

# locktronics

Simplifying Electricity

**Advanced electronic principles**



LK3008 - introduction

**MATRIX**

[www.matrixtsl.com](http://www.matrixtsl.com)

Copyright © 2015 Matrix Technology Solutions Ltd

# Contents

## Advanced electronic principles

Package introduction	3
Introducing filters	4
Introducing the digital oscilloscope	5
Worksheet 1 - Active low pass filter	7
Worksheet 2 - Active high pass filter	9
Worksheet 3 - Active band pass filter	11
Instructor Guide	13

# Package introduction

## Advanced electronic principles

This workbook is designed to cover the Advanced electronic principles unit which is part of the BTEC Higher national award in engineering—unit 39.

The worksheets that make up this workbook are contained in several sub-workbooks:

### LK3008 - Advanced electronic principles introduction (in this book)

Some supplementary material on active filters.

### LK3008 - Advanced electronic principles part 1

Diodes and diode types, full and half wave rectifiers, rectifier efficiency, reservoir capacitors, voltage multipliers, thyristor and SCR circuits, zener diodes and circuits, LEDs in AC and DC circuits.

### LK3008 - Advanced electronic principles part 2

NPN and PNP transistors, transistor characteristics, transistor bias and decoupling, common base, common emitter, and common collector circuits, class A, B and C amplifiers, other transistor circuits.

### LK3008 - Advanced electronic principles part 3

AND, OR, NAND, NOR and NOT gates, simple logic circuits, operational amplifiers, inverting and non-inverting amplifiers, integrators, differentiators, comparators, positive and negative feedback in amplifiers.

### LK3008 - Advanced electronic principles part 4

Open and closed loop systems, Oscillators, analogue transducers, damping in feedback systems

# Introducing filters

## Advanced electronic principles

### What is a filter?

A filter is a subsystem that:

- has a voltage gain that depends on the frequency of the signal;
- does not change the mix of frequencies present in the signal;
- emphasises some signal frequencies and depresses others.

### Types of filters:

#### 1. Passive filters:

- contain no active components (that amplify the signal - transistors, op-amps etc);
- have a voltage gain less than 1.0 - can only *cut* and cannot *boost*;
- can be significantly affected by the load attached to the filter;
- prevail at high frequencies because of the bandwidth limitations of active devices.

#### 2. Active filters:

- contain active components and require a power supply;
- can have a voltage gain greater than unity and so can cut or boost;
- predominate at low frequencies because inductors for passive filters are very bulky.

### Filter behaviour:

The diagrams illustrate the behaviour of four common types of filter and the meaning of the terms 'Pass band' and 'Stop band'.

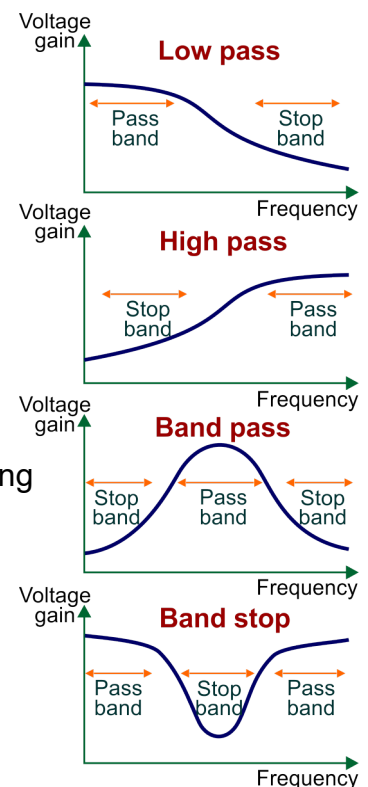
Each shows a different variation in voltage gain with frequency.

Alternative names:

low pass filter	⇔	treble cut filter
high pass filter	⇔	bass cut filter
band stop filter	⇔	notch filter

The steepness of the curve between the pass band and stop band depends on the 'order' of the filter:

- in a first-order filter, the amplitude halves (or doubles, depending on the type of filter,) when the frequency doubles;
- in a second order, this change is one-quarter (or four times);
- the higher the order, the more complicated the circuit.



# Introducing the digital oscilloscope

## Advanced electronic principles

### The digital oscilloscope:

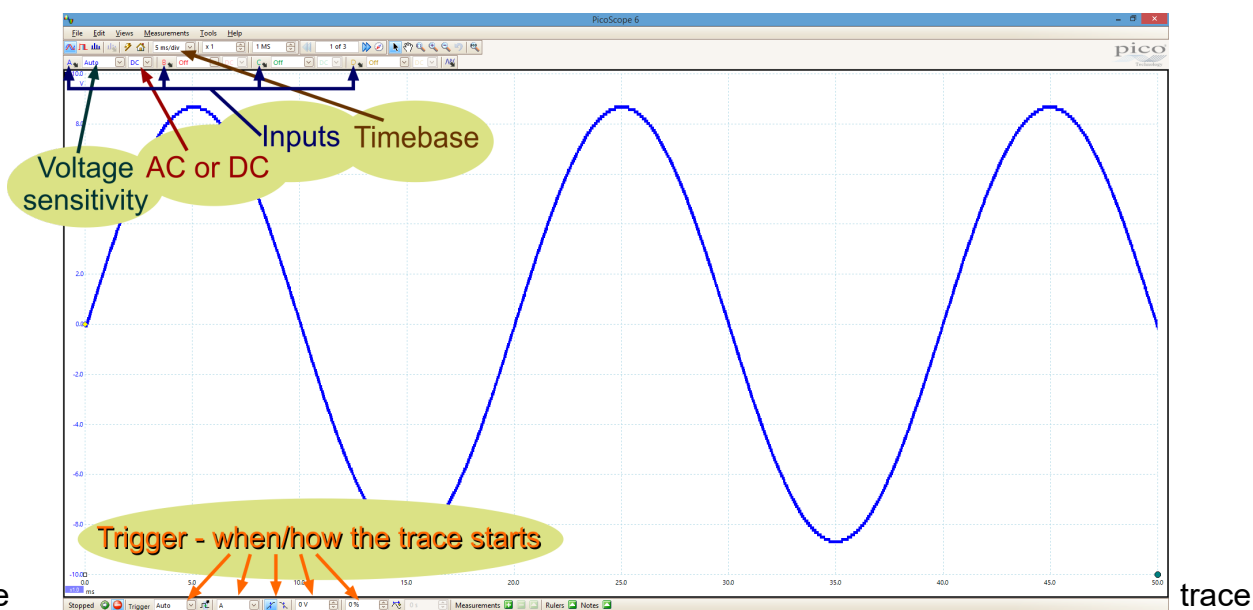
Computer-based oscilloscopes, like Picoscope, are data-loggers. They monitor voltages, at regular intervals, and pass the results to software in the computer. There, it is processed to produce voltage/time graphs, frequency information etc. to be displayed on the monitor, stored as a file, or printed, like other information on the computer.

The Picoscope uses the oscilloscope controls described above, plus:

- AC or DC - shows only varying voltages for 'AC' (so centres the trace on 0V;)  
- shows the true voltage levels if DC is chosen.
- Stop / Go - '**Stop**' - the trace is 'frozen' (i.e. as a stored event, suitable for saving to a file;)  
- '**Go**' - the trace is showing events in real-time;  
- click on the appropriate box to change from one to the other.

The settings are selected on-screen using the drop-down boxes provided.

The following diagram shows some of the main controls on the Picoscope 6 screen.



The uses the following settings:

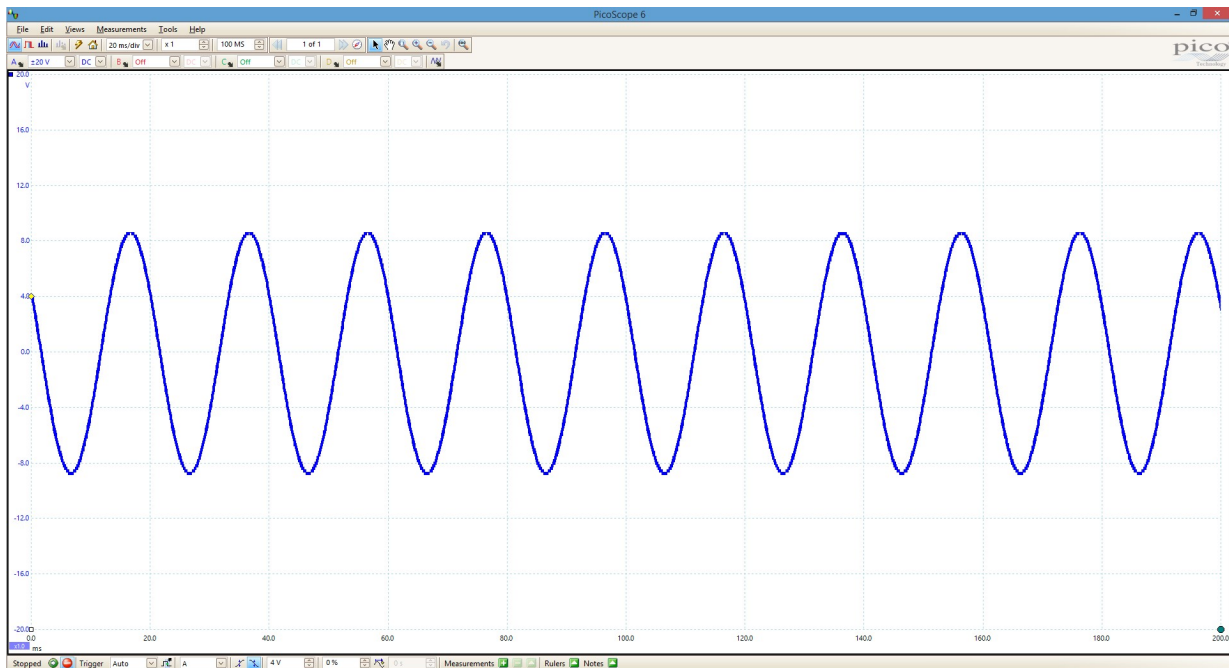
- |                            |   |
|----------------------------|---|
| Timebase - 5 ms/div        | - so the time scale (horizontal axis) is marked off in 5 ms steps.  |
| Voltage sensitivity - auto | - so the software adjusts the voltage scale (vertical axis) to suit the signal. The scale on the left-hand edge of the image increases in 2V steps. The trace shown has a maximum value of around 8.7V. |
| Trigger - Auto             | - so will show any changes in the signal as they happen.  |
| Ch <b>A</b>                | - so looks at the signal on channel <b>A</b> to decide when to start the trace.   |
| <b>Rising</b>              | - so waits for a <b>rising</b> voltage to reach the threshold;  |
| Threshold - <b>0</b> mV    | - so starts the trace when the signal on channel <b>A</b> <b>rises</b> through <b>0V</b> .  |
| Pre-trigger - 0%           | - so the display starts with the very first data captured.  |

# Introducing the digital oscilloscope

## Advanced electronic principles

### Picoscope continued...

For the next trace, the signal is the same, but some of the settings have been changed.



The new settings are:

- |                     |                       |   |
|---------------------|-----------------------|---|
| Timebase            | - 20 ms/div           | - so the time scale is marked off in 20 ms steps.                                     |
| Voltage sensitivity | - 4V/div              | - so the voltage scale is marked off in 4V steps.                                     |
|                     |                       | The trace still has a maximum value of around 8.7V.                                   |
| Trigger             | - Auto                | - so still shows any changes in the signal as they happen.                            |
|                     | Ch <b>A</b>           | - so still looks at the signal on channel <b>A</b> to decide when to start the trace. |
|                     | <b>Falling</b>        | - so now waits for a <b>falling</b> voltage to reach the threshold;                   |
|                     | Threshold - <b>4V</b> | - so starts the trace when the signal on channel <b>A falls</b> to <b>4V</b> .        |
|                     | Pre-trigger - 0%      | - so the display starts with the very first data captured.                            |

More information about using Picoscope is given in the Picoscope User manual, found on the CD-ROM that comes with the instrument or on the website [www.picotech.com](http://www.picotech.com).

# Worksheet 1

## Active low pass filter

# Advanced electronic principles



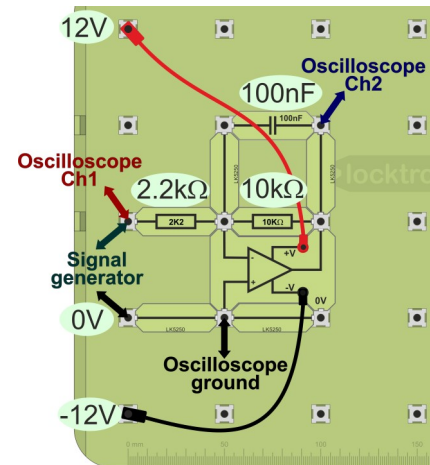
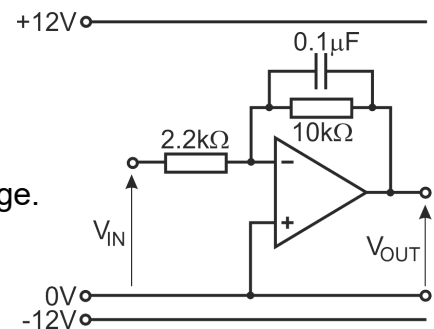
The frequency range for human hearing is taken to be the range 20Hz to 20kHz. An ideal amplifier offers the same voltage gain to all these frequencies.

However, sometimes we want to boost or cut frequencies within that range. For example, where a signal sounds ‘tinny’ or too shrill, a low pass filter could reduce the amplitude of treble frequencies in that signal.

The circuit investigated here does just that.

### Over to you:

- Build the circuit shown opposite - yet another modification of the inverting amplifier. A suitable layout is provided.
- The input signal is provided by a signal generator.
- The output is monitored on a dual-trace oscilloscope such as the Picoscope. Suitable settings are given on the next page.
- Set the signal generator to give a sine-wave signal with a frequency of 10Hz and an amplitude of 1.0V.
- Copy the table and use it to record your results.
- Measure the amplitude of the input and output signals and record them in the first row of the table.
- Obtain a trace showing the input and output signals and save it for your records.
- Repeat this process for the other frequencies in the table. Aim for an input signal amplitude of 1.0V each time but measure and record the actual amplitude. Measure and record the output signal amplitude each time.
- Obtain a second trace showing the input and output signals for a frequency of 1kHz, for contrast with the first, and save it for your records.



- Complete the ‘Gain’ columns, using the formula:  

$$\text{Voltage gain} = V_{OUT} / V_{IN}$$
- Plot a graph of voltage gain against frequency and draw a smooth curve through the points.

Frequency	V <sub>IN</sub>	V <sub>OUT</sub>	Gain	Frequency	V <sub>IN</sub>	V <sub>OUT</sub>	Gain	Frequency	V <sub>IN</sub>	V <sub>OUT</sub>	Gain
10Hz				100Hz				600Hz			
20Hz				200Hz				700Hz			
30Hz				300Hz				800Hz			
40Hz				400Hz				900Hz			
50Hz				500Hz				1000Hz			



# Worksheet 1

## Active low pass filter

## Advanced electronic principles

### So what?

Suitable settings for the Picoscope are:

Timebase	Input (Ch B)	Output (Ch A)	Trigger			
			Mode	Channel	Direction	Threshold
5ms/div	±5V AC	±5V AC	Auto	Ch A	Rising	0V

### How does this low pass filter work?

For an inverting amplifier:

$$\text{voltage gain} = R_F / R_{IN}$$

where  $R_F$  = feedback resistance and  $R_{IN}$  = input resistance.

The low pass filter circuit has a capacitor in parallel with the feedback resistor. This behaves like a large resistor at low frequencies and a smaller and smaller resistor as the frequency rises.

At **high** frequencies, it acts as an easy route for AC current. The current increasingly flows through the capacitor instead of through the feedback resistor. This reduces the effective value of the feedback resistor, reducing the voltage gain of the filter.

### Challenge:

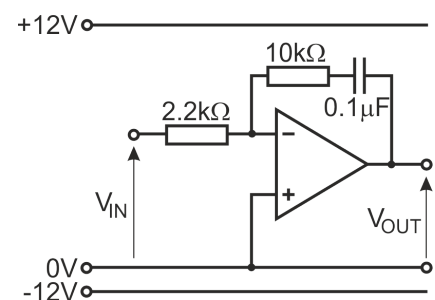
A relative of this filter is the active bass boost filter, which favours low frequencies over higher ones.

The circuit diagram shows one form of this filter.

It uses the same components as the one you just

Investigated but produces a very different performance.

- Using the same approach as before, investigate its performance over the frequency range 100Hz to 1kHz.
- Draw a voltage gain versus frequency graph for this filter and draw a smooth curve through the points.



### For your records:

- Explain the difference between active and passive filters.
- Copy the diagrams showing the behaviour of the four types of filter.
- Draw the circuit diagram for the low pass (treble cut) filter.
- Write an account of what you did to obtain the results.
- Draw the circuit diagram for the bass boost filter.
- Describe the difference between a low pass treble cut filter and a low pass bass boost filter.
- Research possible applications for treble cut and bass boost filters and write a report on your findings.



# Worksheet 2

## Active high pass filter

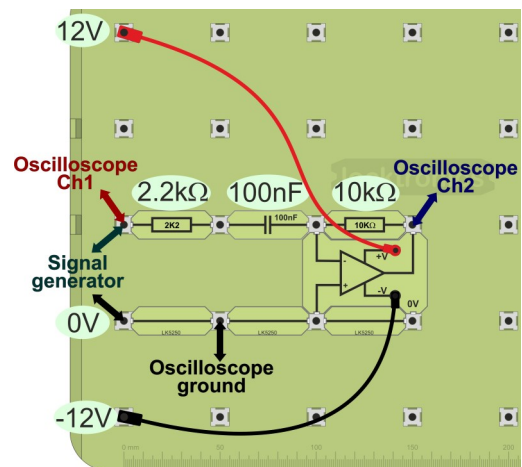
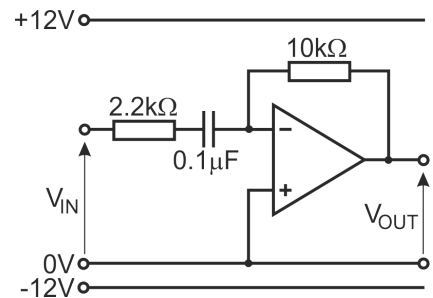
# Advanced electronic principles



Vinyl records are very much in vogue. Favoured for their 'warm' sound, they do, however, come with issues. They can transmit a very low frequency 'rumble' caused in some cases by the turntable's bearings or, in others, by deformation of the vinyl disc itself. To remove it, the audio system can incorporate a 'rumble' filter - one form of active high pass filter.

### Over to you:

- Build the circuit shown opposite with the same components as in worksheet 1. This time, the 10kΩ resistor and the 0.01μF capacitor are in series in the input section of the op-amp. A possible layout is provided.
- Once again, the input signal is provided by a signal generator and the output is monitored on a dual-trace oscilloscope. Suitable settings are given on the next page.
- Set the signal generator to give a sine-wave signal with a frequency of 200Hz and an amplitude of 1.0V.
- Copy the table and use it to record your results.
- The procedure is the same as before:
  - Measure and record the input signal amplitude.
  - Measure and record the output signal amplitude.
  - Repeat the process for all other frequencies in the table.
- Complete the 'Gain' columns of the results table.
- Plot a graph of voltage gain against frequency and draw a smooth curve through the points.



Frequency	V <sub>IN</sub>	V <sub>OUT</sub>	Gain	Frequency	V <sub>IN</sub>	V <sub>OUT</sub>	Gain	Frequency	V <sub>IN</sub>	V <sub>OUT</sub>	Gain
200Hz				1200Hz				2200Hz			
400Hz				1400Hz				2400Hz			
600Hz				1600Hz				2600Hz			
800Hz				1800Hz				2800Hz			
1000Hz				2000Hz				3000Hz			

# Worksheet 2

## Active high pass filter

## Advanced electronic principles

### So what?

Suitable settings for the Picoscope are:

Timebase	Input (Ch B)	Output (Ch A)	Trigger			
			Mode	Channel	Direction	Threshold
5ms/div	±5V AC	±5V AC	Auto	chA	Rising	0V

### Break frequency:

- The circuits used here behave like 'normal' inverting amplifiers, except for the effect of the capacitor. It acts like a large resistor at low frequencies, getting smaller as frequency rises.
- At a very low frequency, the capacitor behaves like a break in the circuit and the combined 'resistance' (impedance) of the series resistor and capacitor is huge - the voltage gain is tiny.
- At a very high frequency, the capacitor has no effect. The resistor alone controls the input current. Now, the voltage gain is  $R_F / R_{IN} = 10\text{k}\Omega / 2.2\text{k}\Omega = 4.5$  and remains fairly constant with frequency (if the resistors are 100% accurate!)
- Somewhere in between, the capacitor has the same effect as the input resistor. More precisely, the reactance of the capacitor is equal to the resistance of the input resistor.
- This happens at a frequency called the break (or cut-off) frequency, marking the frequency at which the voltage gain of the filter starts to fall as the frequency reduces.
- At the break frequency,  $f_B$ :

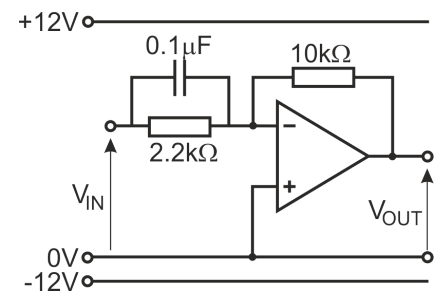
$$X_C = R \quad \text{so that:} \quad 1/2\pi f_B C = R$$

$$\text{or re-arranging:} \quad f_B = 1/2\pi RC$$

### Challenge:

Related to this, the active treble boost filter favours high frequencies over low. The circuit diagram opposite shows one form of this filter, using the same components as before.

- Investigate its performance over the frequency range 100Hz to 1200Hz.
- Draw a voltage gain versus frequency graph for this filter and draw a smooth curve through the points.



### For your records:

- Why is the term 'break frequency' important when considering the behaviour of filters?
- Write down the formula for break frequency.
- Calculate the break frequency for the circuit you investigated on the previous page.
- Draw the circuit diagram for the bass cut filter.
- Write an account of what you did to obtain the results.

# Worksheet 3

## Active band pass filter

## Advanced electronic principles

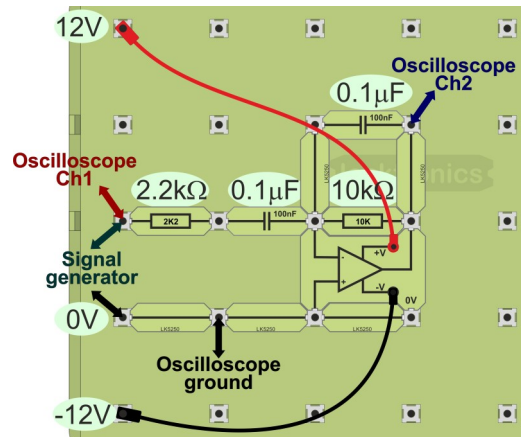
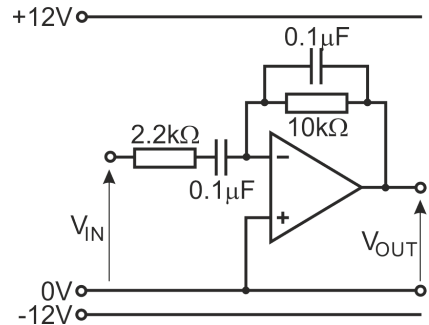


The simplest form of band pass filter uses a combination of a low pass and a high pass filter. This investigation looks at its behaviour.

A typical use is in equalisation circuits for speaker systems, where a low pass filter delivers output to the bass speakers, a band pass filter to the mid-range and a high pass filter to the treble speakers.

### Over to you:

- Build the circuit shown opposite. A possible layout is shown underneath.
- Once again, the input signal is provided by a signal generator and the output is monitored on a dual-trace oscilloscope. Suitable settings are given on the next page.
- Set the signal generator to give a sine-wave signal with a frequency of 100Hz and an amplitude of 1.0V.
- Copy the table and use it to record your results.
- The procedure is the same as before:
  - Measure and record the input signal amplitude.
  - Measure and record the output signal amplitude.
  - Repeat the process for all other frequencies in the table.
- Complete the 'Gain' columns of the results table.
- Plot a graph of voltage gain against frequency and draw a smooth curve through the points.



Frequency	V <sub>IN</sub>	V <sub>OUT</sub>	Gain	Frequency	V <sub>IN</sub>	V <sub>OUT</sub>	Gain	Frequency	V <sub>IN</sub>	V <sub>OUT</sub>	Gain
100Hz				1100Hz				2100Hz			
200Hz				1200Hz				2200Hz			
300Hz				1300Hz				2300Hz			
400Hz				1400Hz				2400Hz			
500Hz				1500Hz				2500Hz			
600Hz				1600Hz				2600Hz			
700Hz				1700Hz				2700Hz			
800Hz				1800Hz				2800Hz			
900Hz				1900Hz				2900Hz			
1000Hz				2000Hz				3000Hz			

# Worksheet 3

## Active band pass filter

## Advanced electronic principles

### So what?

Suitable settings for the Picoscope are:

Timebase	Input (Ch B)	Output (Ch A)	Trigger			
			Mode	Channel	Direction	Threshold
5ms/div	±5V AC	±5V AC	Auto	chA	Rising	0V

### Circuit design:

Earlier worksheets looked at high pass and low pass filters. This circuit combines both, as the diagrams opposite illustrate.

Put simply:

- The high pass filter eliminates low frequencies in the signal.
- The low pass filter eliminates high frequencies.

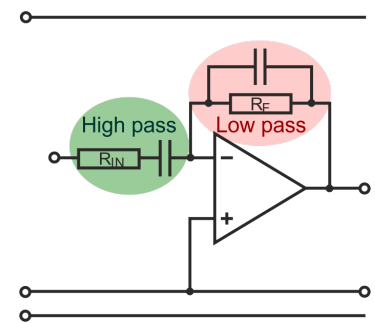
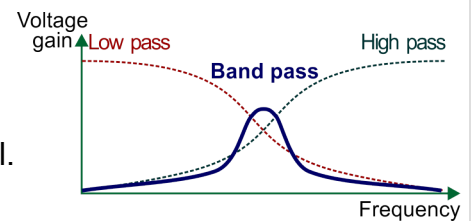
The only frequencies which experience significant voltage gain are the mid-range frequencies. This results in the band pass curve.

The voltage gain for the filter is given by the formula:

$$\text{Voltage gain} = R_F / R_{IN}$$

as usual for an inverting amplifier.

The selectivity of the filter depends on the break frequencies of the high pass and low pass filter.



### Challenge:

- Investigate the effect of changing the component values in the circuit to change the break frequencies of the low pass and high pass sections.
- For each combination, plot a graph of voltage gain versus frequency.

### For your records:

- Draw the circuit diagram for the simple band pass filter.
- Calculate the break frequencies of the low pass and high pass sections of the circuit.
- Write a brief explanation of the shape of the voltage gain / frequency graph for this circuit.
- Use the internet or other reference source to research one of the following:
  - a second order low pass filter;
  - a second order high pass filter;
  - a notch filter.

For your chosen subsystem, write a report, including a circuit diagram, with a brief description of how it works.

# Instructor Guide

## Advanced electronic principles

### About this course

#### Introduction

The course is essentially a practical one. Locktronics makes it simple to construct and test electrical circuits. The result mirrors the circuit diagram, thanks to the circuit symbols printed on the carriers.

#### Aim

The course is part of the 'Electronic Principles' module. It explores the use of an op-amp inverting amplifier, modified to exhibit first-order filter behaviour.

#### Prior Knowledge

It is recommended that students have followed 'Electricity Matters 1' and 'Electricity Matters 2' or have equivalent knowledge of concepts such as current, voltage, and resistance. They should be familiar with the use of an op-amp, configured as an inverting amplifier, and the corresponding voltage gain formula. They should also be familiar with the behaviour of capacitors, the concept of reactance and the formula linking it to capacitance and frequency. They should be able to construct and test circuits, using a range of measuring instruments, including multimeters and oscilloscopes.

#### Learning Objectives

On successful completion of this course the student will be able to:

- describe the function of a filter subsystem;
- distinguish between active and passive filters;
- distinguish between first order and higher order filters;
- draw frequency spectrum graphs to distinguish between the following types of filter:
  - low pass;
  - high pass;
  - band pass;
  - band stop.
- define and explain the significance of the term 'break frequency (cut-off frequency);
- state and use the formula linking break frequency to capacitor and resistor values;
- perform calculations using the prefixes 'kilo', 'micro' and 'nano';
- draw the circuit diagram for a low pass (treble cut) active filter;
- draw the circuit diagram for a high pass (bass cut) active filter;
- draw the circuit diagram for a simple band pass active filter;
- use a signal generator and oscilloscope to measure the frequency response of an active filter;
- describe the performance of bass boost and treble boost filters;
- explain the operation of a simple band pass filter in terms of its low pass and high pass sections.

# Instructor Guide

## Advanced electronic principles

### What the student will need:

To complete the course, the student will need the following equipment:

- |   |                                       |
|---|---------------------------------------|
| 1 | LK5202 1k $\Omega$ resistor carrier   |
| 1 | LK6218 2.2k $\Omega$ resistor carrier |
| 1 | LK5203 10k $\Omega$ resistor carrier  |
| 2 | LK5222 0.1 $\mu$ F capacitor carrier  |
| 1 | LK6216 0.47 $\mu$ F capacitor carrier |
| 8 | LK5250 connecting links               |
| 1 | LK8900 Locktronics Baseboard (0)      |
| 1 | Multimeter                            |
| 1 | Signal generator                      |
| 1 | Dual-trace oscilloscope               |

This pack is designed to be used with the Locktronics power supply/signal generator.

### Using this course:

The experiments in this course should be integrated with teaching to introduce the theory behind it, and reinforced with written examples, assignments and calculations.

The worksheets should be printed / photocopied / laminated, preferably in colour, for the students' use. They should make their own notes, and carry out the tasks identified in the 'For your records' sections. They are unlikely to need their own permanent copy of the worksheets, but the instructor may choose to distribute copies of the Introduction for students' records.

Each worksheet has:

- an introduction to the topic under investigation;
- step-by-step instructions for the investigation that follows;
- a section headed 'So What', to collate and summarise results, offer extension work and encourage development of ideas, through collaboration with partners and with the instructor.
- a section headed 'For your records', to be copied and completed in students' exercise books.

This format encourages self-study, with students working at a rate that suits their ability. The instructor should monitor that students' understanding keeps pace with their progress through the worksheets. One way to do so is to 'sign off' each worksheet, as a student completes it, and in doing so have a brief chat with the student to assess grasp of the ideas involved in the exercises it contains.

### Time:

It should take students between 2 and 4 hours to complete the worksheets. It is expected that a similar length of time will be needed to support the learning that takes place as a result.



# Instructor Guide

## Advanced electronic principles

Worksheet	Notes for the Instructor	Timing
<b>Introducing filters</b>	<p>This course begins with an introduction to the general concepts involved in filters - the difference between active and passive filters and an overview of filter types based on their frequency spectrum. The instructor, knowing the students' background can judge how much support to provide at this point.</p> <p>Power supply possibilities - the layout diagrams are arranged so that the new Locktronics power supply can be clipped onto the baseboard and used directly. Other power supplies can be connected using the Locktronics power supply carrier or 4mm leads.</p> <p>The course assumes that students have access to dual-trace oscilloscopes. If these are computer-based, like the 'Picoscope' range, even better as they can then save their traces for future reference. The instructor could project some during tutorial work to make appropriate points.</p>	<b>15 - 30 mins</b>
<b>1</b>	<p>In the first worksheet, students build and test the frequency response of an active low pass filter.</p> <p>It is assumed that the students are already familiar with the use of an op-amp as an inverting amplifier. It may be prudent to revise this circuit beforehand.</p> <p>Students use a signal generator and dual-channel oscilloscope (or equivalent virtual instrument). Where necessary, support in the form of instruction or demonstration on using these should be given before the students begin their own measurements. It is important to remind students that the common ground connection to the signal generator and oscilloscope should be taken to the 0V supply rail. With some students, the instructor may wish to check the settings on the signal generator and oscilloscope. Where a digital oscilloscope is used, the final traces will demonstrate that the settings were correct.</p> <p>It is assumed that the students understand the term 'amplitude' and are able to measure this from the oscilloscope traces. Similarly, it is assumed that they are familiar with the voltage gain formula.</p> <p>If there are problems with the circuit, the first check should be that the power supply is working and connected correctly. One way to do this is to measure the voltage across the power supply connections to the op-amp. Secondly, if the op-amp is functioning correctly, the voltages on its two inputs should be identical, providing that the output is not saturated. If the output is saturated, the student may have chosen incorrect values for the resistors, may have the wrong amplitude setting on the signal generator, may be adding a DC offset to the input signal, or may have an incorrect 0V connection.</p> <p>The 'So what' section outlines the way that the filter works. This explanation assumes that the students are familiar with the AC behaviour of capacitors. The instructor may wish to reinforce this explanation where necessary.</p>	<b>50 - 75 mins</b>



# Instructor Guide

## Advanced electronic principles

Worksheet	Notes for the Instructor	Timing
<p><b>1</b> continued...</p>	<p>The challenge is to investigate the behaviour of a bass boost filter, using the same component values. No layout is suggested for this, but the instructor may wish to give the one shown here to weaker students.</p> <p>The distinction between treble cut and bass boost lies in the values for voltage gain. 'Cut' implies a gain less than one. The results for the treble cut filter should show this for high frequency signals. On the other hand, 'boost' implies a gain greater than one. The results for the bass boost should show a voltage gain increasing well above unity for low frequency signals.</p>	
<p><b>2</b></p>	<p>In this worksheet, students set up a high pass filter, again using the same components and so giving the same break frequency.</p> <p>The procedure is the same as in the first worksheet. However, the instructor may wish to check the settings on the signal generator and oscilloscope with weaker students. (The frequency range is different so that the students see the wider behaviour of the filter.)</p> <p>Where appropriate, the students can be asked to plot the results on log-log or lin-log scales. Some initial support would probably be needed for this.</p> <p>The 'So what' section offers an explanation of the term 'break frequency' and obtains a formula for calculating it. Students will need practice in its use. Misuse of the multipliers 'kilo' and 'micro' (or 'nano') is widespread!</p> <p>The challenge is to investigate the behaviour of a treble boost filter, still using the same component values and so having the same break frequency. The instructor may wish to give the layout shown opposite to weaker students.</p> <p>Where a range of component values is available, faster students could be asked to investigate the effect of changing resistor and capacitor values.</p> <p>The issue of the distinction between cut and boost (now bass cut and treble boost) arises here. The explanation is the same as in worksheet 1.</p>	<p><b>50 - 75 mins</b></p>

# Instructor Guide

## Advanced electronic principles

Worksheet	Notes for the Instructor	Timing
3	<p>In this worksheet, the student combines the experience gained, in worksheets 1 and 2 on low pass and high pass filters, to create a simple band pass active filter and test its performance.</p> <p>The process is the same as that used in earlier worksheets. The frequency range used is necessarily wider and more 'granular' than that used previously - the instructor may wish to extend it even further to clarify the contributions of the two sections.</p> <p>Depending on the oscilloscope used, it may be necessary to give advice on changing the time base setting as the frequency increases. Where a Pico-scope device is used, the student can make use of the 'Measurement' facility to read off the peak-to-peak voltages of the traces directly. (It may be that the instructor prefers to develop students ability to take measurements off the trace itself.)</p> <p>Interpreting the resulting frequency spectrum is not straightforward and it may be best to limit it to the simplified description given in the text. Faster students should be encouraged to experiment with this circuit by changing the break frequencies of the low pass and high pass sections. They must bear in mind desirable levels of voltage gain when changing resistor values. Depending on the choice available to them, a useful way forward is to leave the low pass section alone initially and increase the break frequency of the high pass section, bearing in mind that this circuit is supposed to be a device operating in the audio frequency range.</p> <p>The 'For what' section offers the opportunity for combining the findings of the different groups, on second order and notch filters, through presentations delivered to the whole class.</p>	50 - 75 mins