

Chapter 3 – SIGNALLING

3.1 Activity 20D: Demonstration What do digital signal look like?

Requirements

Mounted phototransistor – to make

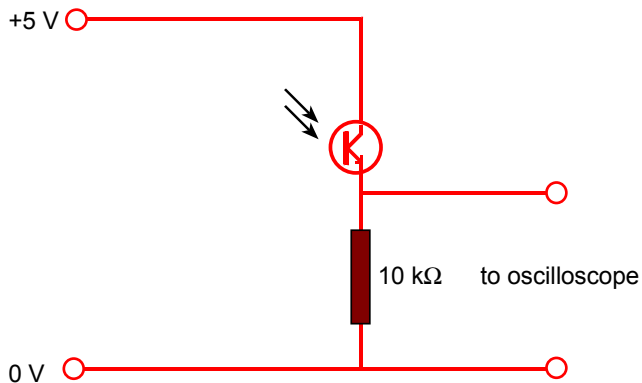
Resistor 10 k Ω

Power supply, 5 V d.c.

Oscilloscope

TV or VCR remote control

+ Solar cell, Loudspeaker



Practical Advice

The phototransistor (e.g. SFH309) will need to be mounted and shielded. The room needs to be darkened. If it is convenient you may also wish to show the remote control operating normally, controlling a TV or video recorder, making the point that different buttons must send different codes. The position of the infrared detector on the receiver is worth identifying. Covering it up, or pointing the remote control in different directions, demonstrates the absorption and reflection of infrared radiation.

A similar experiment may have been done as a team task in work on chapter 2. If so, this may be a good opportunity for students to report back.

Alternative Approaches

A photodiode can be used but is less sensitive. You may wish to try a remote car key, raising the question of how many different codes are needed and how to ensure that the key only opens one particular car. Another way of doing the demonstration combines it with a demonstration of signals on optical fibres.

3.1 Activity 30D: Demonstration Data transfer on an optical cable

Physics in Action boards?

Requirements

Kit which contains:

- Fibre-optic transmitter with variable gain
- Fibre-optics receiver/amplifier
- Optical fibre, a length between 5m and 25m
- Tuned circuit for AM reception around 100 kHz using ferrite aerial and variable capacitor
- Radio receiver
- Connectors
- Audio amplifier
- Loudspeaker

And also:

- Oscilloscope
- Connecting leads
- 2 power supplies, 5 V d.c.

Practical Advice

The approach should be to give a quick, slick demonstration of analogue and digital methods, the use of electromagnetic waves as the fastest information carriers, and of fibre-optic techniques. The kit is self-contained and modestly priced. With an oscilloscope the signal can be followed as it is processed by the system.

It helps the realism of the demonstration if the optical transmitter and receiver are run from separate power supplies, and are separated as far as the length of fibre-optic allows. Features that could be demonstrated:

1. Power up the boards and connect a potential divider (5 k Ω) across the supply with its wiper connected to the transmitter input. Show that varying the transmitter input voltage varies the intensity of the LED and that the light propagates down the length of fibre available (5 or 25 m) and is still modulated at the far end, even if attenuated.
2. Show the varying output voltage at the receiver end with the oscilloscope across the power amplifier output. Always measure voltages with respect to the negative power rail.
3. Connect the AM tuning circuit and radio receiver to the transmitter input and insert the ferrite aerial rod in the coil. Connect the fibre-optic from transmitter to receiver and the loudspeaker to the power amplifier output. Adjust the tuning capacitor and aerial rod direction until a signal is detected.
4. Show the fluctuations in the intensity of light on the fibre and how the signal decreases when one end of the fibre is disconnected.
5. Use the oscilloscope to show how the signal changes from modulated radio-frequency to an audio signal, as it passes from the tuned resonant circuit through the radio receiver into the fibre. To observe the radio-frequency signal across output of the tuned receiver, set the oscilloscope time-base at a few milliseconds per centimetre.
6. A TV or video remote control transmitting in the infrared can also be detected by the photodiode receiver. With an oscilloscope across the power amplifier output, the digital nature of the signals from different control buttons can be observed. This provides an alternative to another demonstration with a remote control.

Alternative Approaches

Any radio or fibre-optic demonstration that can illustrate some or all of these features could be adapted to introduce the key ideas.

3.1 Activity 40D: Demonstration Sampling vibrations on a string

Nuffield Unit D

Requirements

Signal generator

Vibration generator

Oscilloscope

Stroboscope

4mm leads

about 2m of thick white string/elastic

Single pulley on bench clamp

Mass hanger with slotted masses, 100g

Practical Advice

Drive a white string about 2 m long from a vibration generator, with the other end carrying a weight of a few newtons over a pulley (perhaps 2–5 N). An alternative is to use light shirring elastic thread tensioned between the vibrator and a fixed end. Place an oscilloscope across the output of the signal generator, for a visual indication of the waveform and frequency. Fundamental and harmonic vibrations can be nicely demonstrated at an integer series of harmonics, $f_n = n f_1$, where n is the harmonic number of vibrating half-wavelength loops.

Here we do not as usual stress the standing wave aspect, but mention can be made of nodes as positions of no vibration, and antinodes, their opposite. If the demonstration is performed in a darkened lab, the dramatic effect of strobing, slowing and freezing the vibrational motion can be seen. This shows aliasing, the appearance of spurious lower frequencies. To do so, increase the strobe rate until a double image of string is observed and then halve the strobe frequency until the image is frozen. Frequencies near the actual frequency of the string appear to show it moving slowly.

Depending on the tension in and mass of the string the first harmonic or fundamental will have a frequency around 20–50 Hz typically. The possibility of such harmonics on a guitar string plucked off centre can be discussed (later to be shown on a spectrum analyser, or demonstrated from the Multimedia Sound CD-ROM).

3.1 Activity 80E: Experiment Looking at signal conversion

Requirements

analogue to digital converter (ADC) box
power supply unit for measurement amplifier
two digital multimeters
digital to analogue converter (DAC) box
oscilloscope
signal generator

Practical Advice

This activity is based on an article by Martin Gregory first published in School Science Review, September 1997. We deliberately use a low resolution so that the process is made explicit.

Alternative Approaches

Stepped signals can be seen on many sound processors. Showing that these correspond to certain levels only is hard. It is nearly possible to convince yourself if you record a low-amplitude sound and then amplify it several times.

3.1 Activity 50E : Experiment Guessing a waveform from a sample

Requirements

Tracing paper
Paper

3.1 Activity 60D: Demonstration Noise:A problem and a solution

Requirements

2 signal generators
2 x 5m long leads twisted tightly together and terminating with 4mm plugs
Oscilloscope
Measurement amplifier, gain 10
Power supply unit for measurement amplifier
Signal diode
AND gate
Power supply, 5 V d.c.

Practical Advice

Part 1: Analogue

To start, connect the signal ground outputs of two signal generators to the earth input of the oscilloscope. One end of the twisted pair of leads is then connected to the high-impedance output of each signal generator. The opposite end of the twisted pair which is connected to the low-frequency (40 Hz) signal generator has to be connected to the input of the oscilloscope: the remaining 4 mm connector is left free. You should now have the arrangement which is shown in the first figure.

If the 40 Hz signal generator is turned on you will see a waveform on the oscilloscope screen. By adjusting the scope and the output level of the signal generator you should be able to produce a trace showing two or three waves with an amplitude of about 0.8 V. The oscilloscope trace will, as usual, be a fine line. Noise can be introduced if you turn on the 100 kHz signal generator and turn its output up to maximum. The fine line will now be much broader because some of the 100 kHz signal has been 'picked-up' by the 40 Hz signal in the 5 m twisted leads. Compare the height of this pick-up with the amplitude of the original signal.

Now connect an amplifier (gain 10) between AB and CD. By adjusting the gain of the oscilloscope, you can show that both the 40 Hz signal and the noise have been amplified by the same factor. It is probably better not to set the oscilloscope timebase to a setting which shows the 100 kHz signal. This could give a misleading impression of the form of a noisy signal.

Technician's note: The twisted leads can be made by taking two 5 m leads and securing one end of each in a vice. The other ends should be held in a (hand) drill. Turning the drill slowly will form a twisted pair of leads.

Any amplifier will do. A gain of 10 gives a reasonable signal and a voltage level which is suitable for use with the AND gate later.

Part 2: Digital

Using the same system as before, alter the output of the 40 Hz signal generator to give a square wave rather than a sine wave. The oscilloscope trace shows a signal which has two distinct levels even though both are broadened by noise. At the moment, the two levels are equally spaced above and below 0 V, which is not the norm for digital where one level is usually 0 V. A diode can be used to remove the negative half of the signal, giving a signal in which the noise is only present in the upper voltage level. This can be seen by connecting a oscilloscope to point X in the final circuit shown.

When the signal is used as the inputs of an AND gate, the output of the gate gives a signal in which there is no noise – point D in the final circuit. The electronics of the gate can tolerate some variation in the input voltage but can only generate one output voltage, i.e. it effectively cleans up the signal. If a dual beam oscilloscope is available, compare points X and D.

Alternative Approaches

A similar display can be obtained if the 40 Hz and 100 kHz signals are combined with a measurement amplifier configured as an adder. The twisted wire technique suggested here makes it easier to explain that noise is an additional unwanted signal that arises from another source

3.1 Activity 100D: Demonstration The C.D. with the hole

Requirements

Unwanted music C.D. with hole 1mm to 2mm drilled in it
PC with C.D. drive and sound card, or C.D. player

Practical Advice

If you are demonstrating this, do try the disc out first. If the music has just audible but not very serious flaws you say nothing before playing the disc. Look surprised when it does not sound quite right, and take out the disc as if to clean it. Then 'notice' the hole – laying the disc on an overhead projector shows the hole clearly.

Other patterns may be useful. In general a 2 mm hole is the largest that you can get away with. An instructive pattern is to drill four evenly spaced 1.5 mm holes along each of eight evenly spaced radii.



Each 1.5 mm hole does not halt proceedings by itself, but where these holes obliterate the duplicate information, on the tracks closest to the centre, then the songs are not quite what they were. The amount of damage done to the reproduction of the sound becomes less as you reduce the damage per cm of track. Data are recorded onto CDs in frames. Each frame is 163 mm long and the information for any one piece of music is interleaved with others over 28 frames.

It may be instructive to compare the behaviour of the CD player with a software 'crash'. The two experiences have plenty in common.

Technician's note: First obtain an unwanted music CD! Free offers with newspapers and magazines may be a good source. Alternatively try pop CDs which have gone out of fashion. Pop singles are good on account of not having to listen to an hour of music you do not really like after each drilling to find out whether the hole is appropriate; only a small fraction of the surface area of the CD has music recorded onto it. The students will often know where pop singles may be had most cheaply. Pop singles can be bought for about 99p. A number of the same single can be useful. Try drilling first with a 1 mm drill bit. Choose a sharp bit, and drill carefully through the compact disc from the recorded side (to avoid breaking away plastic over a larger area, which may happen if you drill through from the label side). Very gently blow away any swarf on the playing surface (wipe radially, from centre to edge, with a soft dry lint-free cloth). Test the disc. The ideal is one where the hole causes just audible defects in the playback (hesitations, changes in volume), but where the sound continues without gaps.

Alternative Approaches

The game of 'Chinese Whispers' can remind students how errors can accumulate. It might be worth trying a variation in which each whisperer must repeat the message three times. There may be fewer errors.

3.2 Activity 120P: Presentation Polarisation of waves

Requirements

3 polarising slots (hardboard sheets with slots)
3 or 4 m length of rubber pressure tube that can be threaded through the slots
G clamp, or retort stand, boss and clamp to secure one end of the rubber tubing
3 polarisers, optical 50mm x 50mm, to place on OHP
Plastic moulded transparent ruler with notch
Microwave transmitter
Microwave receiver
Power supply 12 V d.c.
Microwave polarising grill
Audio amplifier
Loudspeaker (in amplifier)
1 GHz UHF oscillator (30 cm kit) with dipole transmitter/receiver and rod to rotate plane of polarisation
Microvoltmeter as detector for rectified 1GHz waves

Practical Advice

This series of demonstrations could readily be adapted to student presentations. They are easy to perform and students will learn a lot by having to explain them to others. The whole could be completed in about an hour. The similarity of the geometries in each case should be emphasised to reinforce the learning.

It really helps students grasp the geometrical aspects if all the polarising filters for each type of wave are labelled clearly with large arrows showing the directions of permitted vibration.

Waves on rope

This should be first because it is the most visually obvious indication of what is meant by polarisation. Refer to slots rather than 'slits' in the mechanical model or students may become confused with diffraction phenomena.

Tie a long rubber tube to a tap or clamp at about bench height. The free end can be tensed gently to produce a relatively slow and easily observed transverse wave. If the free end of the rubber is waggled vertically, a vertically polarised wave is produced, which continues propagating with vertical oscillations. It can be seen to easily pass through a vertically oriented slot in the hardboard sheet; if, however, the slot in the polarising filter is rotated into the horizontal direction, the incident wave is blocked (it may be absorbed or reflected). You should show what happens for other orientations of the direction of vibration of the rubber and for the polarising filter.

Optical

1. Place a piece of polarising filter on the overhead projector and show the reduction in intensity of transmitted light. Now place a second polaroid over the first with the direction of permitted vibration parallel to the first, showing little extra reduction in intensity.
2. Now slowly rotate the upper polariser until its direction of vibration is perpendicular to the lower one, to show the absorption of light by crossed polaroids. If there are sufficient pieces of polaroid let students observe light reflected from surfaces in the lab through the filters. By rotating the filter they should be able to see that reflected light is partly polarised (vertically from a vertical surface and horizontally from a horizontal surface).
3. By placing a third polaroid filter between the other two at an angle of 45° , rotation of the direction of polarisation is observed, and some component of the light is now transmitted through the crossed polar filters.

4. If the third filter is replaced by an injection moulded plastic ruler, coloured contours of light are observed, showing the stress patterns in the plastic (different colours having their directions of vibration rotated by different amounts according to internal stress in the sample). Acetate strips can have a notch cut in them and be stressed effectively between crossed polars, illustrating photoelastic stress analysis.

The permitted direction of electric oscillations for polaroid filters can be labelled by remembering that light reflected from a vertical surface is partly polarised in the vertical direction. Rotate the polaroid until maximum intensity is observed in the reflected light, and then draw a vertical two-headed arrow on the filter in a permanent marker.

Microwaves

1. Face the transmitter towards the receiver a few metres away on the bench. Turn on the transmitter and if possible modulate the amplitude of the signal at an audio frequency (usually 100 Hz or 1 kHz). The receiver can be connected to an audio amplifier and loudspeaker so that the microwave modulation signal can be 'heard'. Inspection of the horns of the devices should suggest that the electric oscillation is vertical (see especially the vertical diode in the receiver). If either the transmitter or receiver is rotated through 90° about the direction of propagation, the received signal drops to zero.
2. A polarising filter for microwaves is a grille of metal wires. You can show the class that the grille does not transmit (absorbs or reflects) if the wires are parallel to the electric vector. At intermediate angles the polarising filter passes the component of the electric vector that is parallel to its direction of permitted vibration.
3. The rotation of the direction of vibration of the electric vector can be shown by crossing the transmitter and receiver until no signal is detected. Then place the polarising filter at say 45° . Polarising filters effectively rotate the direction of polarisation of the incident wave, by transmitting a component of the oscillation parallel to the permitted direction.

Remember that the 3 cm wave polarising grille permits electric vector vibration (conventional direction of polarisation) perpendicular to the wires. The energy of electric vector oscillations parallel to the wires is absorbed by sympathetic motion of the free electrons in the metal wires.

1 GHz waves

You can easily show that 1 GHz radio waves have a unique direction perpendicular to their direction of propagation, i.e. that they are polarised. The UHF transmitter emits waves polarised parallel to the dipole direction (there is an oscillating electric field across the gap between the dipoles).

Face the transmitter towards the receiver a few metres away on the bench and turn on the transmitter. The receiver, which is a diode rectifier, can be connected to a sensitive light beam galvanometer as detector. Again if either the transmitter or receiver is rotated through 90° about the direction of propagation, the received signal drops to zero. At intermediate angles a component of the electrical oscillation is detected.

A polariser for UHF radio waves is simply a metal rod (about 15 cm long or $l/2$). It needs to be held in a non-conducting wooden clamp. You can show the class that the rod rotates the direction of electric oscillation by placing it at 45° between crossed transmitter and receiver.

Alternative Approaches

The greater the variety of equivalent polarisation demonstrations that can be performed in the lesson the better.

Activity 130E: Experiment Polarisation by scattering

Requirements

Parallel beam projector
Power supply 0 – 12 V d.c. and a.c., 6 A
Plastic tank, rectangular
Polariser, optical
Milk (a few drops)

Practical Advice

This demonstration involves a neat piece of logical thinking which good students can and should enjoy. A simple argument tells us the direction of polarisation of scattered light. Because light is transverse, the electric field oscillates at right angles to its direction of travel. But if it is scattered at right angles to the direction of travel, oscillations in the scattering direction cannot contribute to light going in that direction, or it would be longitudinal, not transverse.

More concretely, light in the original beam will set electrons oscillating in scattering particles. Only the oscillations at right angles to a scattering direction can contribute to sending light in that direction.

For the demonstration to work it is essential not to have so much scattering material (milk) that a photon is scattered more than once. Like light from clouds in the sky, scattered light from really milky water is not polarised; it has come from so many directions that the original direction is lost. In practice this means that the scattered beam must be only just visible, which is achieved with much less milk than one would anticipate. Try one drop at first, and one more if necessary.

Alternative Approaches

If the day is sunny and the sky blue, take the chance to check that the blue sky at right angles to the direction of the sun is polarised, and note that the direction agrees with that deduced from the direction of the Sun.

3.2 Activity 140D: Demonstration Polarisation of reflected light

Nuffield Unit J

Requirements

Polarising filter, marked with its permitted direction of vibration (electric vector)

Practical Advice

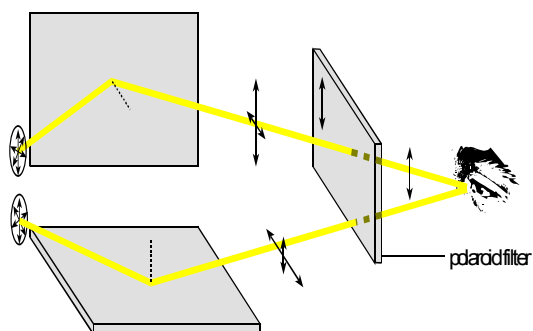
This activity is an optional addition to polarisation by scattering.

Whether or not the effect is observed depends on the substance from which the surface is made, especially whether or not it contains free electrons (i.e. whether it is metallic) and on the depth and transparency of the surface insulating (dielectric) layer.

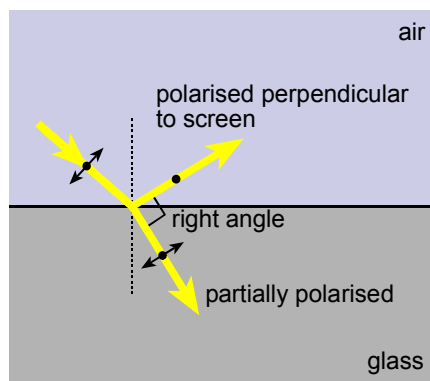
Metals do not generally show the effect, unless coated with thick insulating varnish or a dielectric anodised or oxidised surface layer.

Insulators may show the effect, but not all do so at visible wavelengths, as a certain degree of transparency is required to allow penetration by several wavelength depths into the surface. This is large on the atomic scale, several thousand atoms deep, but small on our scale, so that the bulk material may appear opaque but has sufficient transparency to cause partial polarisation. There is no need to worry students with too much of this.

For example, white polythene plastic causes polarisation although it is opaque in bulk, whereas white paper does not. All transparent insulators produce the effect with light (all insulators are transparent to some electromagnetic frequencies, but not necessarily in the visible region). The direction of vibration of the partial polarisation is parallel to the reflecting surface, but of course transverse to the direction of propagation of the reflected wave.



Placing different surfaces at different angles gives various directions of partial polarisation after reflection. These are detected by the rotated polaroid filter.



More advanced students may notice that the partial polarisation is total at one angle of reflection. This is clear on looking at the reflections from various angles in a large sheet of glass or Perspex. At this angle, the Brewster angle, the reflected and refracted rays are at 90° and the reflection is totally linearly polarised, although its intensity is only about 8% of the original incident beam for glass. The transmitted refracted ray is only partially polarised, but this may be increased by successive refractions at a series of glass-air interfaces. This can nicely be demonstrated with 20 microscope slides and a ray optics lamp.

At the Brewster angle

$$i + r = 90^\circ \text{ and } n = \sin i / \sin r = \sin i / \cos i = \tan i$$

so for glass with $n = 1.5$, the Brewster angle is $\tan^{-1}(1.5) = 56.3^\circ$.

Alternative Approaches

This activity could be run as a home experiment – examining light reflected from different surfaces for polarisation. Students might have their own polarising sunglasses or the school could loan polaroid filter squares overnight. For a quick demonstration of total polarisation by reflection and Brewster's angle, use a stack of microscope slides for multiple reflections and improved polarisation of the transmitted beam. At about 56° for glass the reflection is completely polarised.

Activity 50E: Experiment Guess a waveform from a sample

Requirements

Paper
Tracing paper

Practical Advice

Prepare in advance sheets of paper with a box drawn on them to contain the waveforms. You may find it useful to add ruled lines to show where samples should be taken.

The essential point to realise is that samples can indicate the shape of a waveform, but only if they are frequent enough. You may wish to vary the rules suggested by for example changing the frequency of sampling, or by setting restrictions on the waveforms that can be drawn (for example, no maximum or minimum is allowed between samples).

You may want to bear in mind the background theory. In essence, samples can be used to recover a waveform exactly if (and only if) the rate of sampling is greater than twice the highest frequency present (strictly, greater than twice the signal bandwidth). Suppose the waveform consists of just three harmonics, f , $2f$ and $3f$. Each has an amplitude and phase: these six parameters are needed to determine the compound waveform, plus one more to determine the d.c. level. A Fourier transform can determine these parameters if it has as many (or more) samples as there are parameters to find. Eight samples per frame are just enough to recover a waveform if it has no frequency higher than one which has three cycles in the frame.

Note that this argument means that a signal is recovered from samples not simply by 'joining up the samples smoothly' but by fitting the sum of a set of sinusoidal variations. For this reason a signal can be recovered exactly even if there are not always samples at every maximum or minimum.

A further important point may emerge, but should not be insisted on here. A lot depends on the way the waveform fits into the 'window'; into the box in which it is drawn. Only if the waveform would repeat exactly if continued to the right or left is the task easy. This is called the 'windowing' problem in work on Fourier transforms. Selecting the wrong window for the analysis of a spectrum can give quite false results, since the Fast Fourier Transform algorithm assumes that the waveform repeats indefinitely outside the window. Only with this assumption are there sharp frequencies in the spectrum.

Alternative Approaches

A signal processing programme could be used to show samples from waveforms. With some electronics expertise, you might also be able to show sound signals being sampled, at different rates.

Activity 80E: Experiment Looking at signal conversion

Requirements

Analogue to digital converter (ADC) box
Power supply unit for measurement amplifier
Two digital multimeters
Digital to analogue converter (DAC) box
Oscilloscope
Signal generator

Practical Advice

This activity is based on an article by Martin Gregory first published in School Science Review, September 1997. We deliberately use a low resolution so that the process is made explicit.

Alternative Approaches

Stepped signals can be seen on many sound processors. Showing that these correspond to certain levels only is hard. It is nearly possible to convince yourself if you record a low-amplitude sound and then amplify it several times.

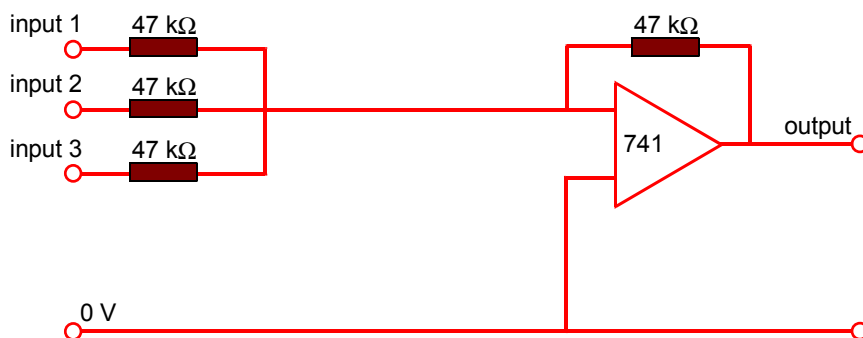
Activity 170E: Experiment Spectrum analysis: Simple signals

Requirements

PC-scope
Three signal generators
Loudspeaker
Measurement amplifier as a signal adder

Practical Advice

An interface which includes real-time spectral analysis makes this initial demonstration a quick introduction to the ideas. Any adder can be used. The circuit below is straightforward to construct.



Alternative Approaches

The adder can be made from standard measurement amplifier boards. The Nuffield operational amplifier board, for example, allows two signals to be combined. The output of this board can be added to a third input with a second Nuffield operational amplifier board: a slightly more clumsy but equally effective approach.

Cool Edit 96, the sound processing software recommended for this course, can generate and analyse harmonics. This can be used if a real-time system is not available.

There is a spectrum analyser built into 'Multimedia Sound' which could be used if a real-time system is not available. Signals to be analysed can be synthesised by 'Multimedia Sound' but this is time consuming. 'Multimedia Sound' also accepts .wav files, so a sequence of signals could be generated with a sound card acting as an interface/recorder.