded delay is therefore the separation between the microphones.



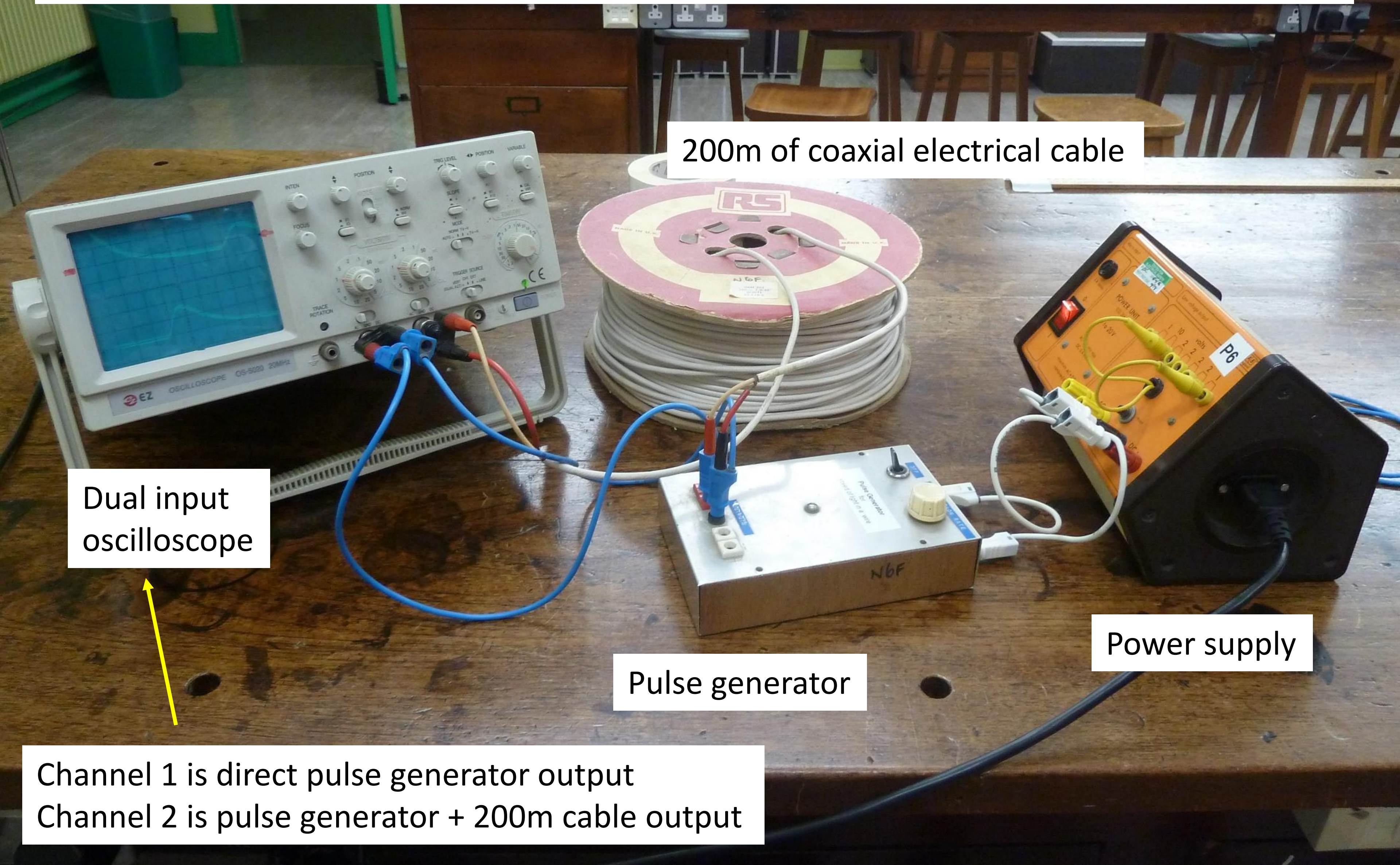
POWER
on/off
X-Y
TV
TIME/DIV.
AT/NORM.
2ms per horizontal division timebase
Store mode on
Reset before hitting block with hammer
oscope HM205
Cable to mic nearest hammer
Trigger on channel 1 (nearest mic to hammer)
Cable to mic 4m away from other mic



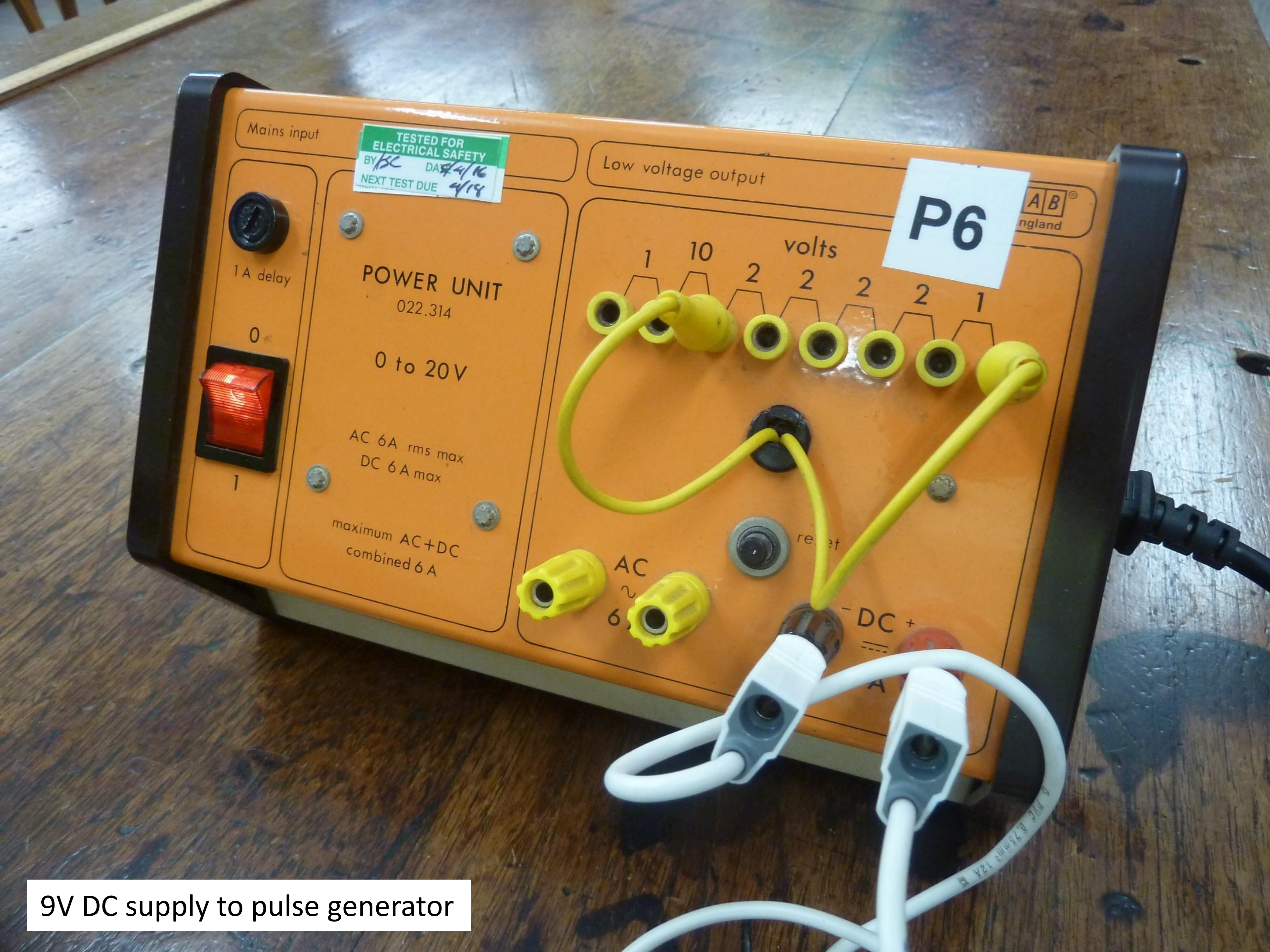
Channel 1
Triggers when sound pulse reaches it
$c = \frac{4.00\text{m}}{5.8 \times 2 \times 10^{-3}\text{s}}$
$c = 345\text{ms}^{-1}$
5.8 x 2ms delay between sound waves received by microphones
2ms
Channel 2 (4.00m from other microphone)
100
90
10
0%

JP Waves Circus Demonstrations

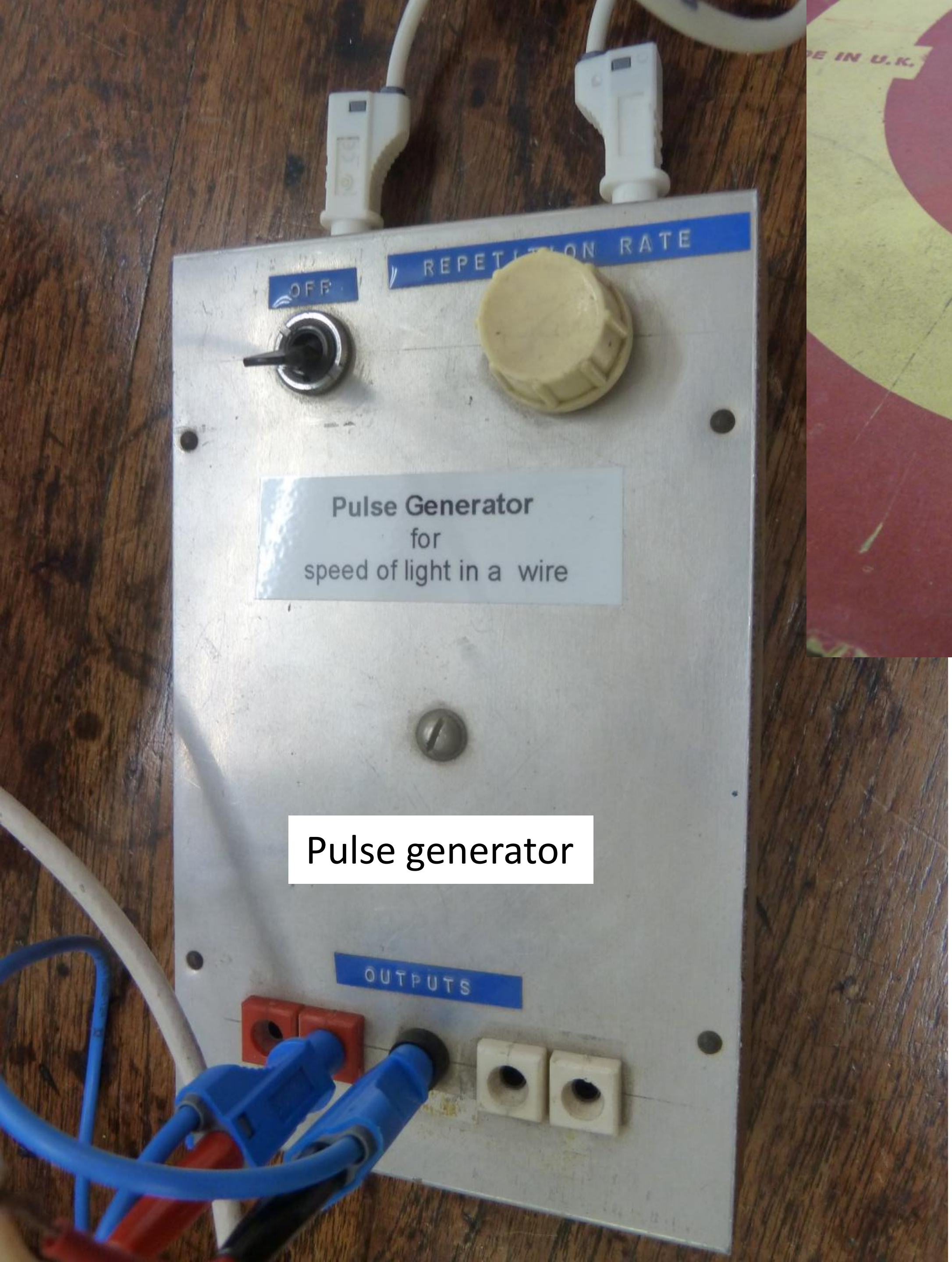
#4 Measuring the speed of light in a coaxial cable



Channel 1 is direct pulse generator output
Channel 2 is pulse generator + 200m cable output

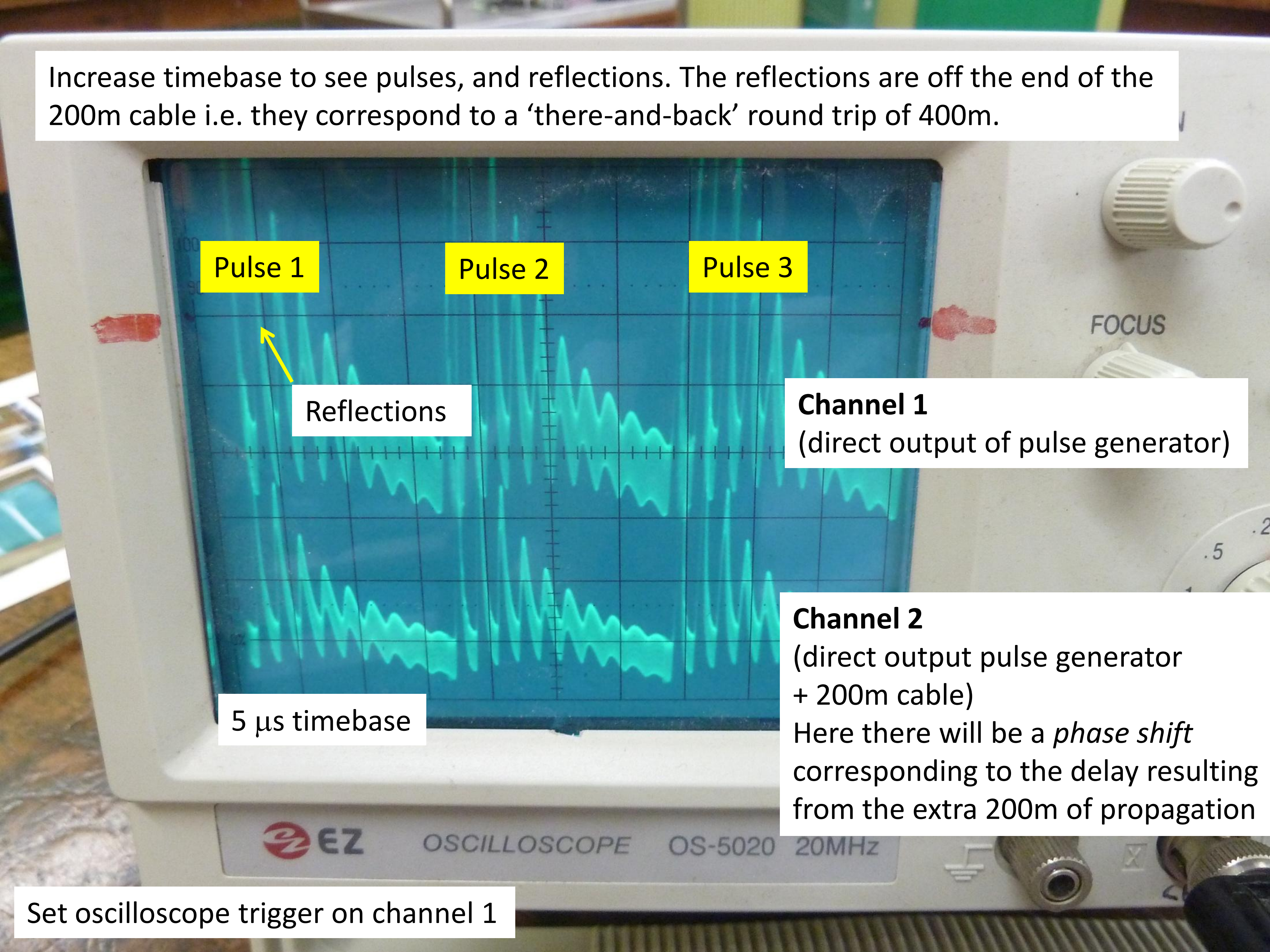


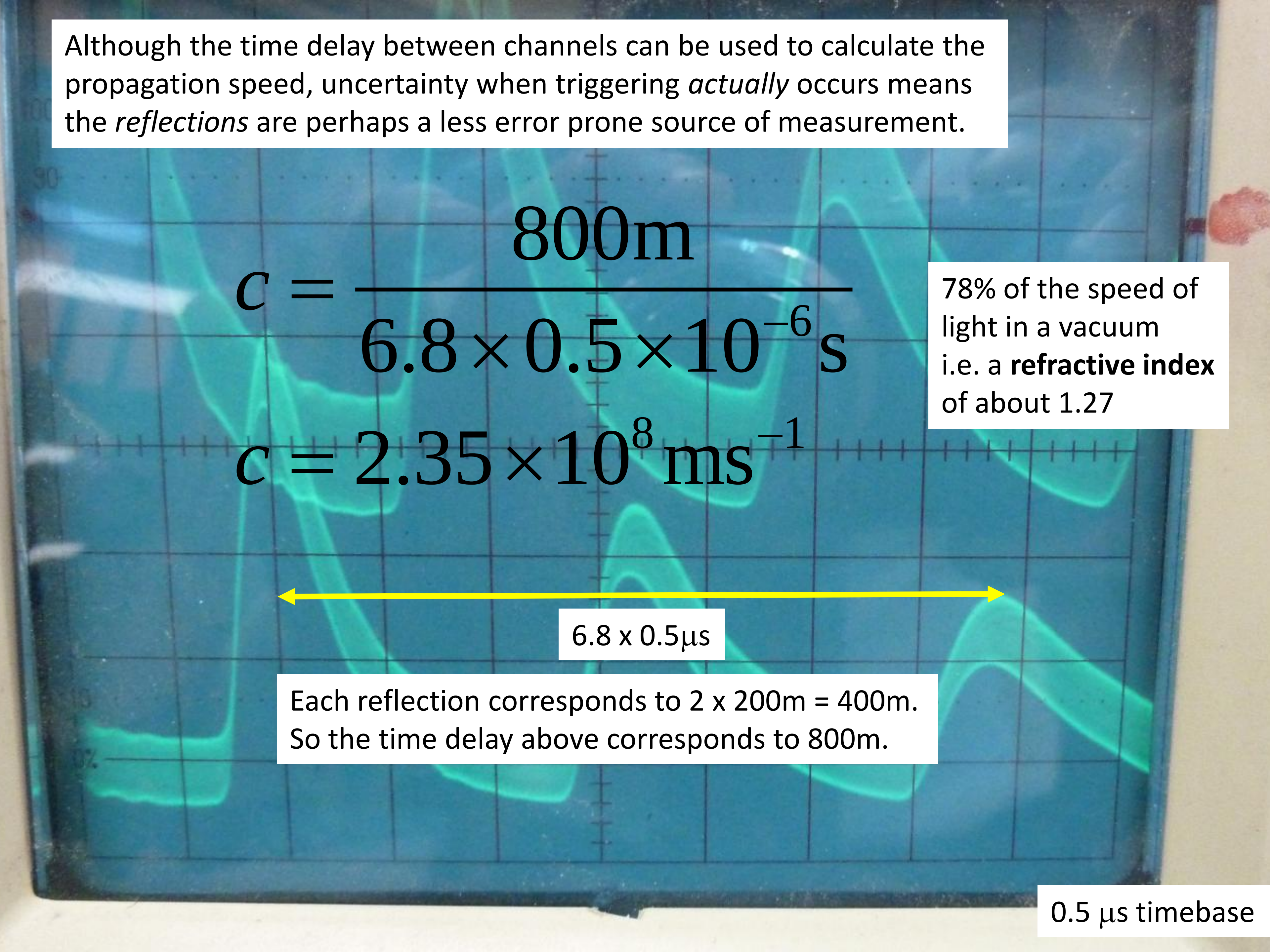
9V DC supply to pulse generator



Pulse generator

Wire specification


Increase timebase to see pulses, and reflections. The reflections are off the end of the 200m cable i.e. they correspond to a 'there-and-back' round trip of 400m.
Pulse 1
Pulse 2
Pulse 3
Reflections
Channel 1
(direct output of pulse generator)
Channel 2
(direct output pulse generator + 200m cable)
Here there will be a phase shift corresponding to the delay resulting from the extra 200m of propagation
5 μs timebase
Set oscilloscope trigger on channel 1
FOCUS
EZ
OSCILLOSCOPE
OS-5020
20MHz



Although the time delay between channels can be used to calculate the propagation speed, uncertainty when triggering *actually* occurs means the *reflections* are perhaps a less error prone source of measurement.

$$c = \frac{800\text{m}}{6.8 \times 0.5 \times 10^{-6}\text{s}}$$

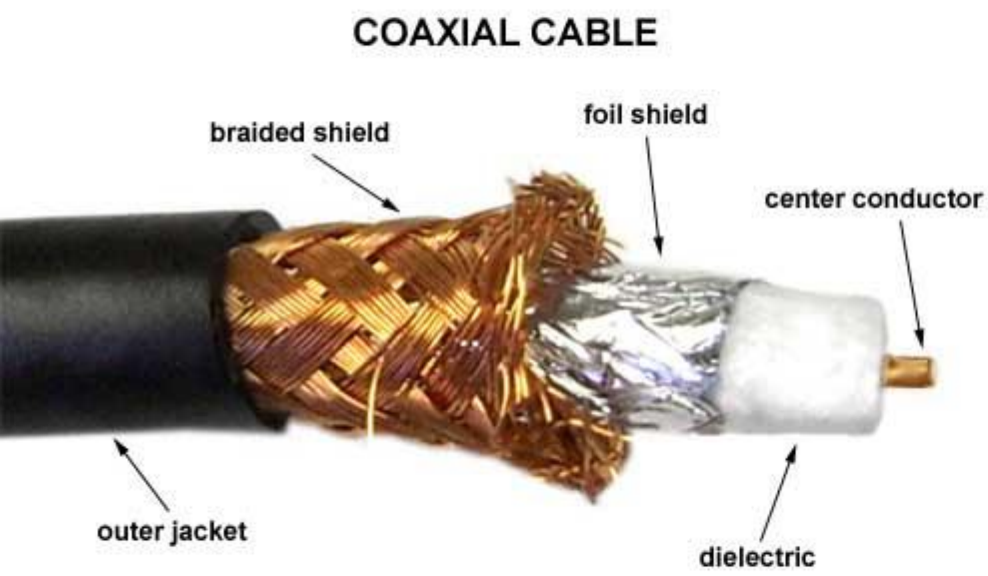
$$c = 2.35 \times 10^{8}\,\text{ms}^{-1}$$

78% of the speed of light in a vacuum i.e. a **refractive index** of about 1.27

6.8 x 0.5μs

Each reflection corresponds to 2 x 200m = 400m.
So the time delay above corresponds to 800m.

0.5 μs timebase



Electromagnetic waves travel at speed v in the coaxial cable

$$v = \frac{c}{\sqrt{\varepsilon}}$$

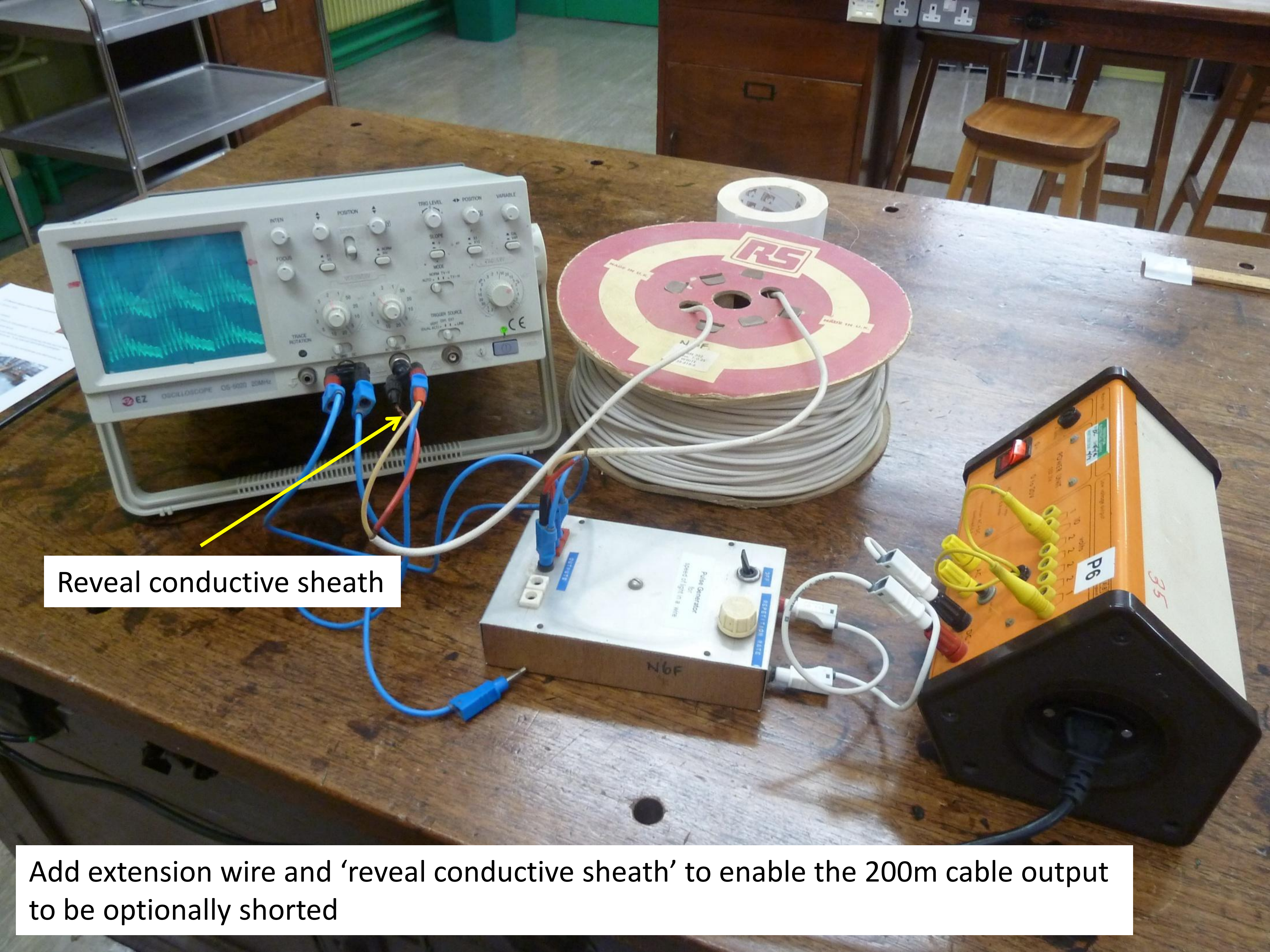
c: Speed of light in vacuum $2.998\times10^{8}\,\mathrm{ms}^{-1}$

ε: *Relative Permittivity* of dielectric

So the relative permittivity of our dielectric is predicted to be:

$$\varepsilon = \left(\frac{c}{v}\right)^2 = 1.27^2 = 1.62$$

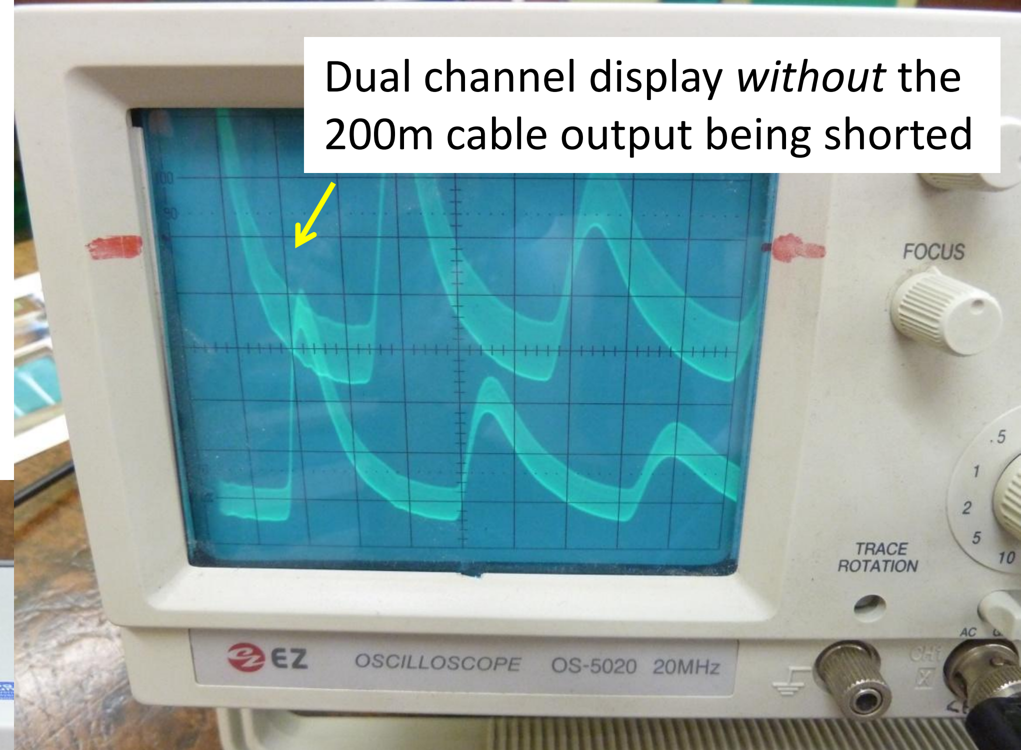
Note relative permittivity of PTFE is about 2.1


Reveal conductive sheath
Add extension wire and 'reveal conductive sheath' to enable the 200m cable output to be optionally shorted
RS
EZ
N6F
P6

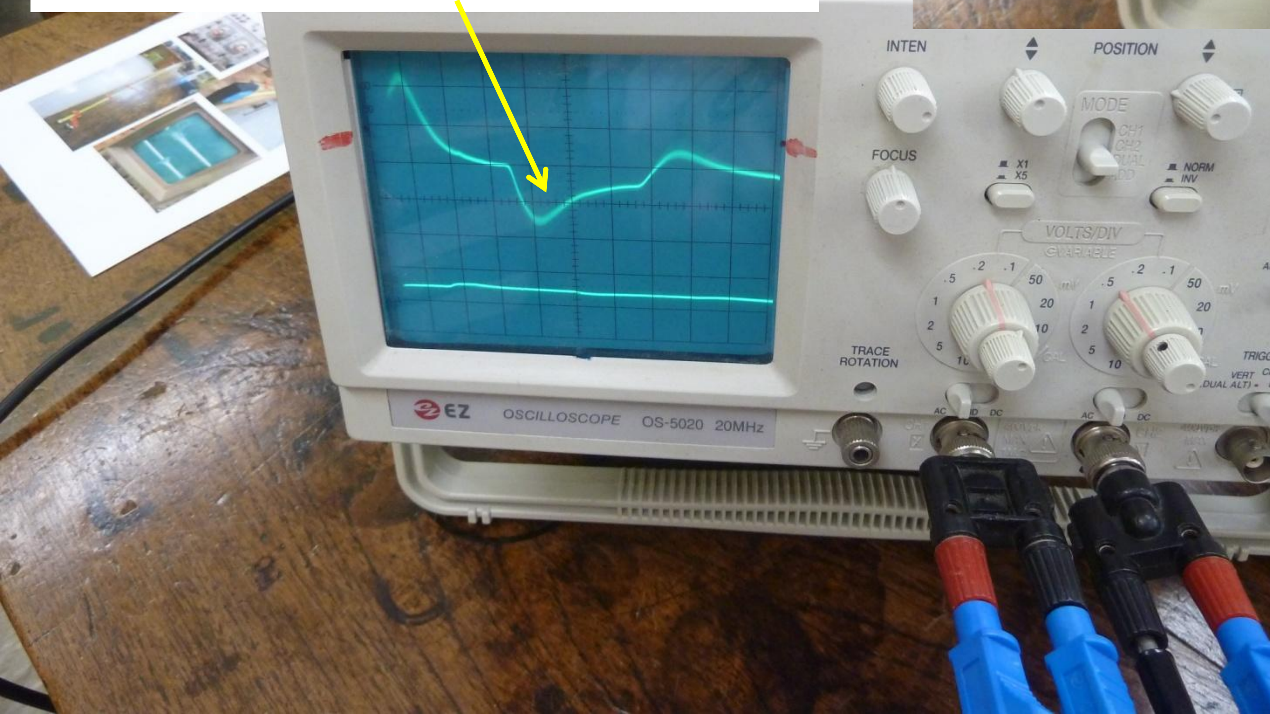
After 200m cable has been shorted. Note this causes the second reflection to be *inverted.*

Unlike the unshorted case, the reflected pulses are phase shifted by 180^o when they reflect of the end of the cable.

This also explains why only odd numbered pulses are inverted.



Dual channel display *without* the 200m cable output being shorted

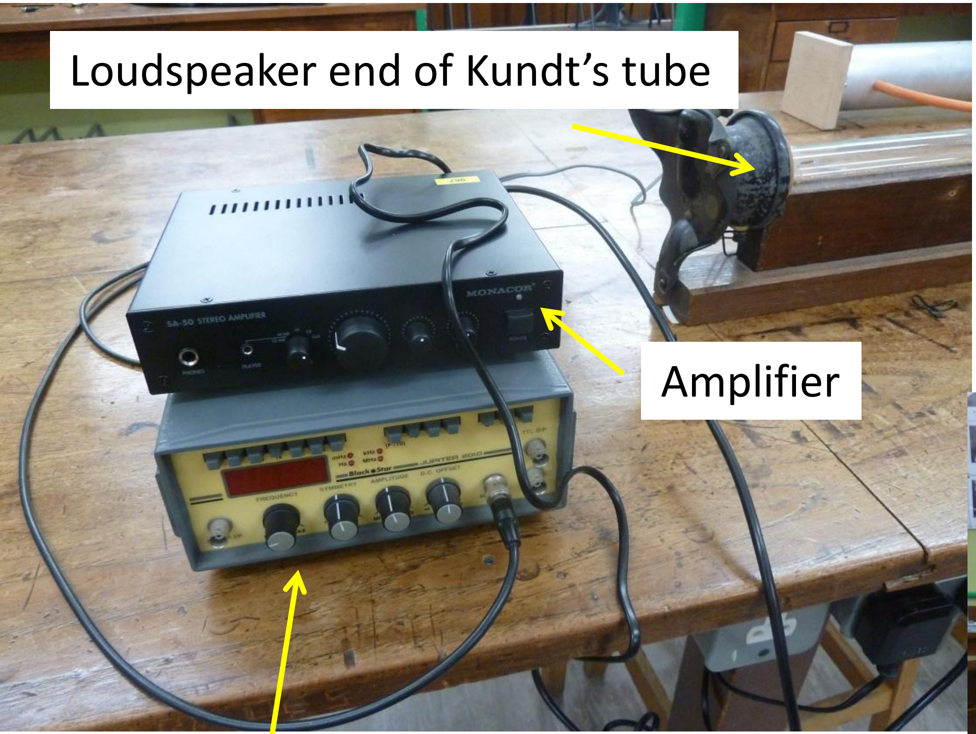


0.5 μs timebase

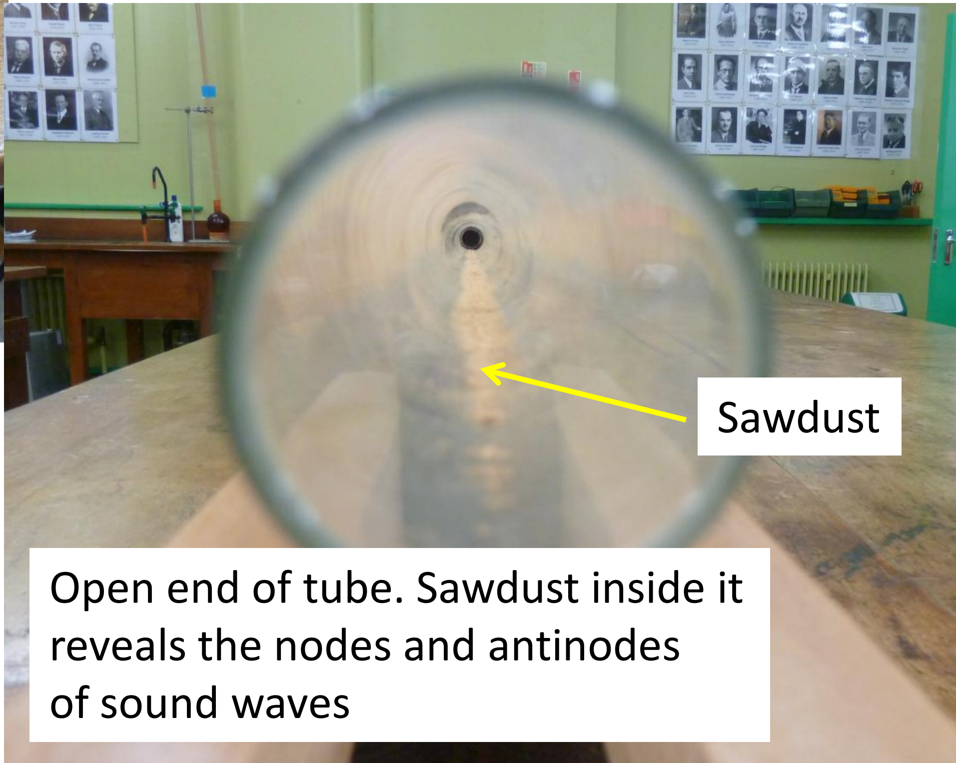
JP Waves Circus Demonstrations

#5 Kundt's tube

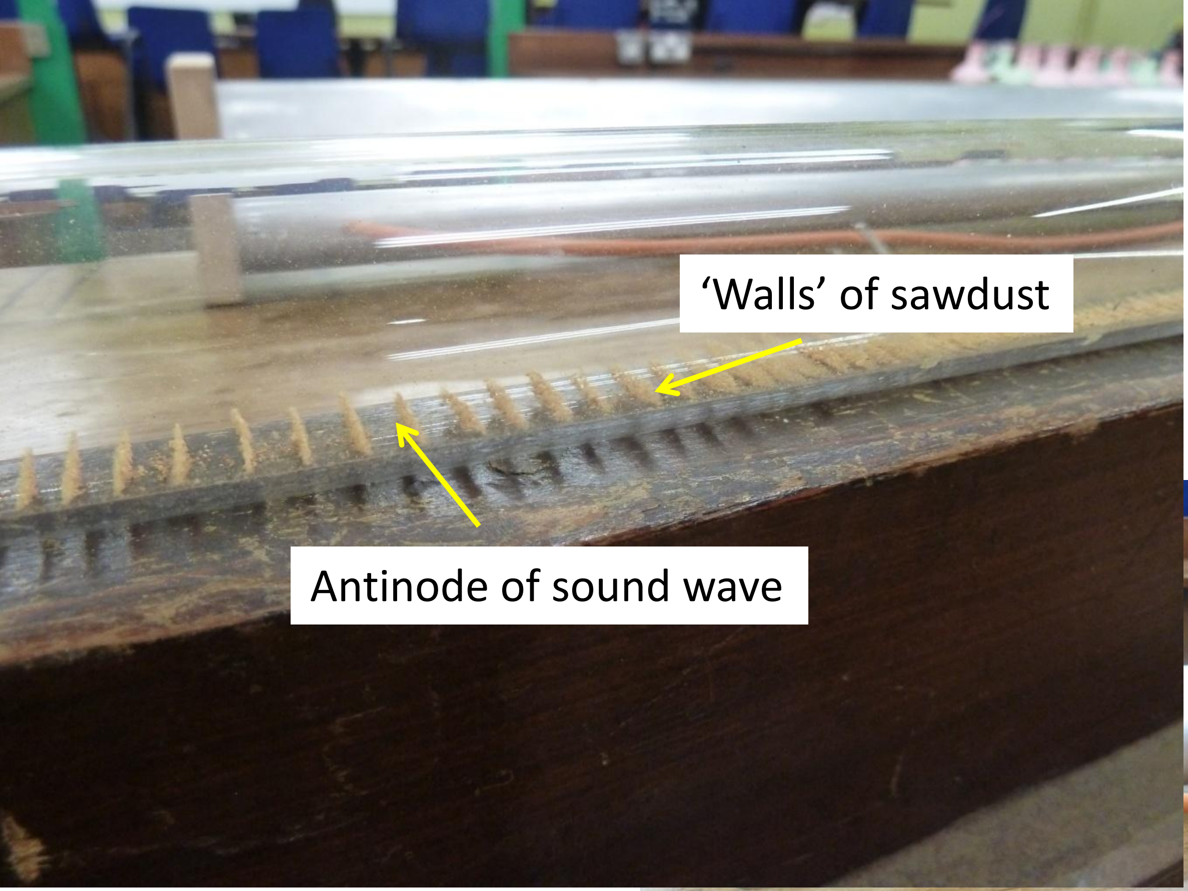
August Kundt
1839-1894

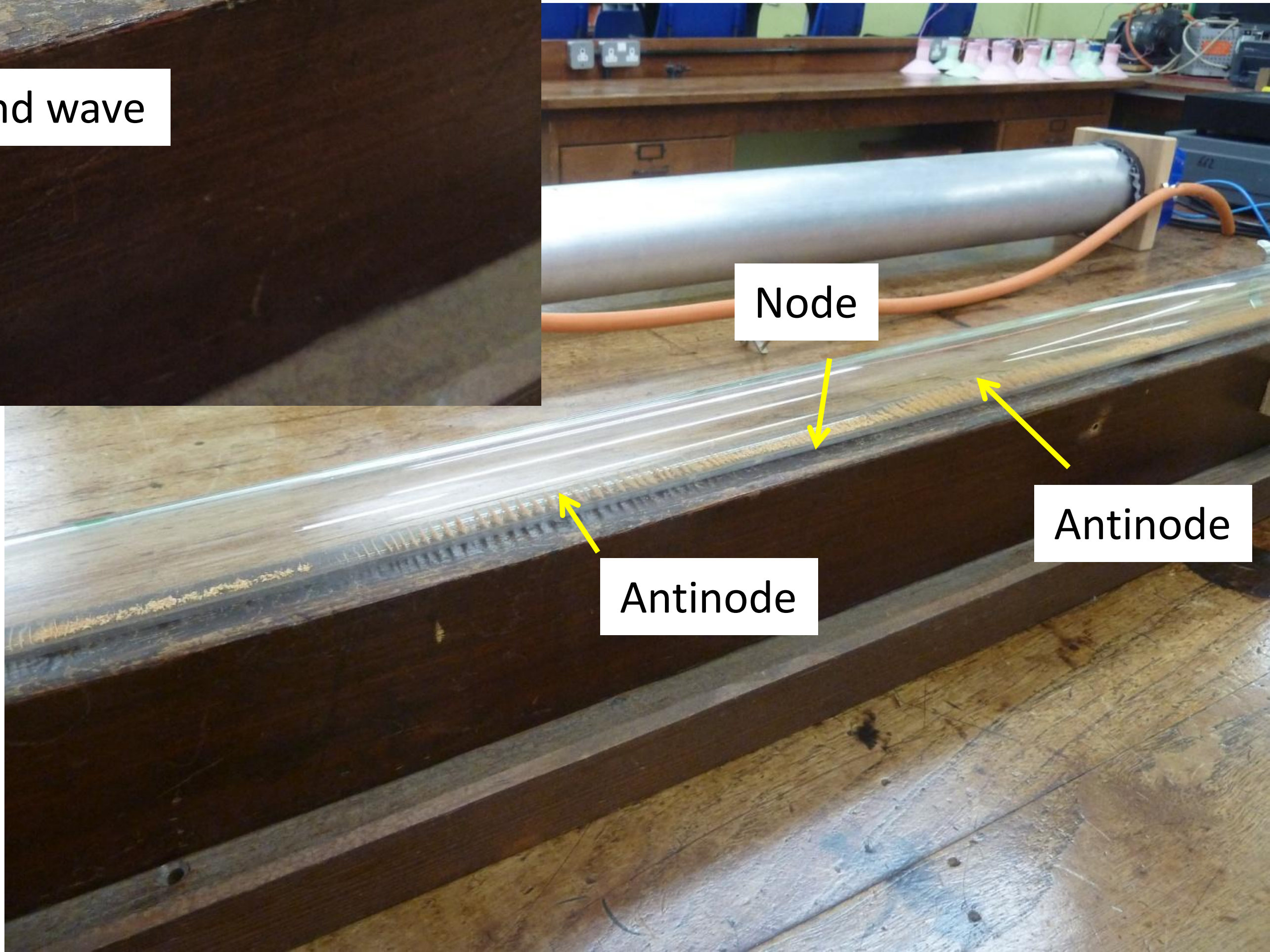


Signal generator

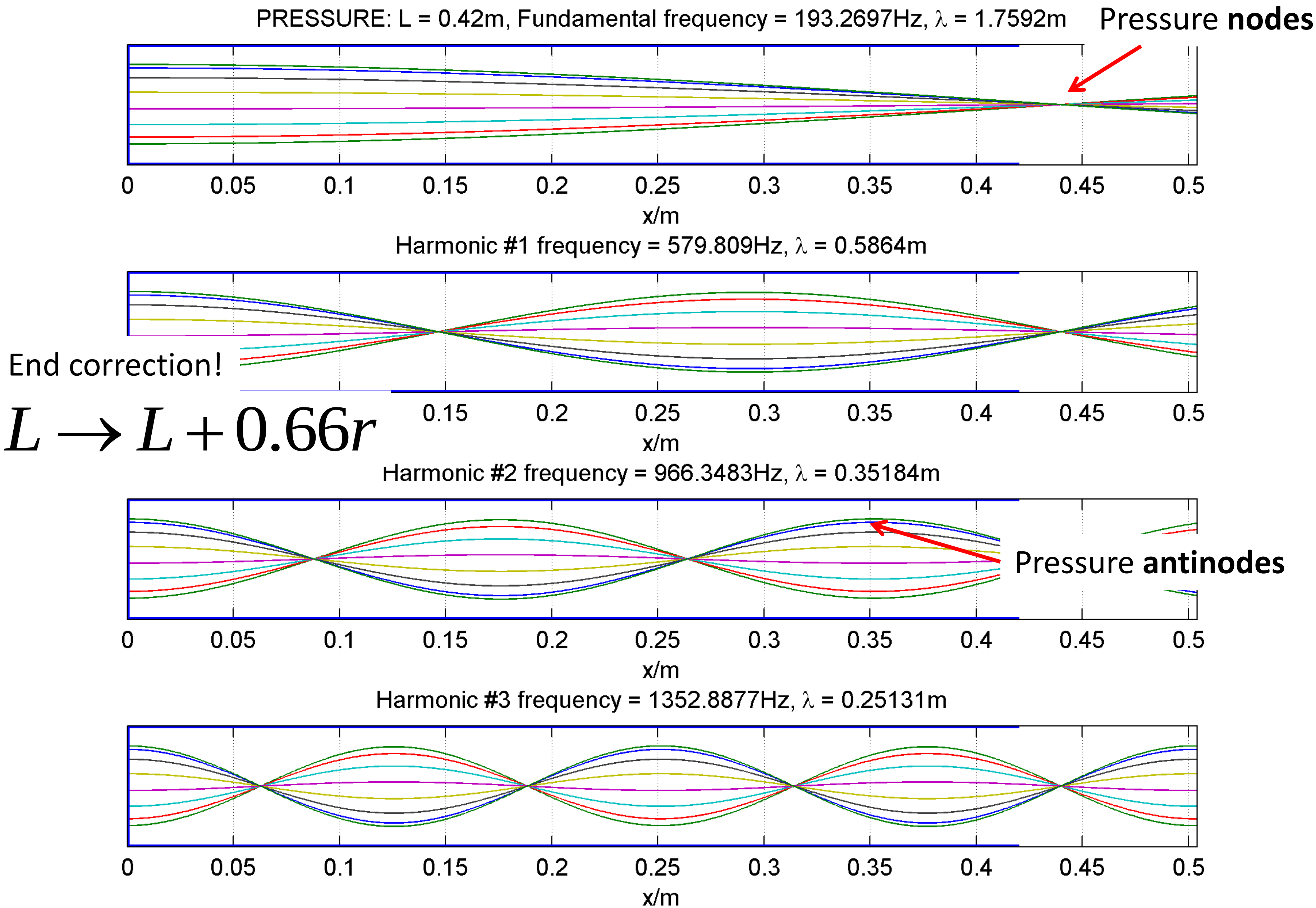


* Wear ear defenders! *





Note *air pressure antinodes* are *air displacement nodes* and vice versa

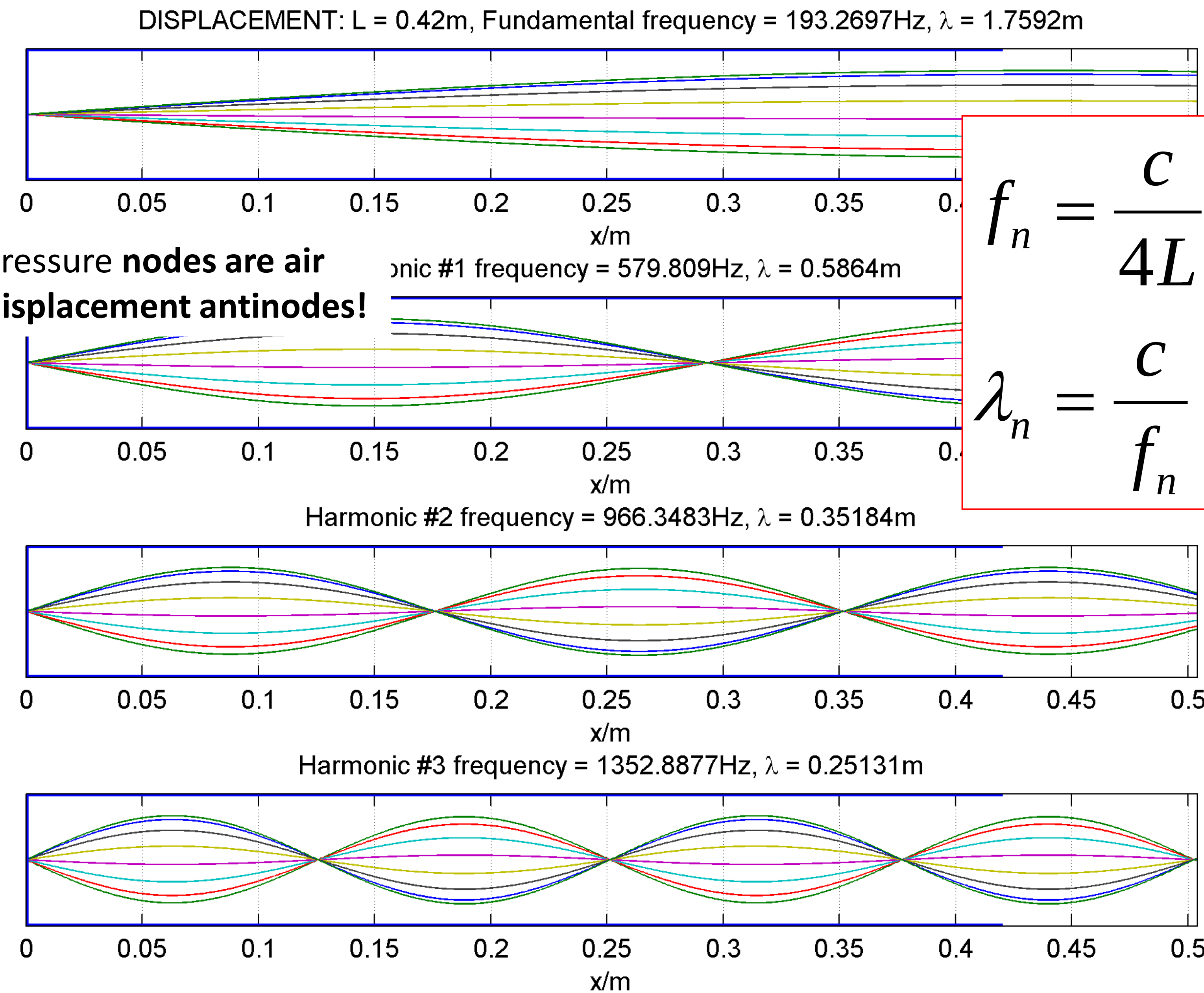


Standing waves in an **open ended tube**: Air pressure vs distance at times within a wave period

Pressure **nodes are air displacement antinodes!**

$$f_n = \frac{c}{4L}(2n-1)$$

$$\lambda_n = \frac{c}{f_n} = \frac{4L}{2n-1}$$

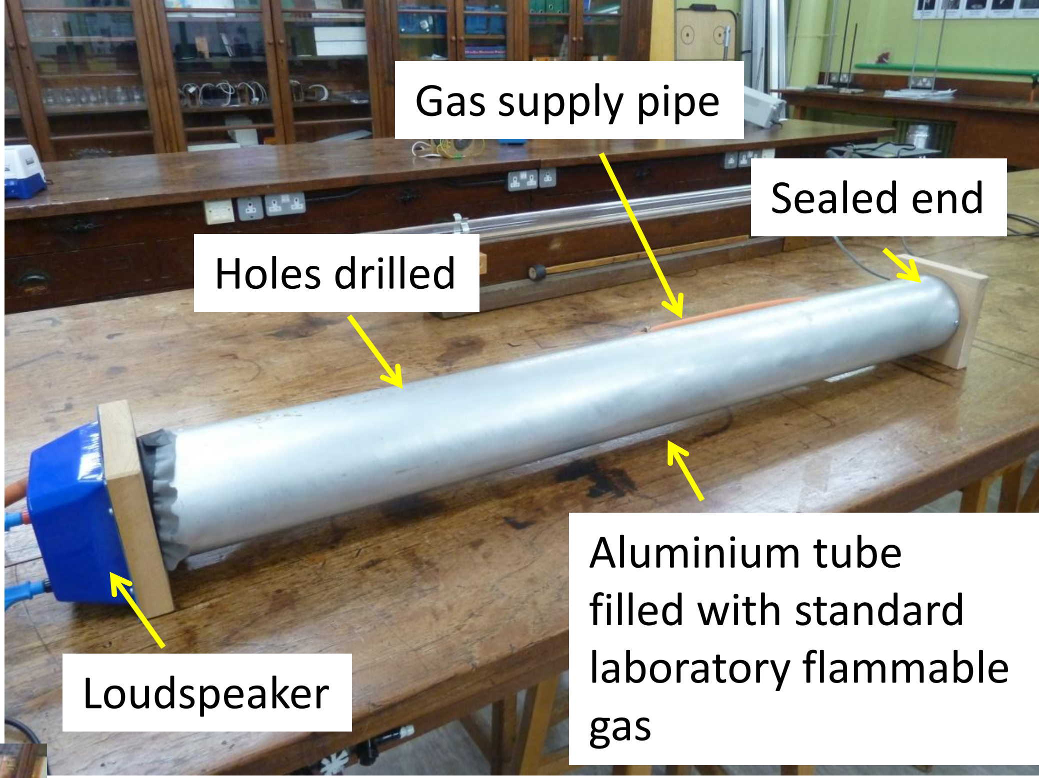


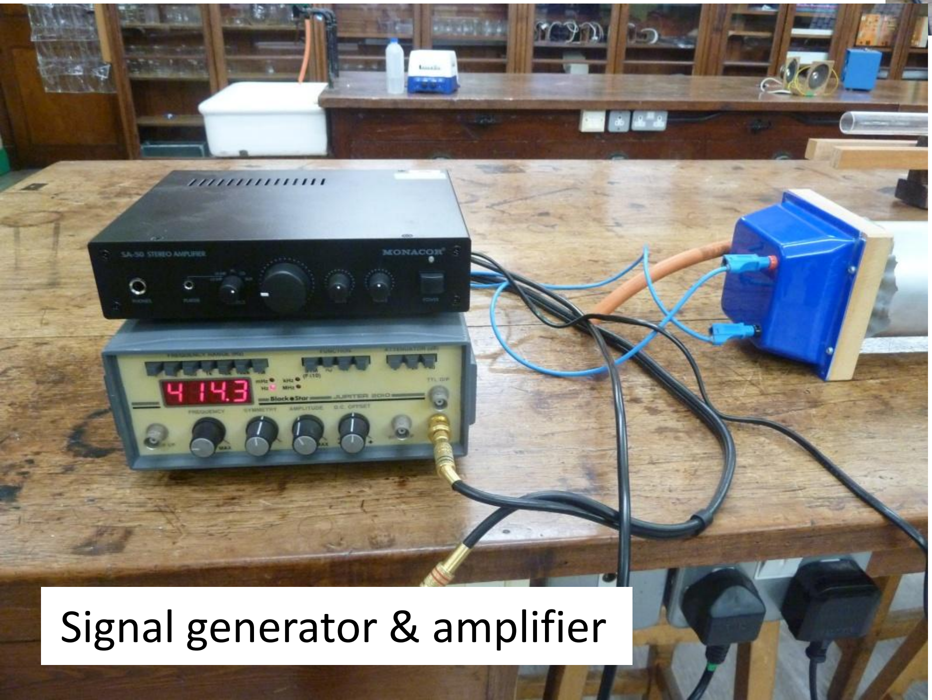
Standing waves in an **closed ended tube**: Air displacement vs distance vs *t* within a wave period

JP Waves Circus Demonstrations

#6 Rubens' tube

Heinrich Rubens
1865-1922

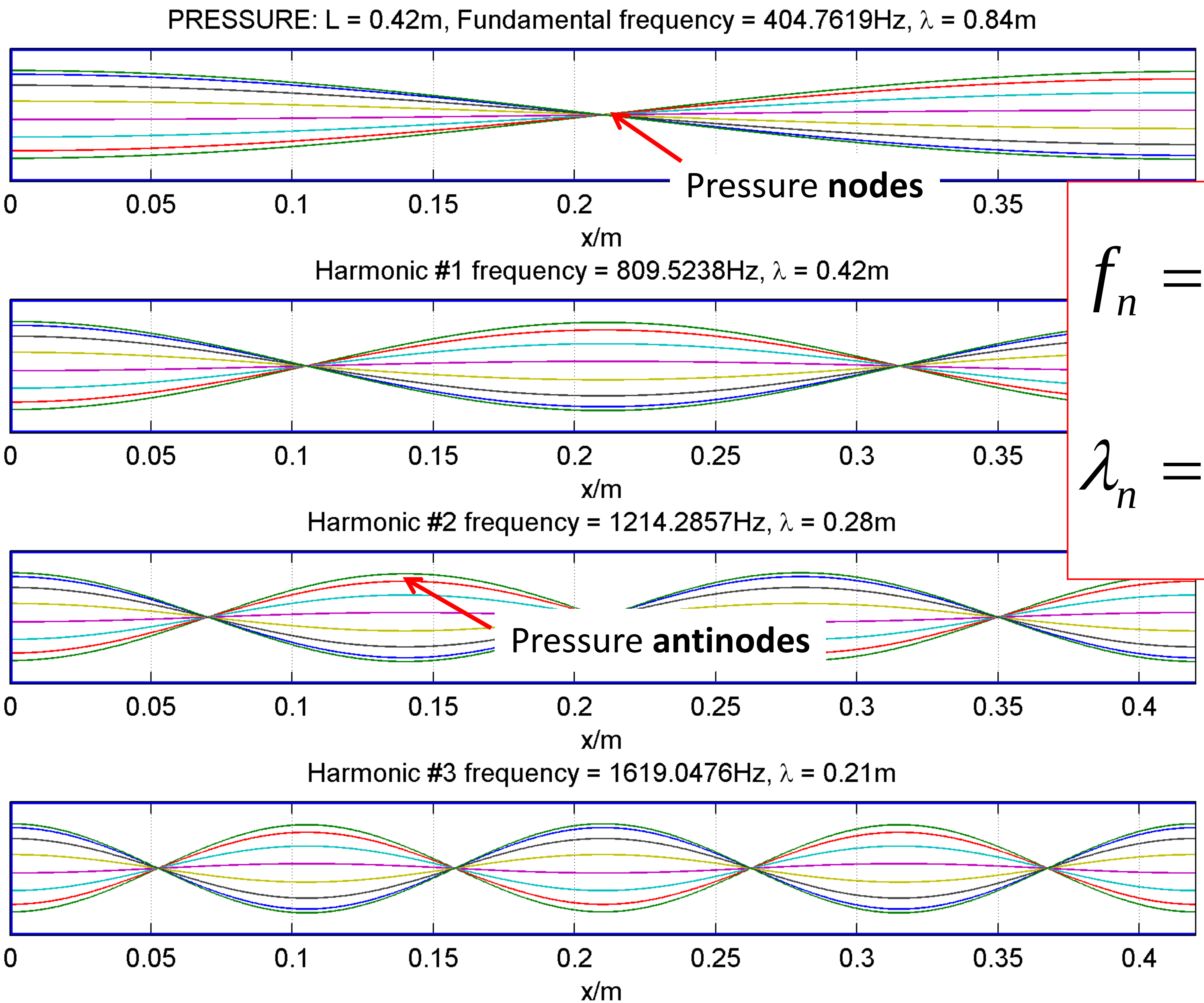




Allow gas to enter tube and then light the holes with a match or lit splint.
Move along tube to alight the fifty or so holes.

As a sound wave is set up in the tube,
the pattern of pressure nodes and antinodes will result in different heights of flames.

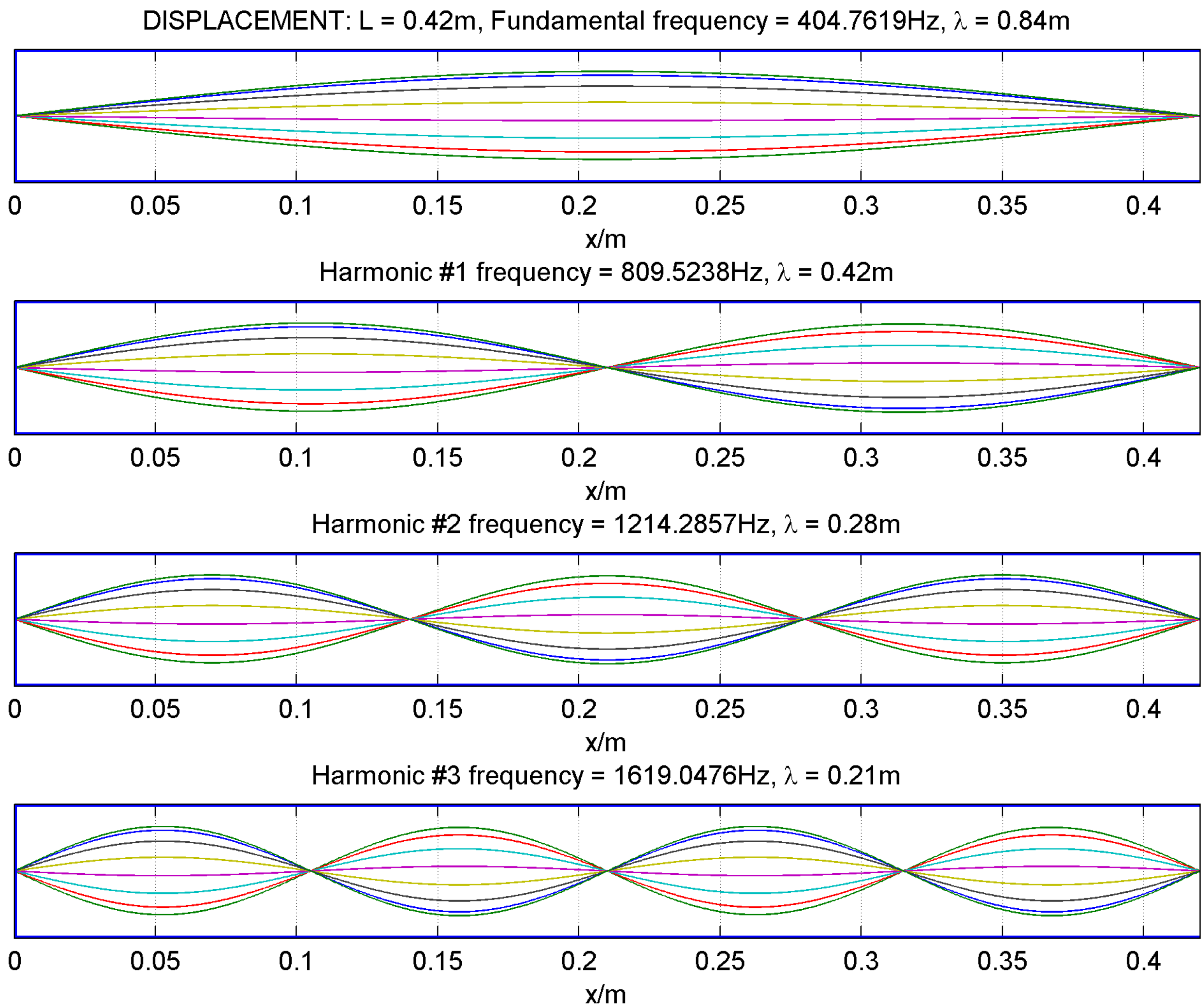
Get enhanced flame height when gas pressure differs the most from atmospheric pressure i.e. at **pressure antinodes**



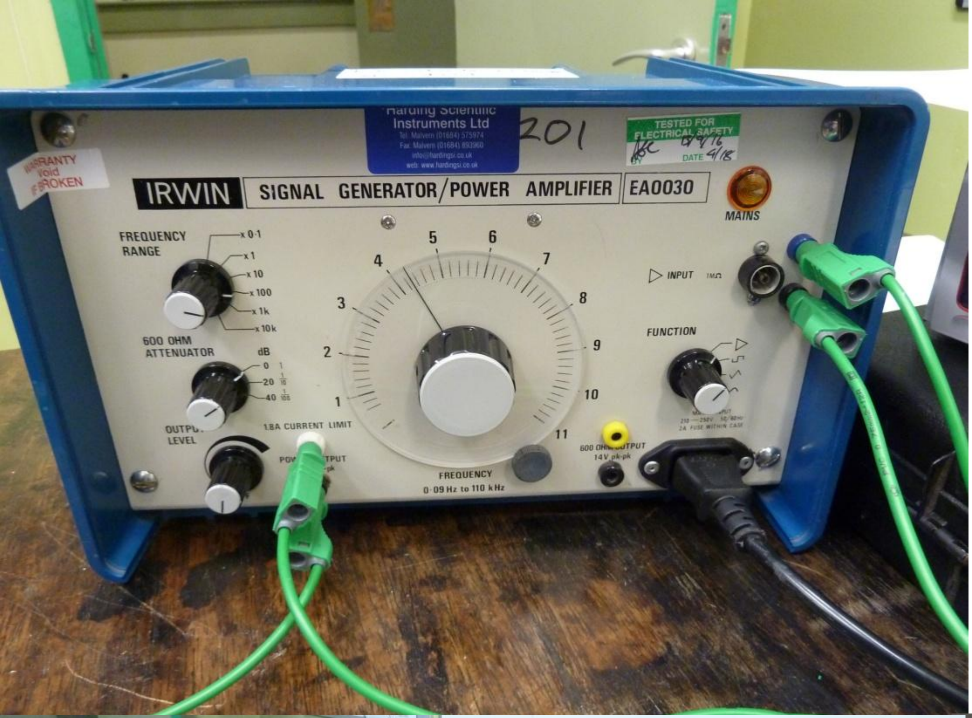
$$f_n = \frac{c}{2L} n$$

$$\lambda_n = \frac{c}{f_n} = \frac{2L}{n}$$

Standing waves in an **closed ended tube**: Air pressure vs distance at times within a wave period

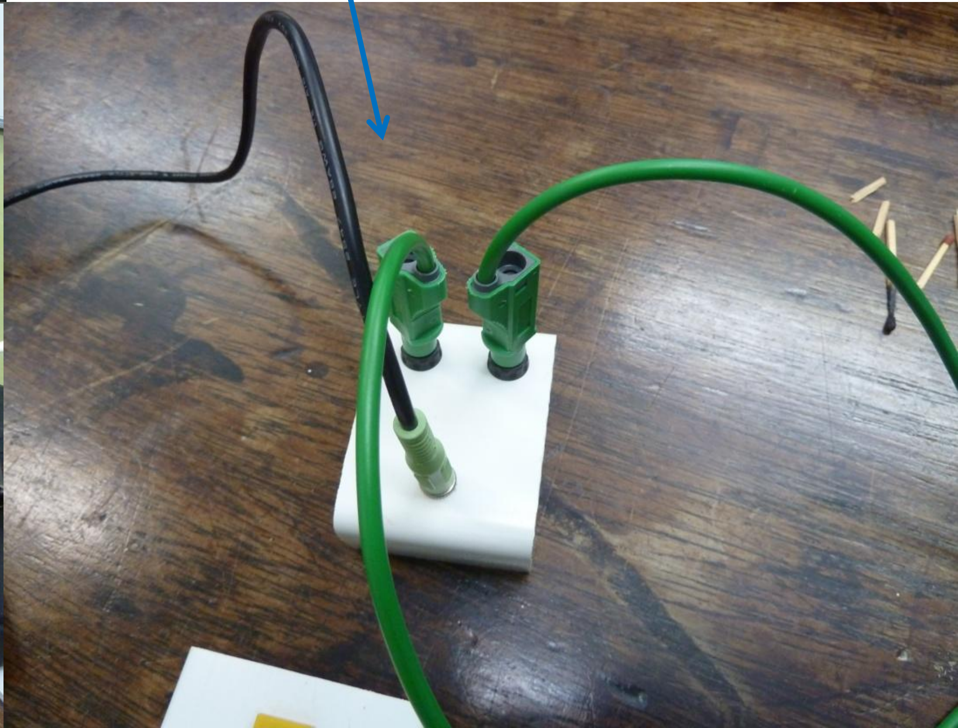


Standing waves in an **closed ended tube**: Air displacement vs distance vs *t* within a wave period



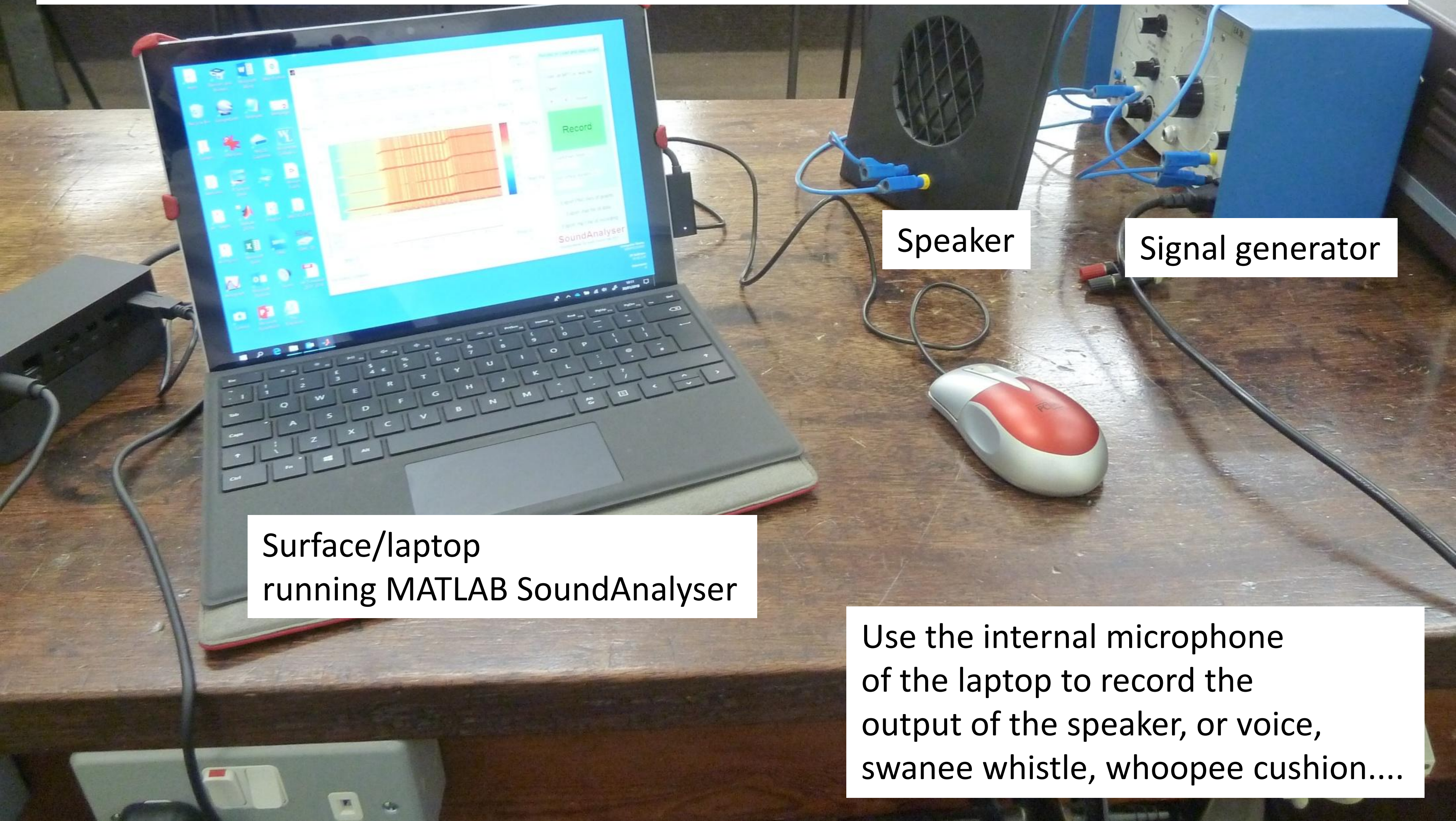
Plug an mp3 player or electric guitar into the signal generator amplifier input.

Use the headphone output of the guitar amplifier as an input to the signal generator.

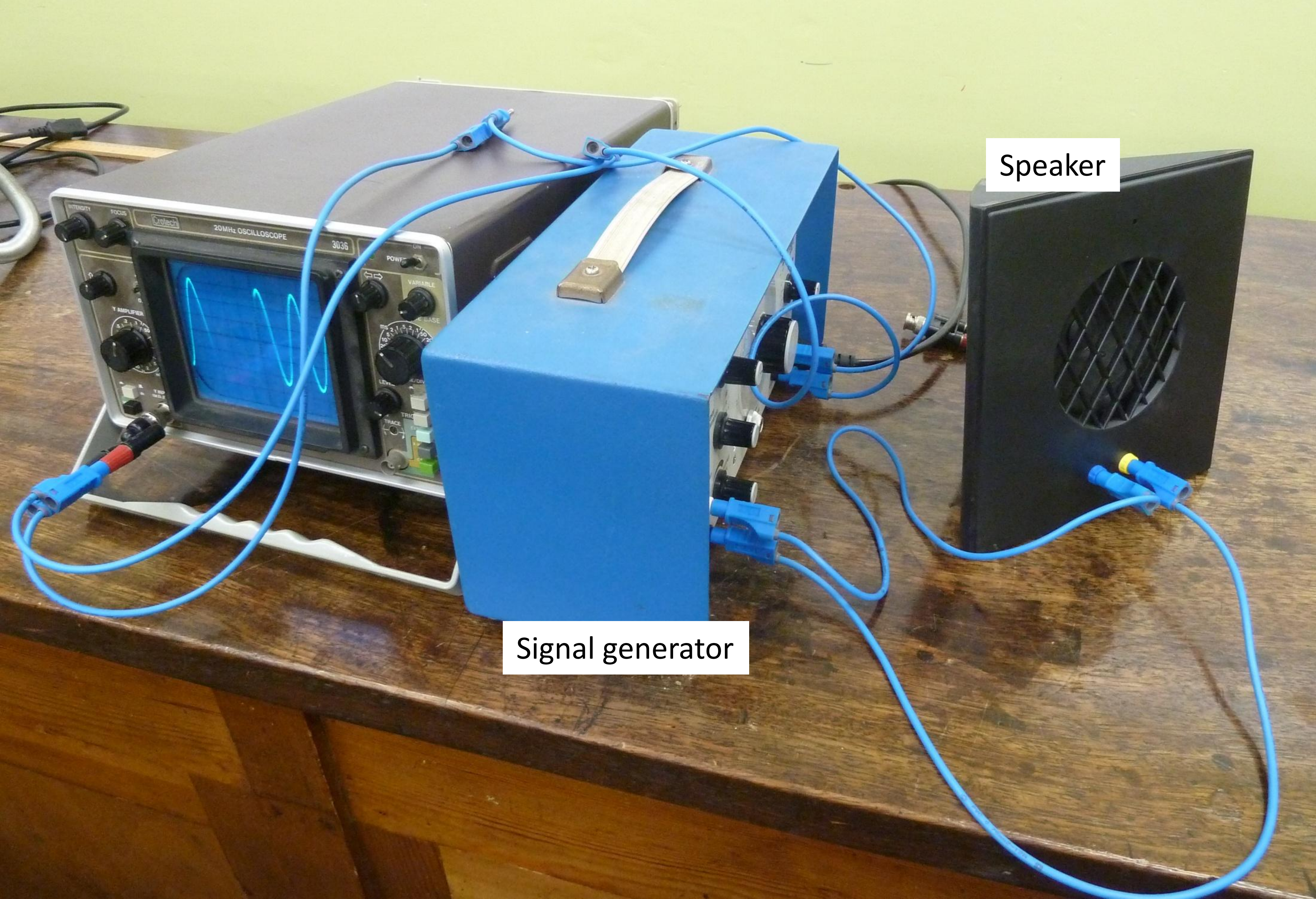


JP Waves Circus Demonstrations

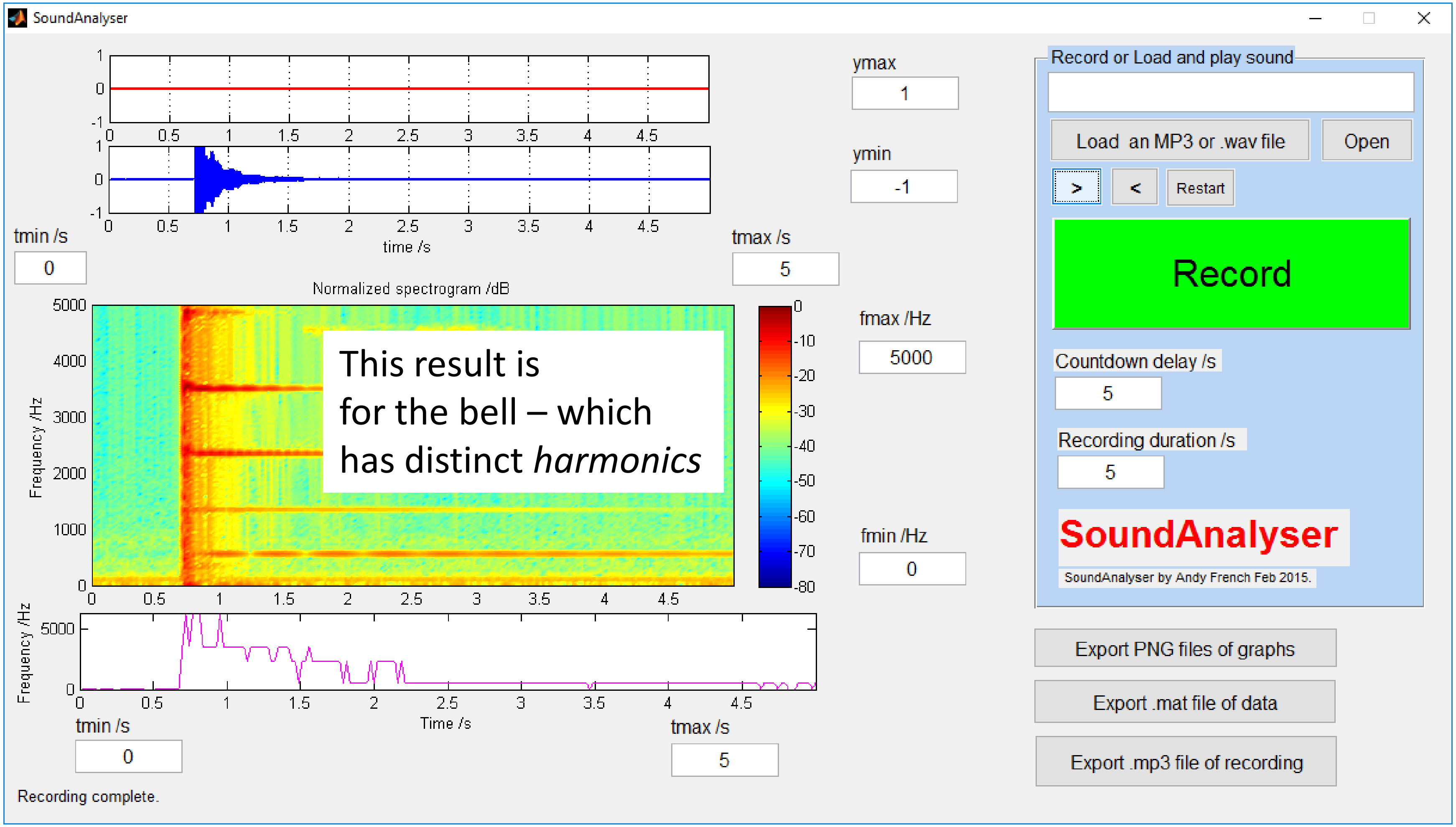
#7 Signal generator, oscilloscope & spectrogram via MATLAB SoundAnalyser



For a signal generator output, additionally display waveform using an oscilloscope



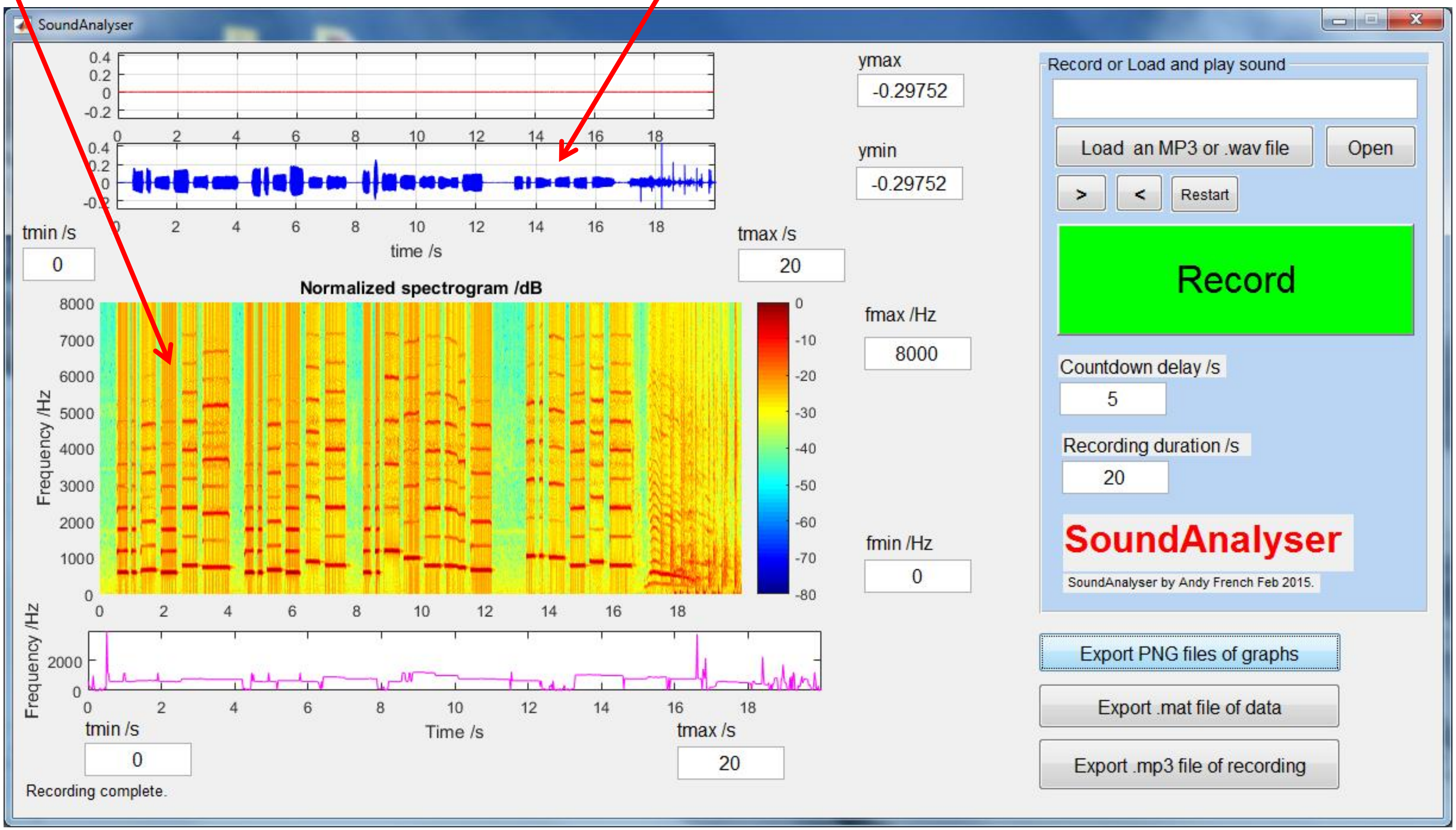
Run **MATLAB** and run **SoundAnalyser.m** within the MATLAB command window. The following GUI will appear.



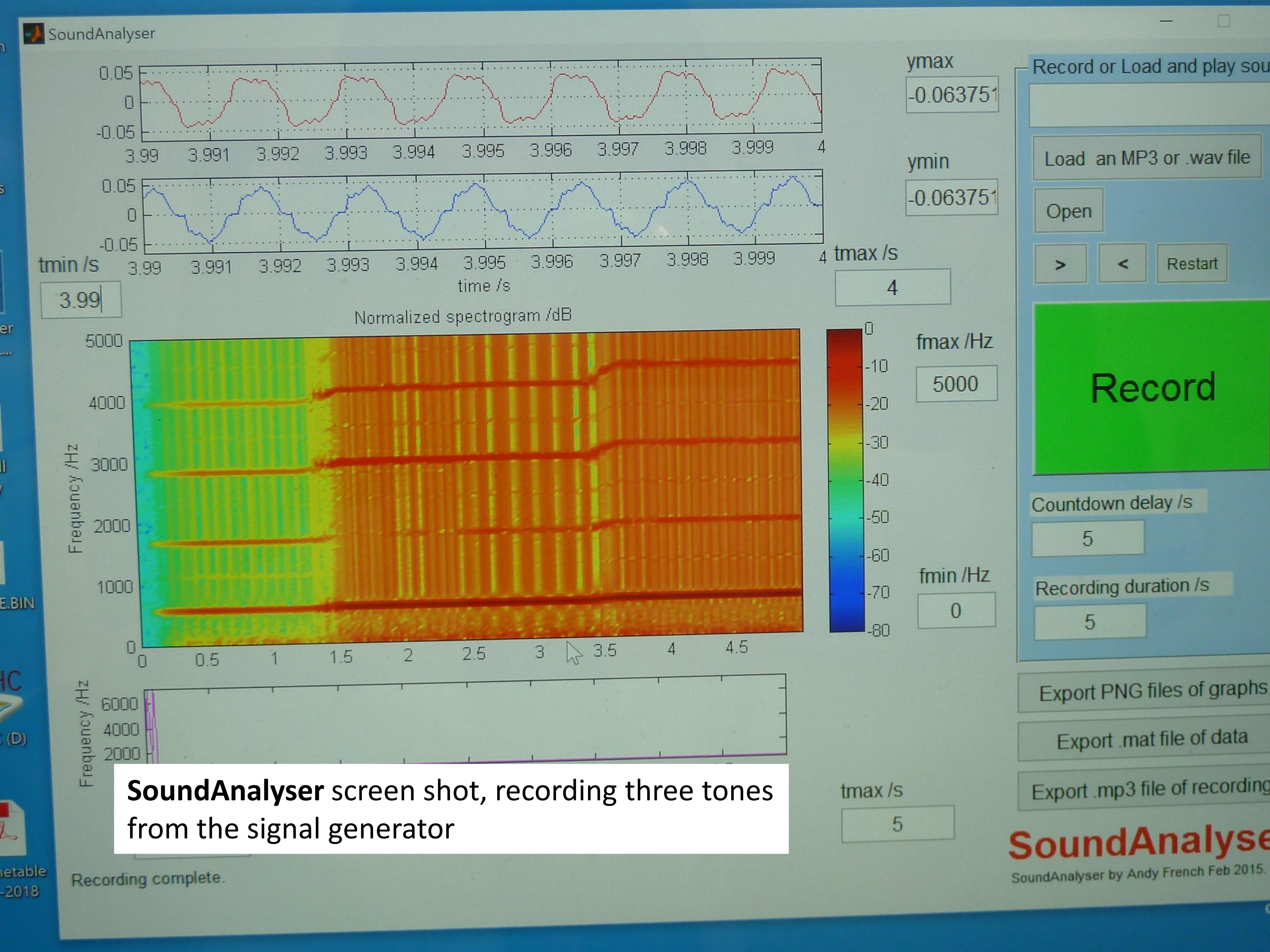
Pressing **Record** will record sound and then analyse it i.e. amplitude vs time and frequency spectrum vs time (plus 'dominant' frequency vs time) graphs will be generated.

Spectrogram – frequency content vs time

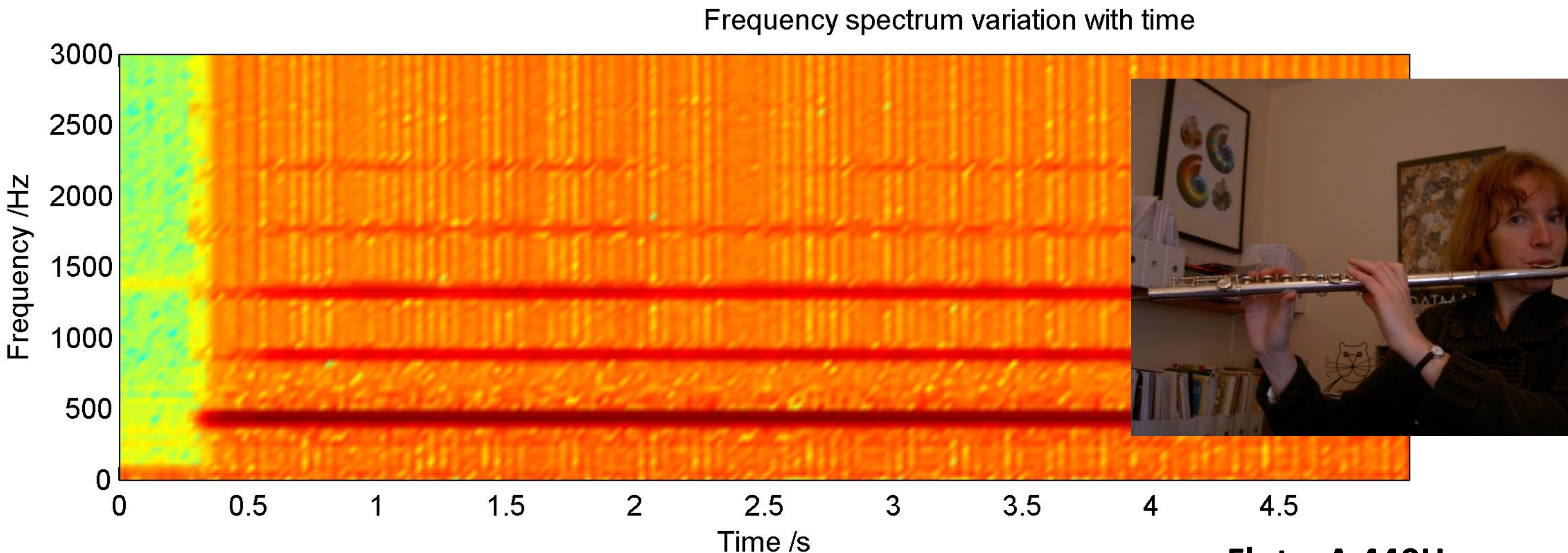
Wave amplitude vs time



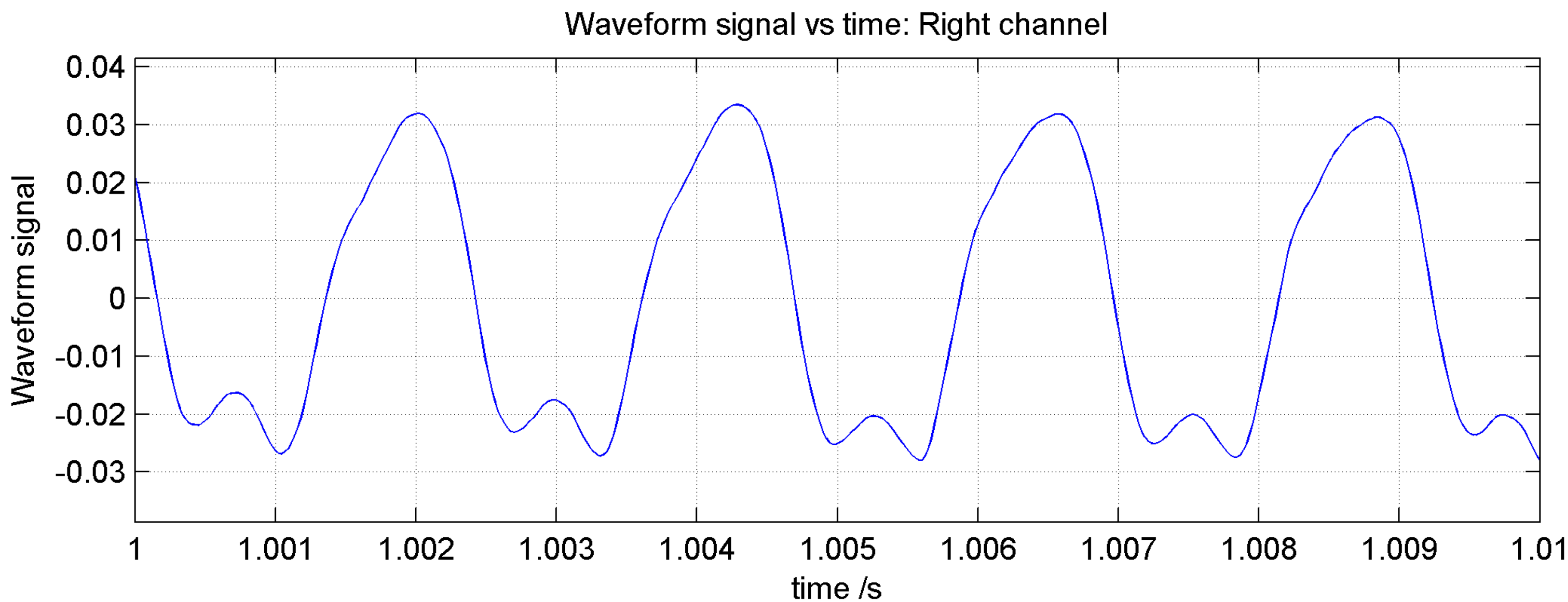
Happy birthday, played by a flute

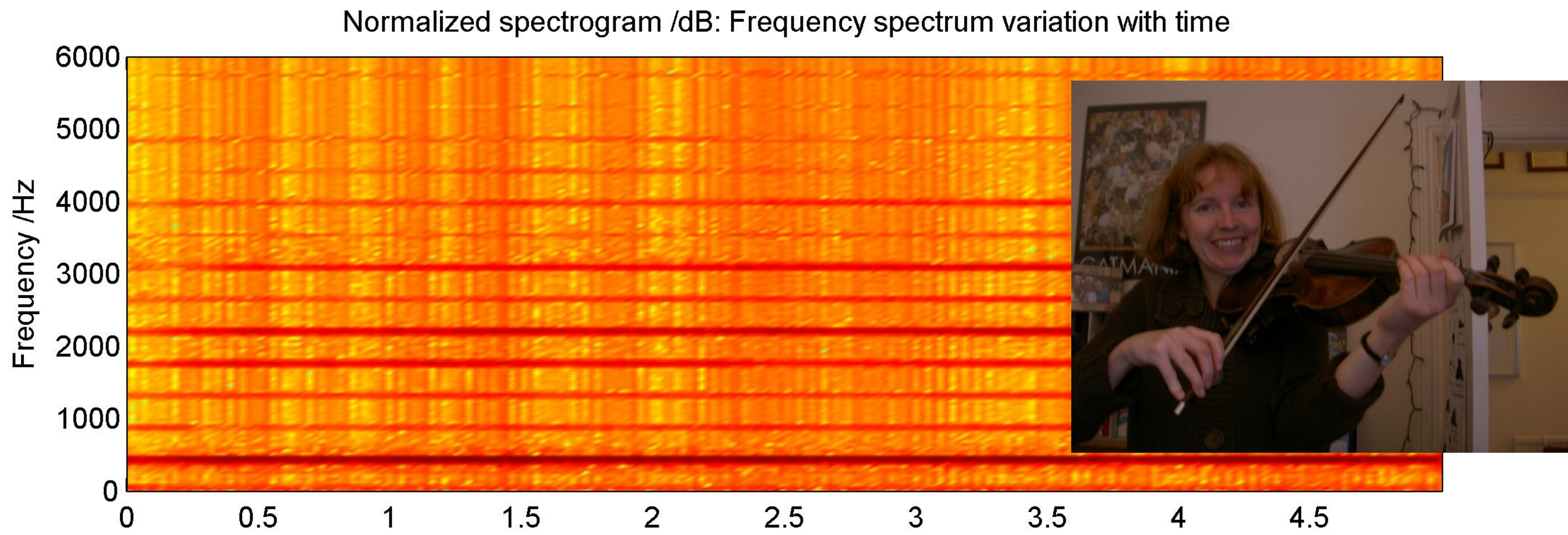


SoundAnalyser screen shot, recording three tones from the signal generator

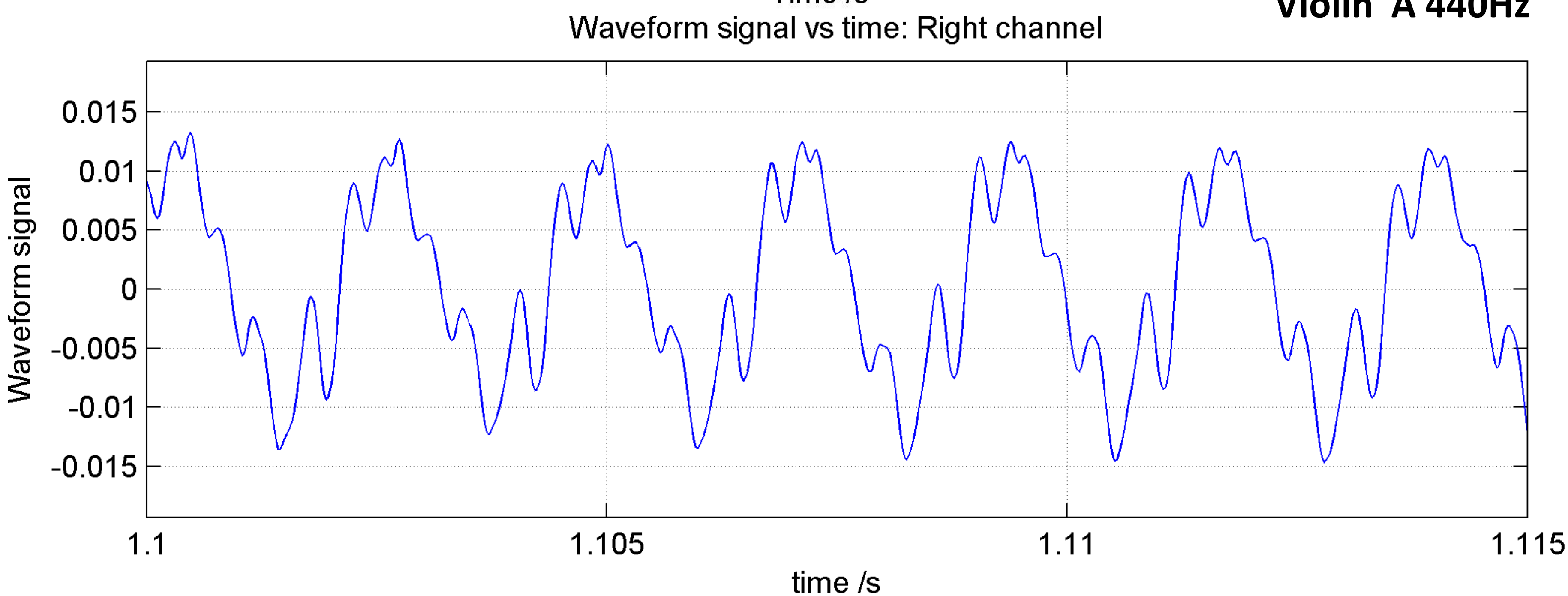


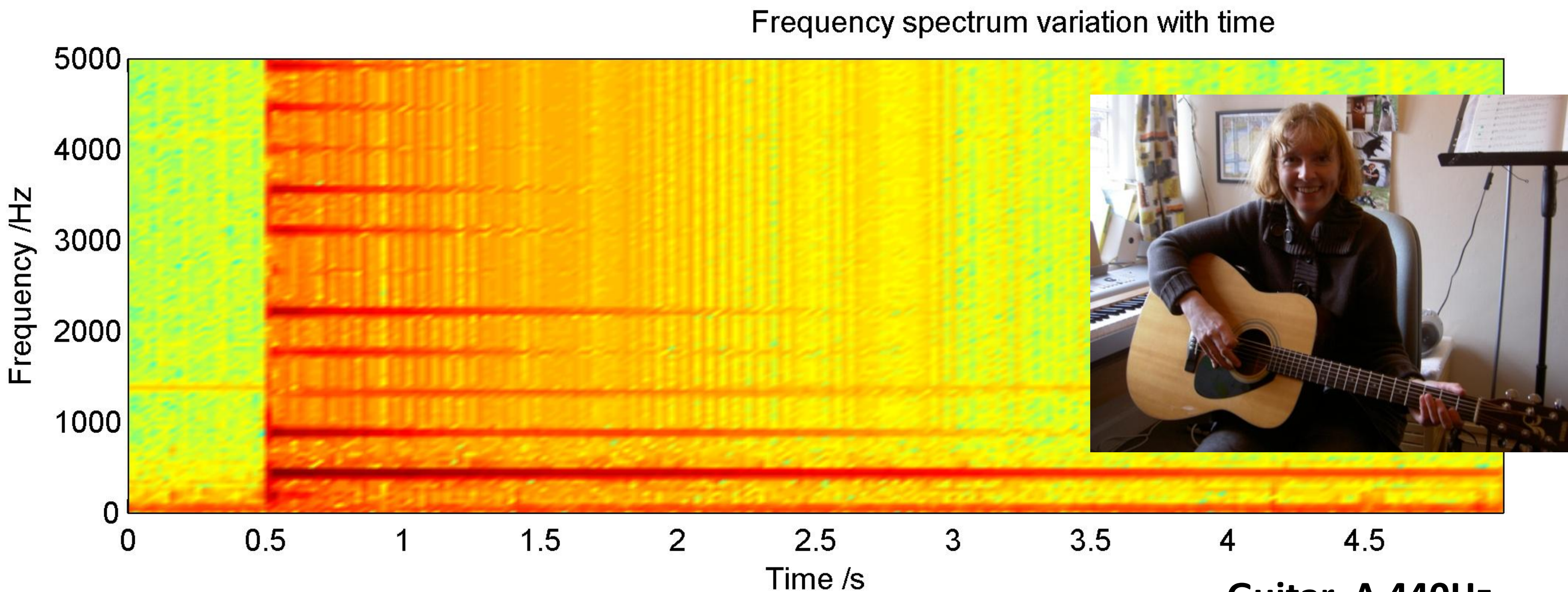
Flute A 440Hz



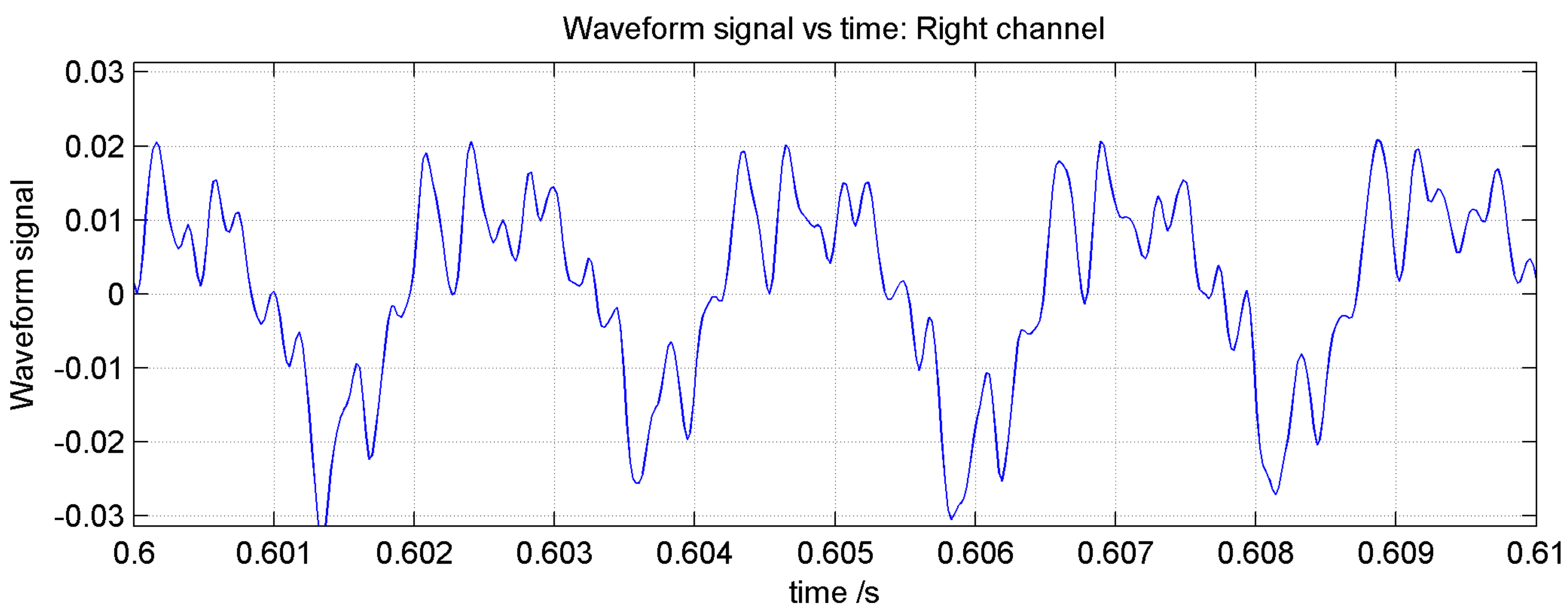


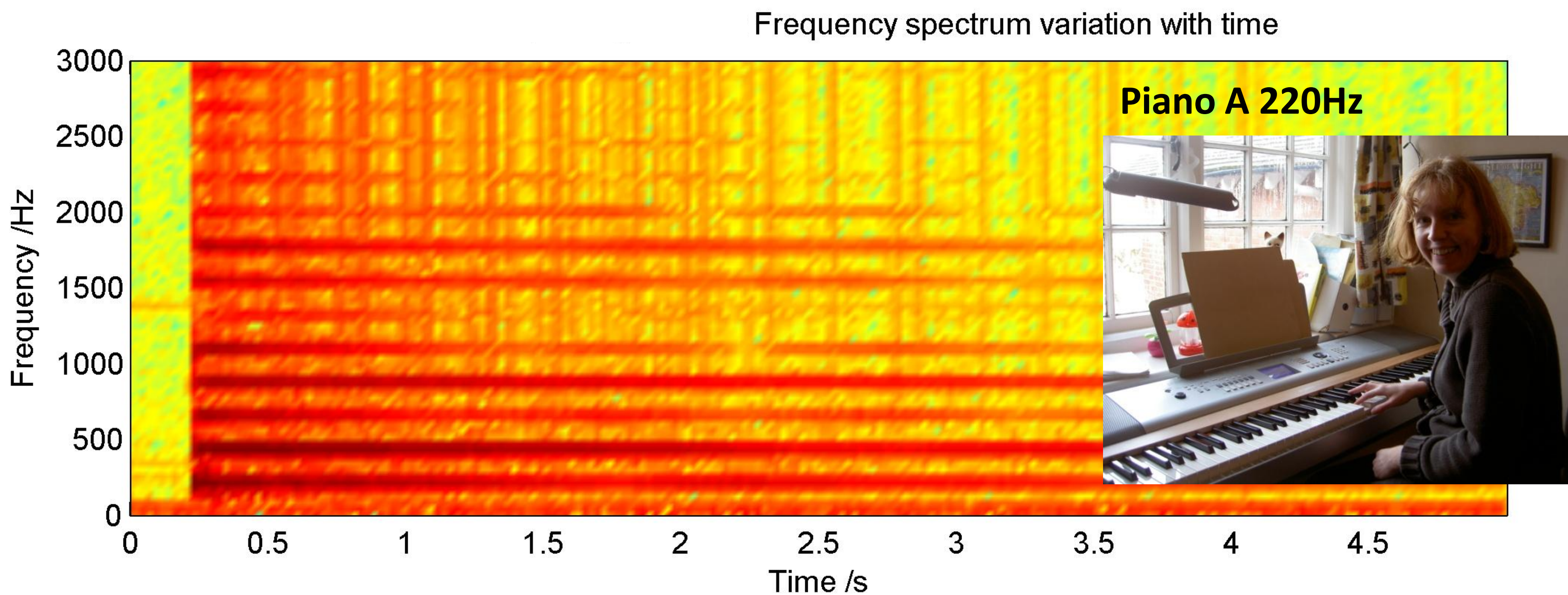
Violin A 440Hz



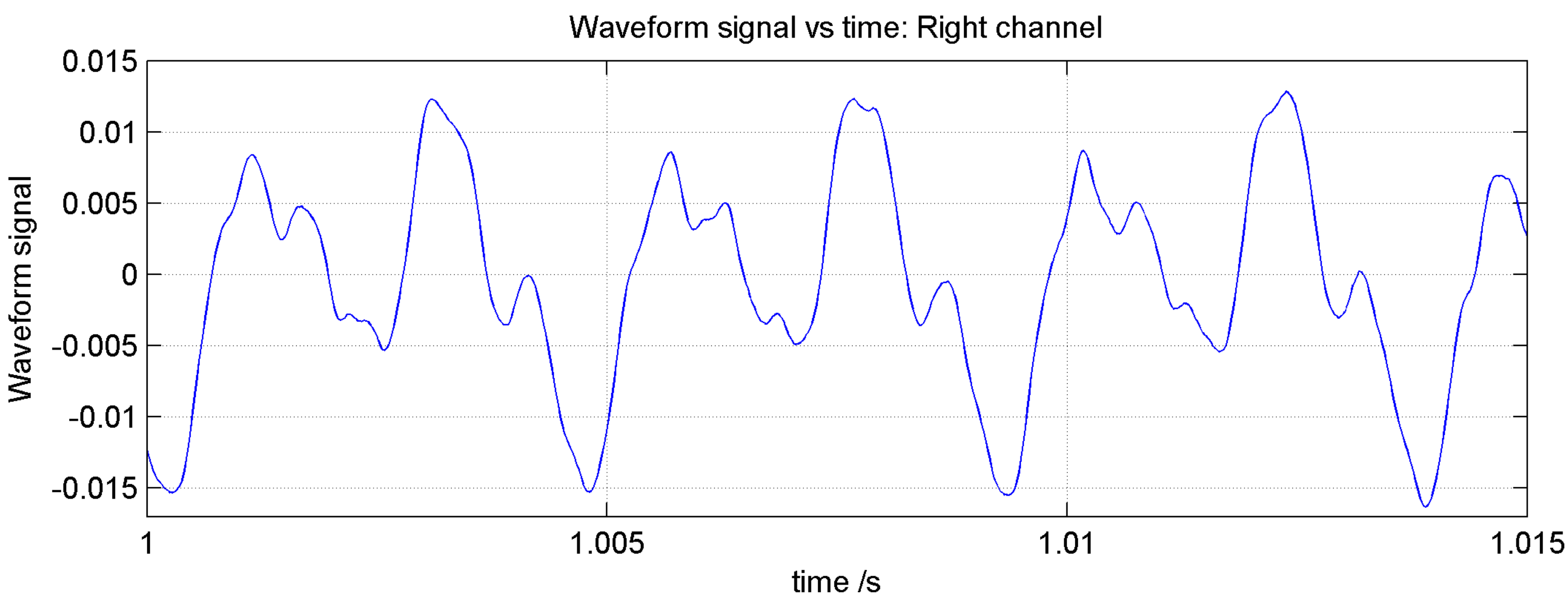


Guitar A 440Hz

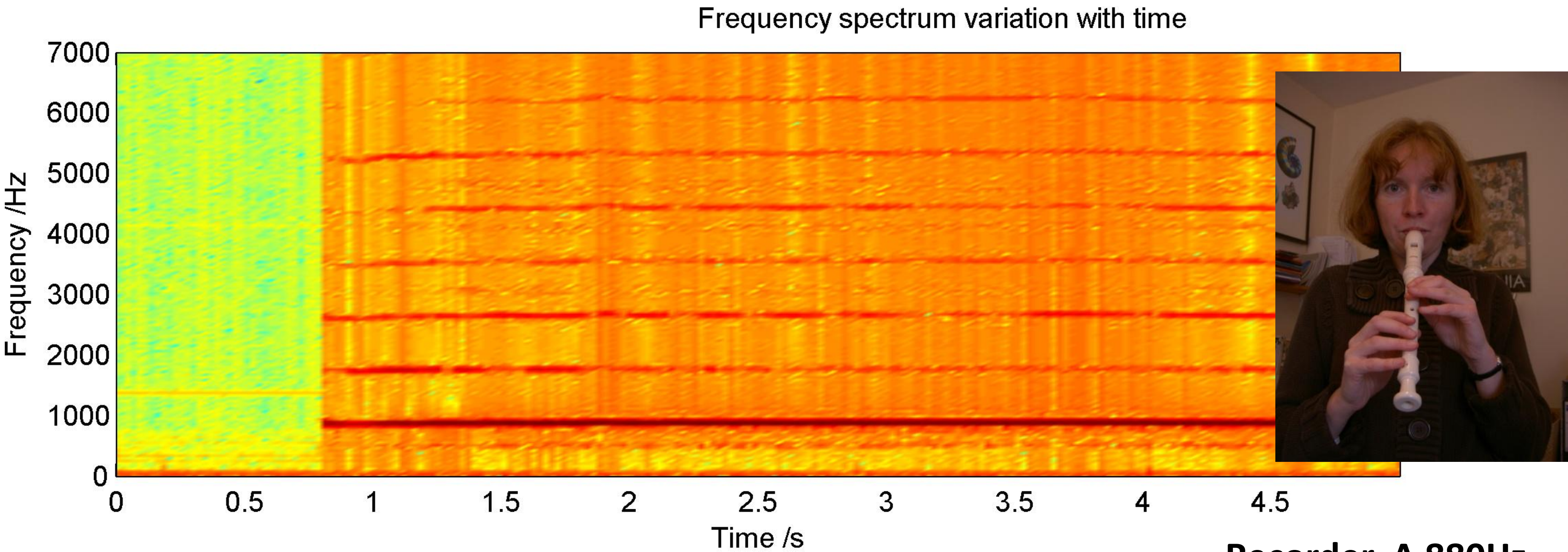




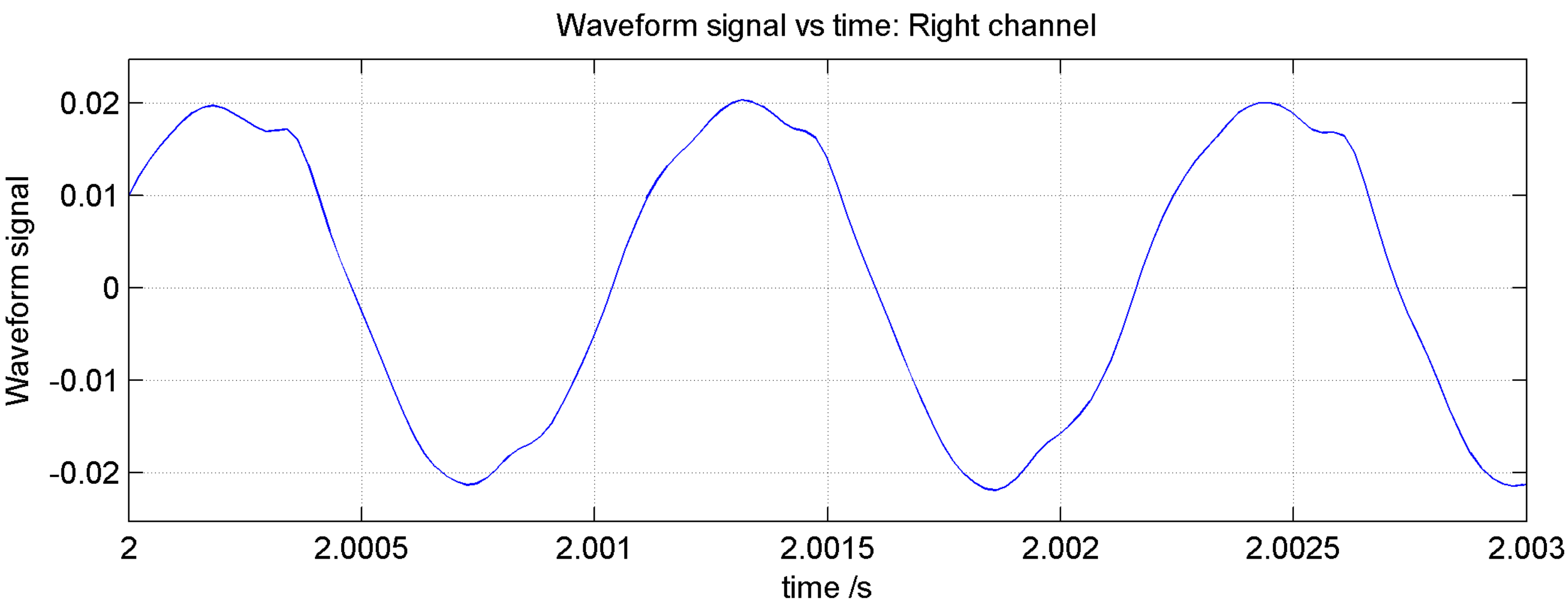
Frequency spectrum variation with time
Piano A 220Hz
Frequency /Hz
3000
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time /s



Waveform signal vs time: Right channel
Waveform signal
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
1
1.005
1.01
1.015
time /s



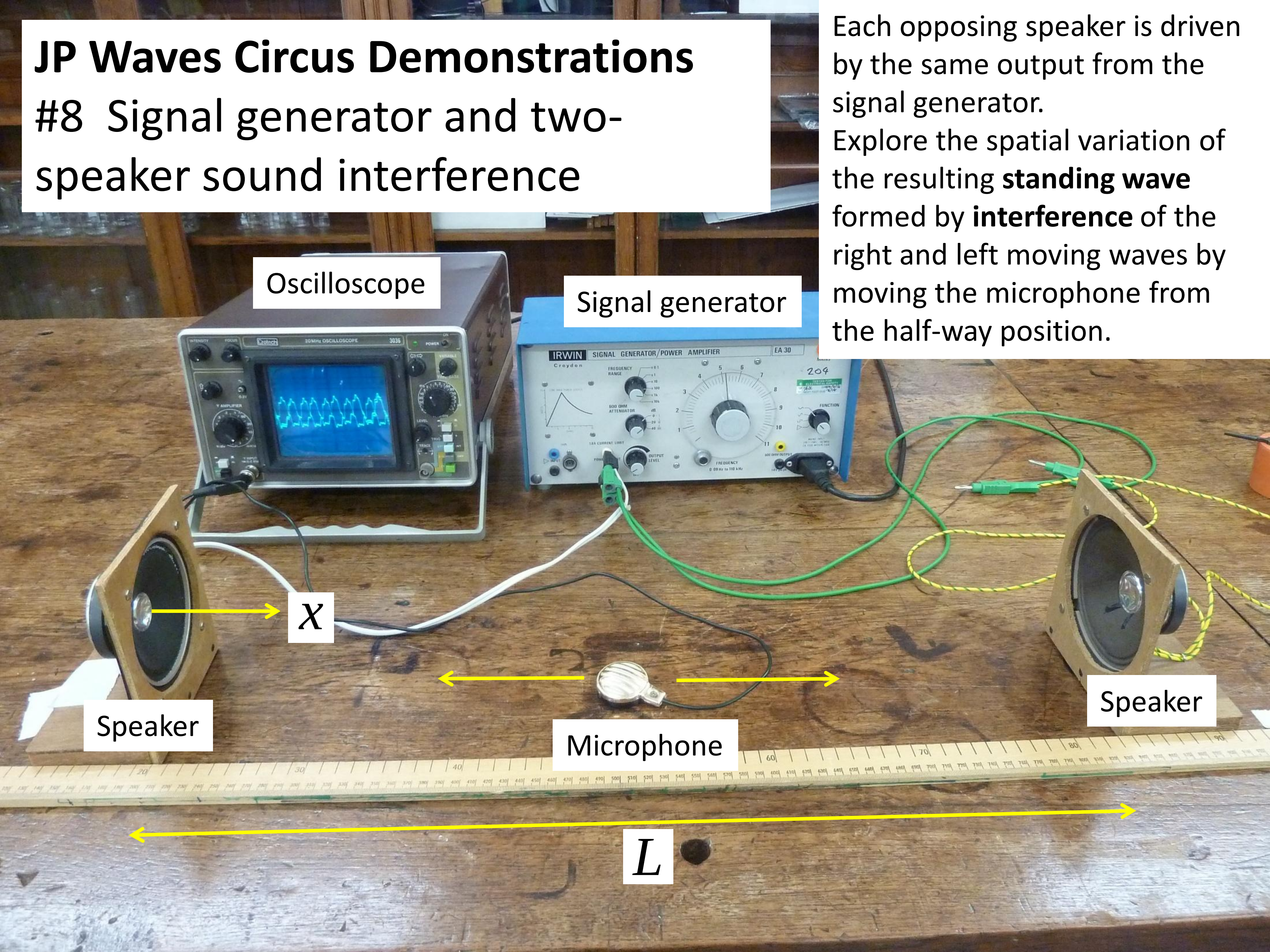
Recorder A 880Hz



JP Waves Circus Demonstrations

#8 Signal generator and two-speaker sound interference

Each opposing speaker is driven by the same output from the signal generator.
Explore the spatial variation of the resulting **standing wave** formed by **interference** of the right and left moving waves by moving the microphone from the half-way position.



Interference of standing waves from speakers separated by distance L

$$\psi = A\cos\left(kx - \omega t\right) + A\cos\left(-k(x-L) - \omega t\right)$$

Assume waves start in phase!

$$\frac{\psi}{A} = 2\cos\left(\frac{kx - \omega t - k(x-L) - \omega t}{2}\right)\cos\left(\frac{kx - \omega t + k(x-L) + \omega t}{2}\right)$$

$$\frac{\psi}{A} = 2\cos\left(\frac{kL - 2\omega t}{2}\right)\cos\left(\frac{2kx - kL}{2}\right)$$

$$k = \frac{2\pi}{\lambda}$$

$$\frac{\psi}{A} = 2\cos\left(\tfrac{1}{2}kL - \omega t\right)\cos\left(kx - \tfrac{1}{2}kL\right)$$

$$\omega = 2\pi f$$

So when $x = L/2$, the above equation predicts that there should always be a **maximum**, which oscillates at the frequency of the tone generator

$$\sin A + \sin B = 2\sin\frac{A+B}{2}\cos\frac{A-B}{2}$$

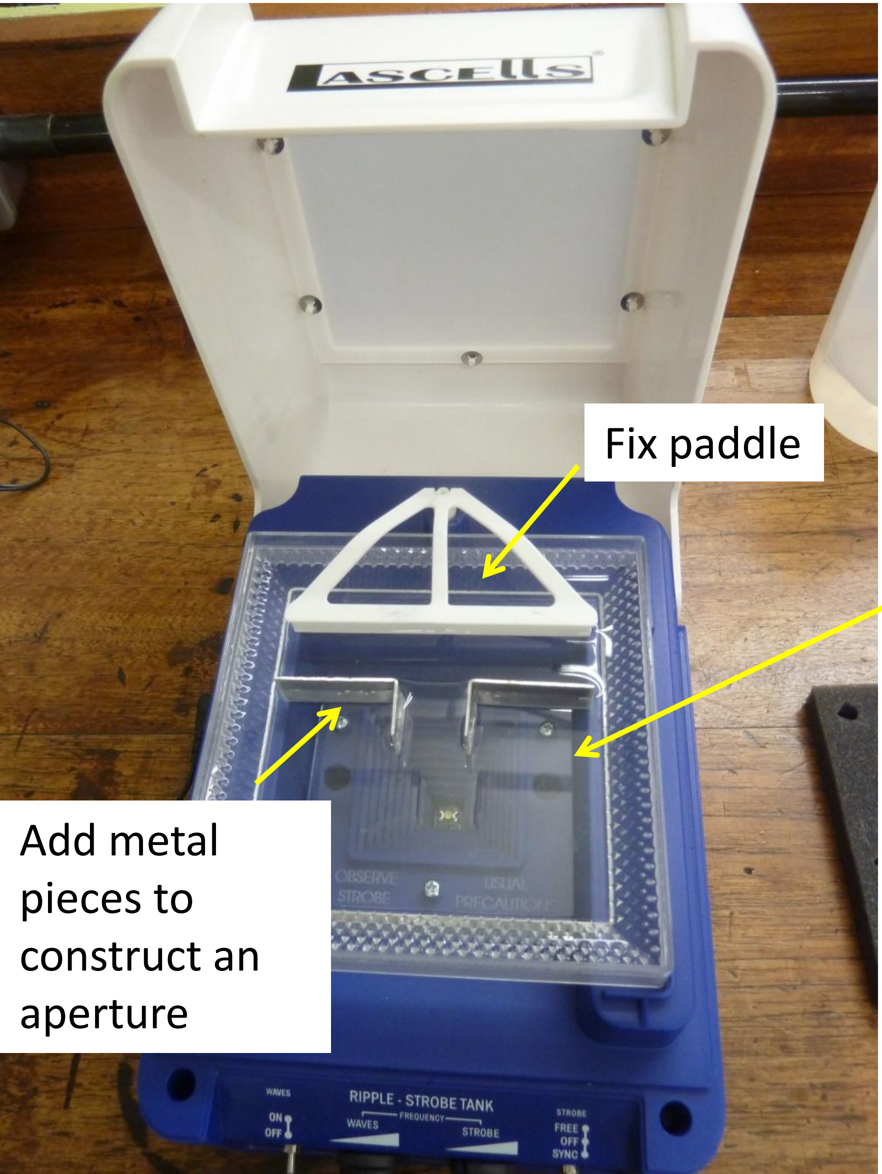
$$\sin A - \sin B = 2\cos\frac{A+B}{2}\sin\frac{A-B}{2}$$

$$\cos A + \cos B = 2\cos\frac{A+B}{2}\cos\frac{A-B}{2}$$

$$\cos A - \cos B = -2\sin\frac{A+B}{2}\sin\frac{A-B}{2}$$

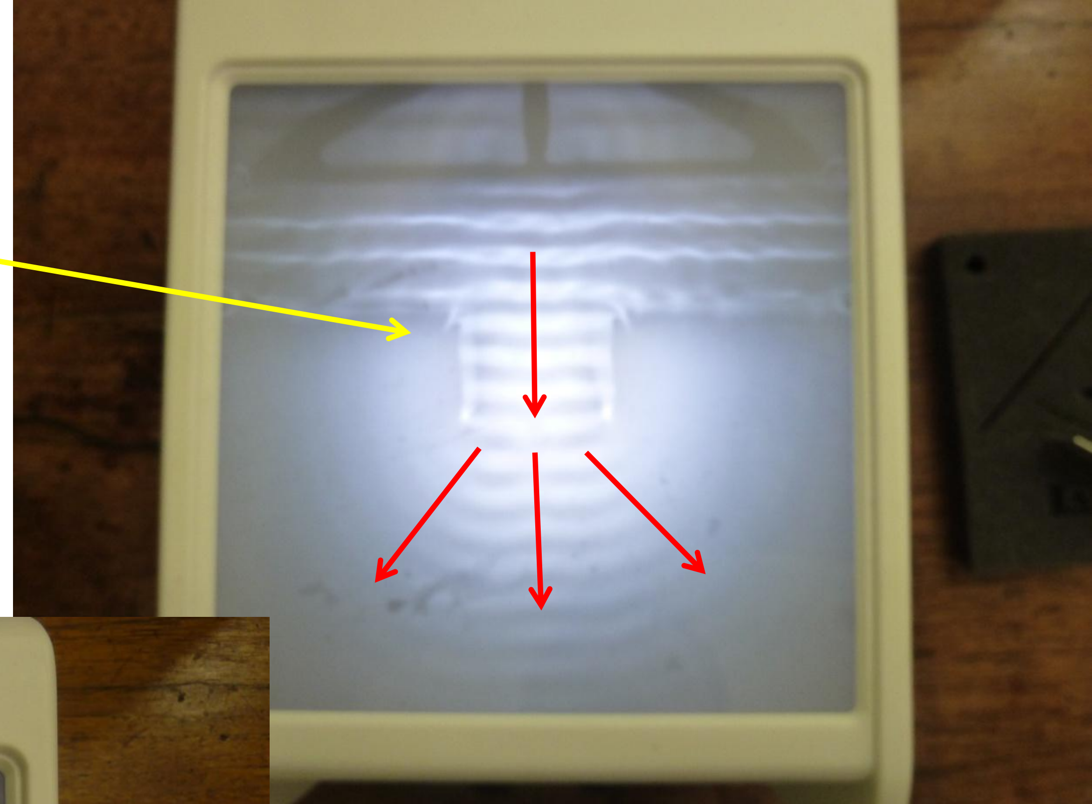
JP Waves Circus Demonstrations

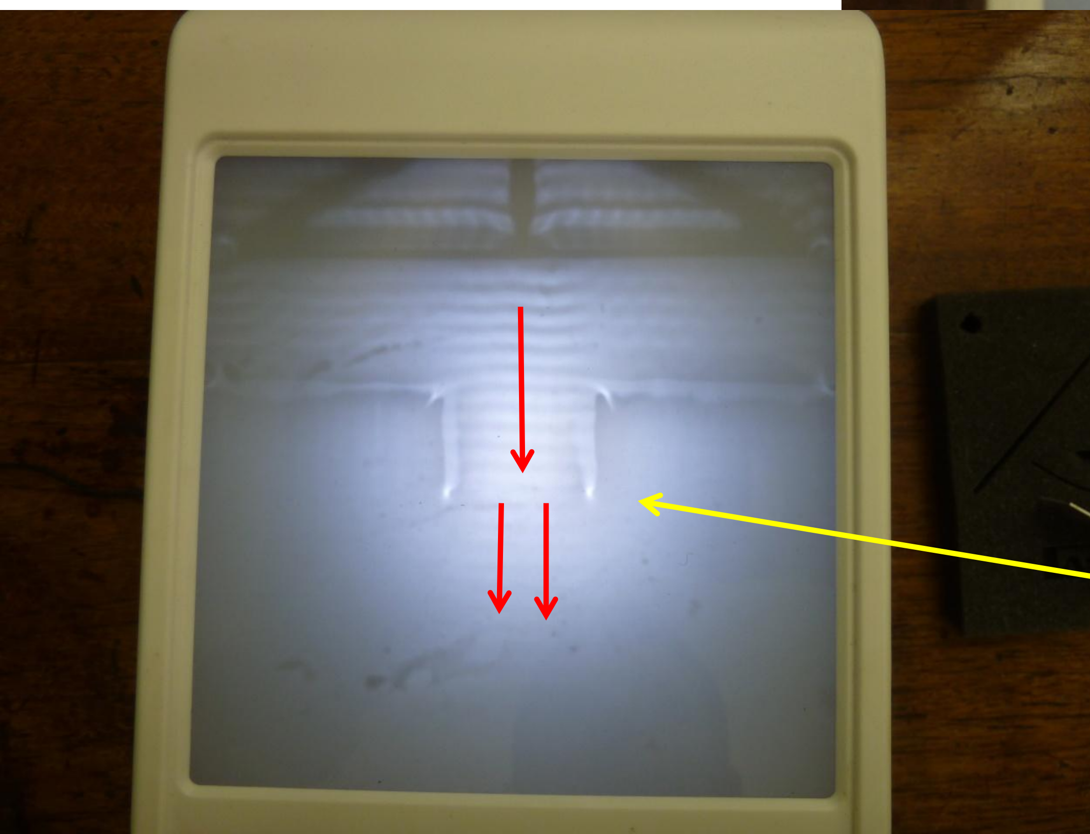
#9 Diffraction of water waves using a ripple tank



Fill ripple tank tray with distilled water

Increase wavelength until it approaches the aperture width. This results in maximum **diffraction**





Reducing the wavelength minimizes diffraction effects. The wavefronts emerge from the aperture without significant circular spreading.