Realization of an Impedometric Respiration System

Learning Objectives

- To understand the concept of SYSTEM---LEVEL design by identifying the subsystems needed to compose the prototype of an impedance respirometer.

- To build part of a prototype impedometric pneumometer on a stripboard by populating it with electronic components and soldering themin to the correct place. This aims at developing PRACTICAL DEVELOPMENT, INSTRUMENTATION & DEBUGGING skills.

- To familiarise with the practical aspects related to the BASIC TESTING of an instrument prototype.

- To identify & appreciate block--level deviations from ideality and how these affect system--level performance.

Introduction

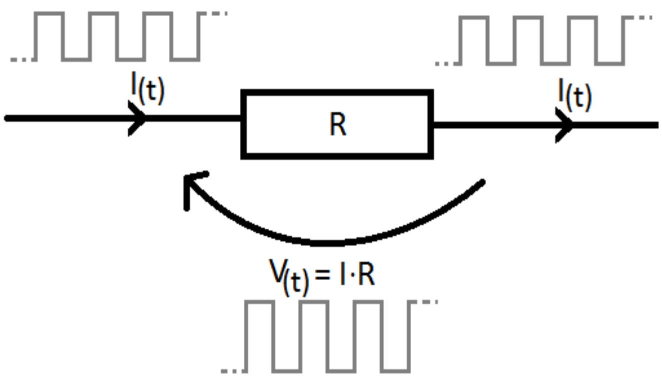
1) What is impedance pneumography?

Pneumography is the measurement of the act of breathing, or the respiratory movements. Various methods exist such as *spirometry* which is performed using as a *spirometer.* The spirometer is an apparatus that measures the air that is exhaled and inhaled from the lungs. This has the advantage of being very accurate but its main two disadvantages is the tampering of the result by constricting the airflow in the lungs by placing a mouthpiece and for some cases it is impossible to seal the airways to record air flow.

A less restrictive method is the impedance pneumography. This method does not cover the airways in any way but its main disadvantage is that it is very prone to motion artefact induced error. The method works by measuring changes in the electrical impedance of the thorax which are caused by breathing. A high frequency current is injected into the tissue. This causes a potential difference to be generated. Since the current is constant and predetermined the potential difference that builds up is an indicative measure of the impedance across the injecting electrodes.

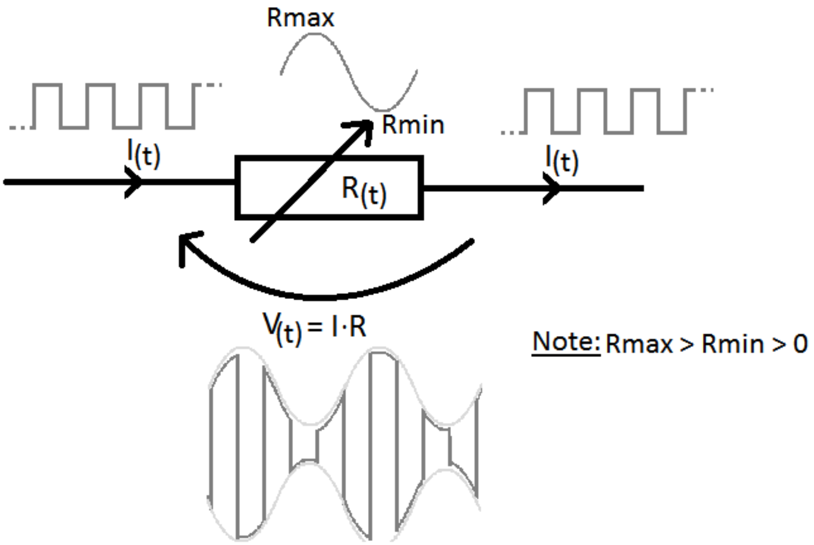
2) The basic mechanism of impedance pneumography

The basic mechanism of impedance pneumography is shown in the following diagrams:



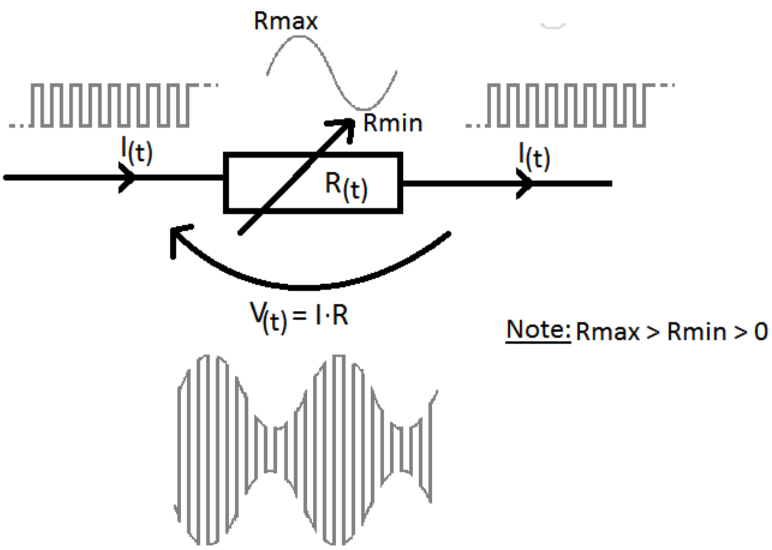
If a square pulse of current is passed through a resistor of constant value then a voltage will be generated across the resistor of value $V = I \times R$ according to Ohm`s law.
In other words the voltage generated across the resistor can be thought of as a rescaled value of the current and the scaling factor is the resistor value.

Now imagine if we let the resistance value vary with time.



If we let the resistance vary in a sinusoidal manner then the amplitude of the voltage across the resistor when current is injected in will also vary sinusoidally.
Notice though that the resistance value is always positive and will never be exactly zero (unless short---circuit) or negative therefore the voltage will never change phase of oscillation, but only amplitude.

As we increase the current frequency, or the so called "carrier" frequency for amplitude modulation (A.M.) encoding of the signal we can better perceive the modulating frequency.

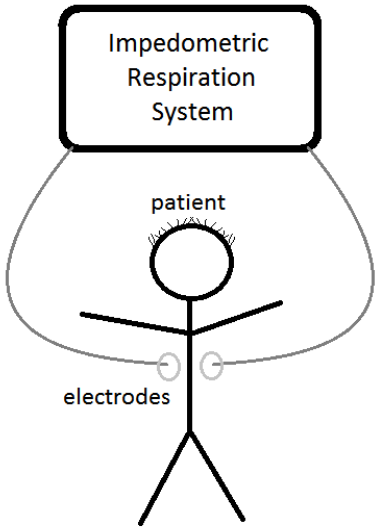


The modulating frequency is the variation in the resistance value and commonly that is the signal of interest whereas the carrier frequency only carries the signal in its amplitude variation, hence its name.
Aliasing effects can exist and the Nyquist-Shannon sampling theorem states that the

maximum possible modulating frequency that exists in the signal to be transmitted or measured should be half of the carrier frequency. If this criterion is not met then aliasing effects can disrupt either the signal transmission or the measurement values.

3) Impedance Pneumography as a system

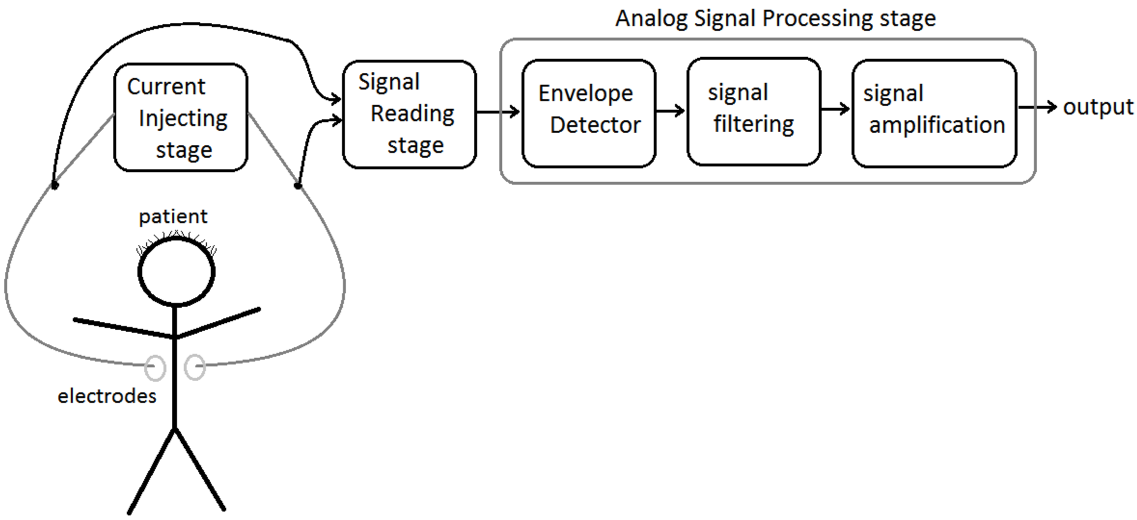
There are two possible arrangements for an impedometric respiration system; the two electrode configuration and the four electrode configuration. In the case of the four electrodes one pair injects current and the other pair records.
In the lab we will realise the two electrode configuration where a single pair of electrodes both injects current and records the voltage output.



The general interface of the system is shown in the above diagram, where a pair of skin electrodes is placed on the chest of the patient and record the impedance change across the chest.

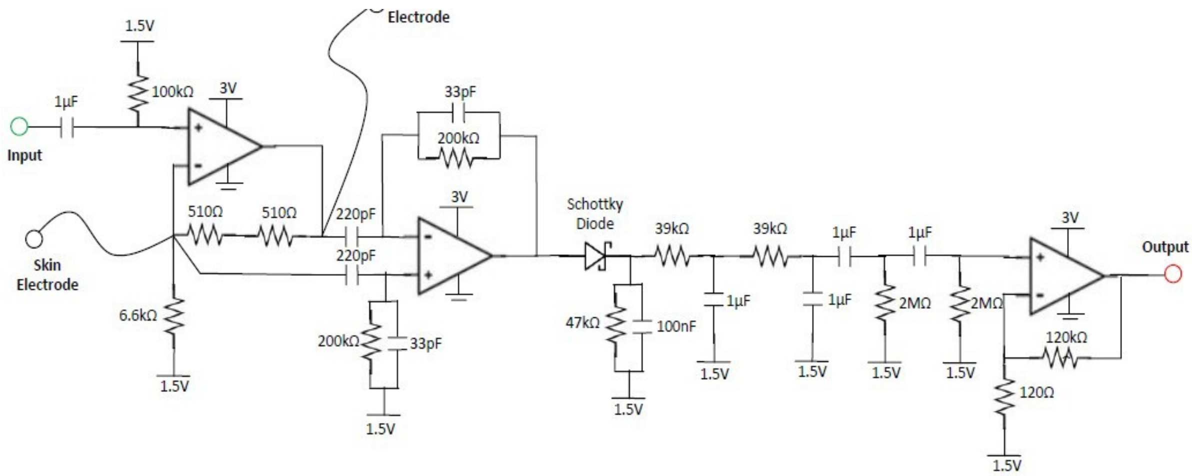
A high frequency current square pulse is injected in the patient`s body via the skin electrodes and the voltage generated across then is measured simultaneously.
The voltage amplitude across the electrodes will be modulated according to the impedance of the tissue between the two electrodes, as explained in the previous section. The impedance of the tissue between the electrodes will vary as air enters the lungs and as the skin stretches when chest moves during respiration.

This gives us a way to relate the voltage change across the electrodes to the impedance change in the tissue which itself relates to chest movement and breathing.



If the impedometric respiration system "box" is opened we can see that it can be separated into subsystems. Each subsystem performs a role in the extraction of the signal and their properties are defined both by the signal generated and the signal we want to extract. Note that the analog signal processing stage is a typical A.M. demodulator strategy.

4) The circuit to be realised in the lab



A bigger view of the circuit can be found in the Appendix.

Lab 1 Passive Filters [20 marks]

Introduction – Lab etiquette

First and foremost it is extremely important to identify the dangers of this lab. The most obvious one is the soldering gun is hot, very hot!

The usual operating temperatures are around 300° --- 400° which is more than enough to scorch skin immediately upon contact leaving a very unpleasant deep burn.

Whenever a soldering iron is not in use (i.e. **when not being held in your hands soldering something**) <u>it must be placed back on its stand</u>.

If it is left unattended on the bench three possible things may happen; first it might damage/burn the bench, second it may be accidentally touched by you when moving around and third (and probably worse) it might roll and fall on your lap.

The reason for using high temperatures is to melt a metal alloy of tin and copper called *solder.* This solder will be melted and guided using the soldering iron to electrically join the components on the stripboard.
This can be a bit tricky to master but it is part of the learning objectives of the lab.
By the end of this lab you should all become skilful operators of the soldering iron.

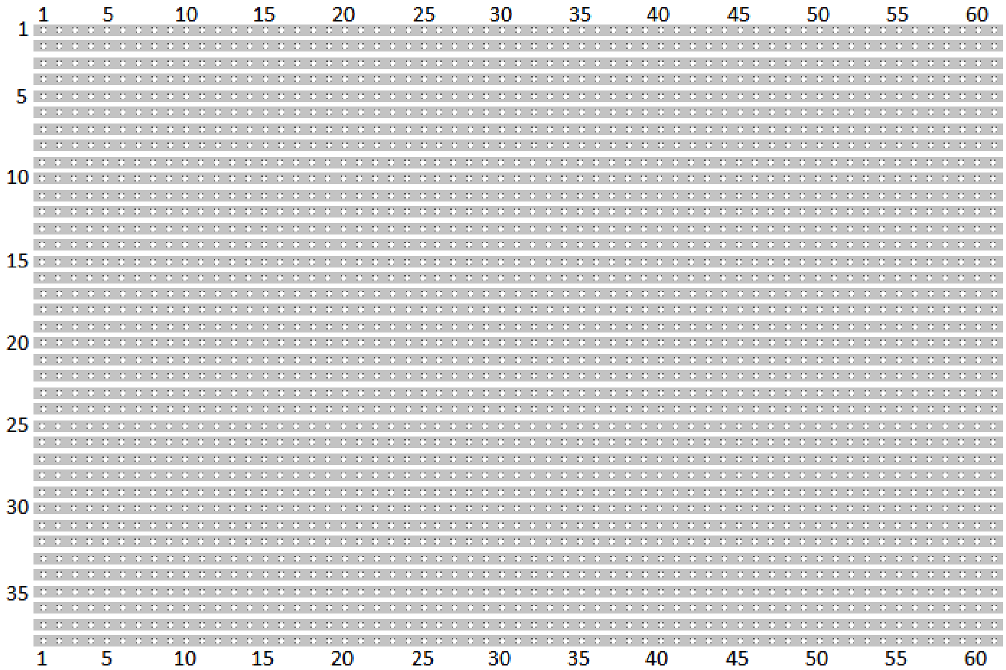
Second risk is the fact that you will be using signal generators and power supplies to power up and measure your circuit`s behaviour. If the lab is followed correctly you shouldn't be exposed to any dangerous currents, but failure to do so can give you unpleasant electrical shocks.
The rule in this case if you are unsure about any of the settings of the setup you have in front of you call any of the invigilators that are around to have a look before you start operating the equipment.

<u>**No food or drink**</u> are permitted in the lab for minimizing the risk of accidents, ingesting unpleasant chemicals and keeping things tidy.

Components

You should all have a stripboard. A stripboard is usually a board made of resin mixed with a structuring material forming a hard base. It has rows of copper on one side which allows components to be soldered on this copper and thus materials that are joined on the same line, or strip, are electrically connected.
The electrical components are usually inserted on the un---coppered side and the terminals stick out on the coppered side where they are soldered.

The stripboard that you have should look like this:



It has 38 strips and each strip has 61 holes giving a 38x61 hole matrix that can be used to design your circuit.

One thing to be noted is that if a component is placed *perpendicular* to the strips then the two terminals are on a different node. This basically means that the two strips of copper are connected via this electrical component.

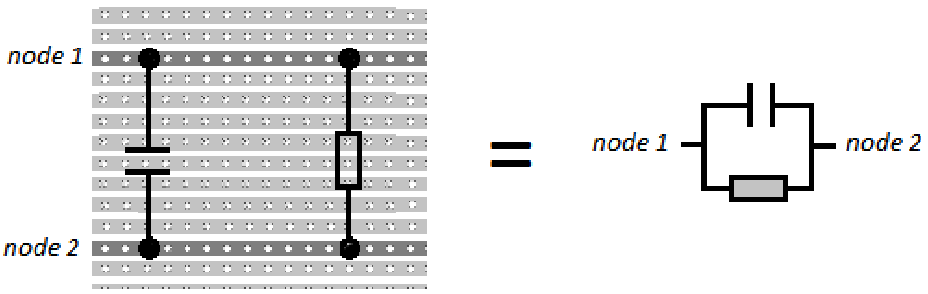


Diagram of *perpendicular* component connection to the copper strips.

If a component is placed *along* a single strip then the strip under the component must be cut in order for the component to have two different nodes across its terminal.

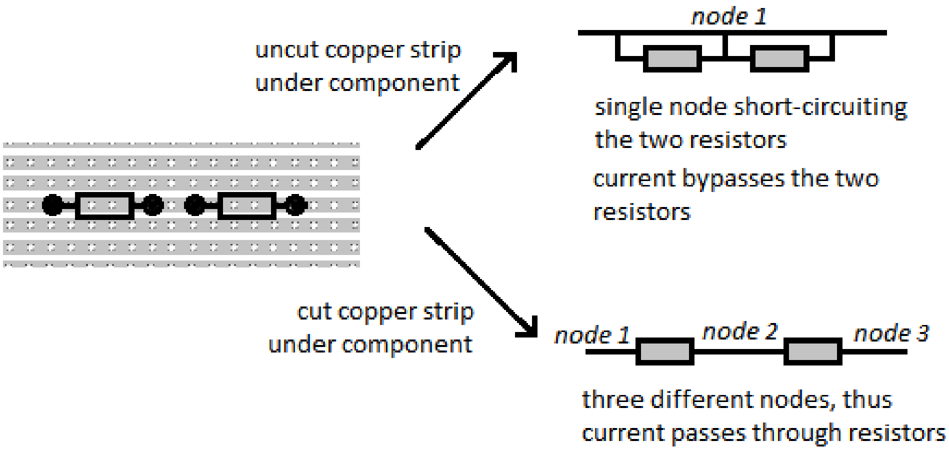
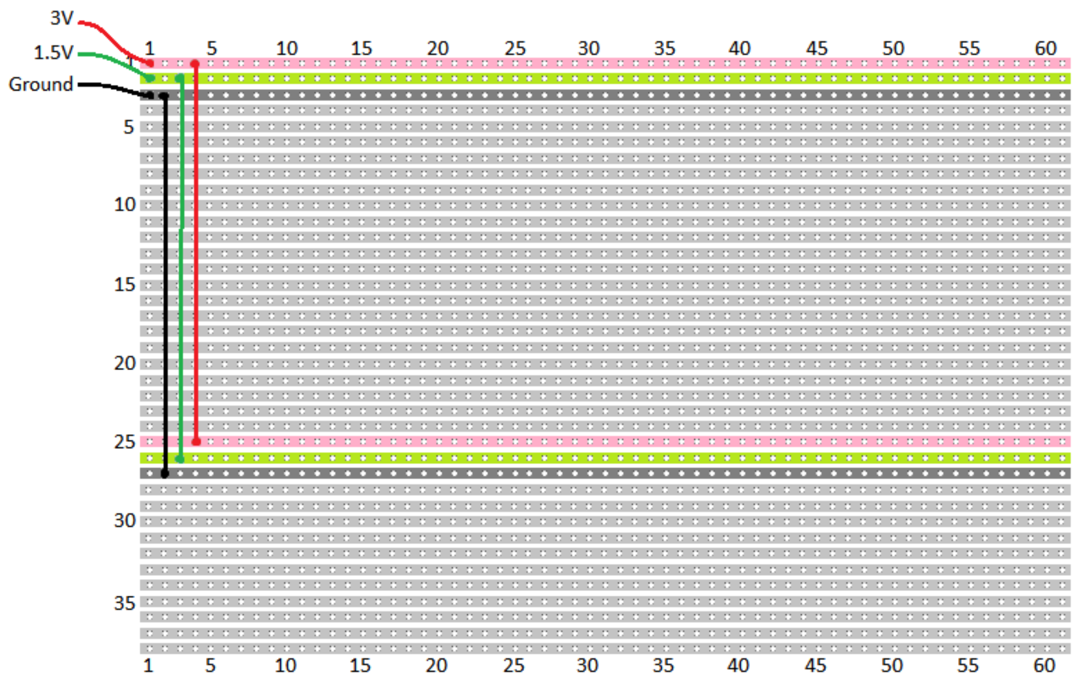


Diagram of *across* a single stripconnection.

By creating different nodes on the stripboard and interconnecting them with electrical components an operating electrical circuit can be prototyped on a stripboard and thus check its operation.
Usually this is the main function of the stripboard hence sometimes called "prototype" boards, were an electrical circuit can be prototyped and tested before the more expensive (and irreversible) process of printed circuit board (PCB) is employed to create circuits.

First step

The first step is to go back to the full schematic on page 5. You should be able to identify three different DC voltage levels that will be used to power up and bias the circuit into its correct operating state. The three levels are 3V, 1.5V and Ground. It is good technique to set up first these electrical potential levels, which essentially are the power supply of the circuit, and work around this stripboard area constrain.



So in order to make your stripboard look like the board in step one, take three wires (it is suggested to be of different colour for your own convenience) and solder them as shown. The three top left wires that are out of the board are going to be the wires that will connect to the power supply later on.

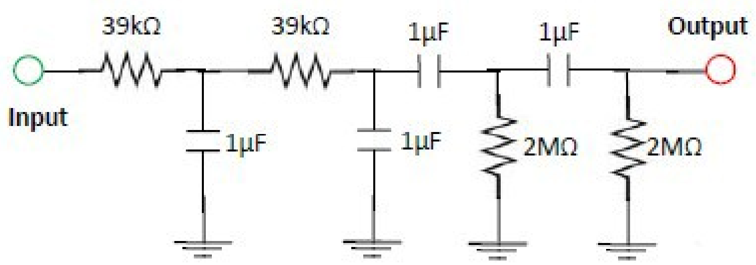
When you are done check the connectivity of your circuit with a multimeter, or multitester. You should rotate the centre knob until it points on the diode icon which should have next to it a speaker sign or a musical note sign, which indicates that the multimeter will make a sound if it finds a connection.
To test whether you have the correct setting, touch the two probes together and the multimeter should produce a sound.

As a test place one probe on the end of one wire that extends out of the board and the other probe should be placed on the strips of copper that the wire connects.
You should observe **two** things:

- The multimeter makes a sound indicating a connection between line 1 and line 25 and the 3V wire. A connection between line 2 and line 26 and the 1.5V wire. A connection between the line 3 and line 27 and the ground wire.
- The multimeter should make NO sound when one probe touches line 1 and the other at line 2 and similarly NO sound between line 2 and line 3. This indicates that the soldering done on the wires is good and not excessive to the point of joining to adjacent strips of copper.

Circuit for Lab 1

The circuit for the first lab is:

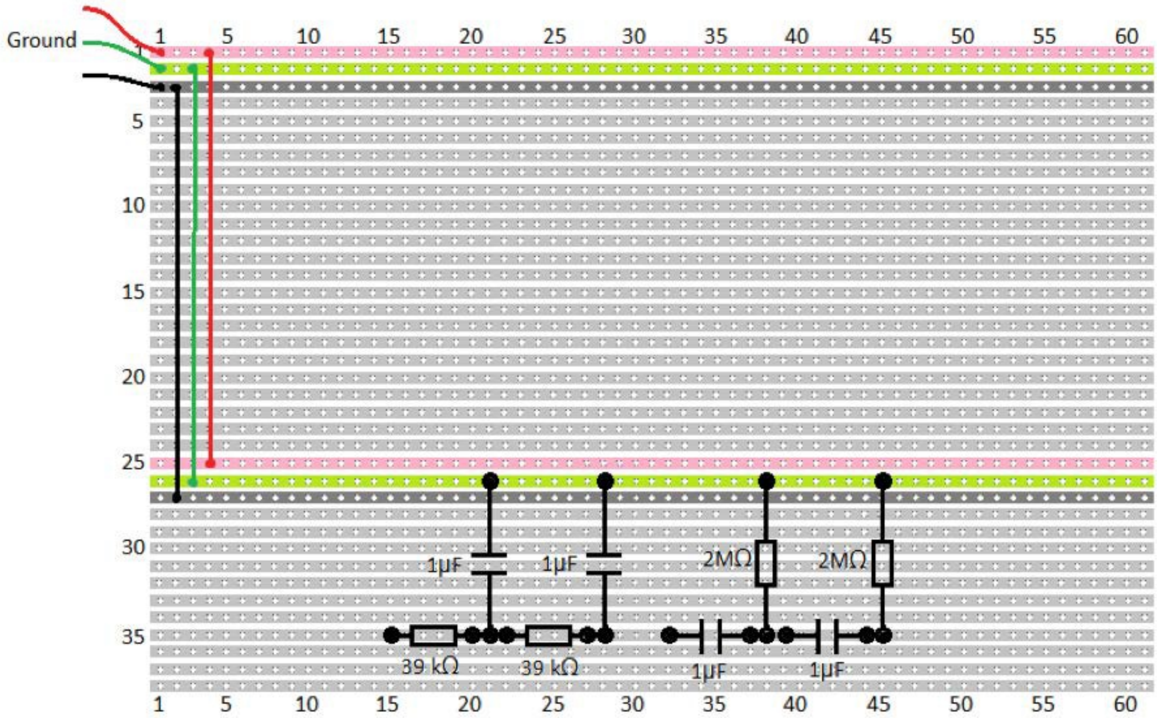


QUESTION 1.1 [7 marks]

(It is strongly advised to solve this before going to the next question)

What function does this circuit perform? Can you identify any possible sub-circuits within it? Write and elaborate on the basic relations needed for deriving the transfer function of this block.

There are many ways to implement this circuit using a stripboard. A suggested topology is shown in the following diagram.



Step 2

NOTE: If anyone wishes to follow their own design feel free to do so but keep in mind that these labs will end up with the full circuit, so any modifications to the suggested topology should be done after you decide how you are going to built you own complete circuit.
In other words **think through your circuit until the end and only then start soldering components.** Unfortunately lab session time is limited and errors in design are very time--- wasting.

IMPORTANT NOTE: The circuit shown above is as if you would look at it when holding the board with the components facing upwards. In other words the copper layers shown in the diagram face on the backside of the board as you hold it.

On the final lab (Lab 3) you will have a chance to design your own component topology so you will have a chance to gain some designing skills.

Measurement of the circuit:

Four different measures are to be taken and the results of them to be discussed. See the next two pages for diagrams of how to wire your circuit for measurement. Note that the crocodile clip shown is injecting the test signal into the circuit, and thus is the positive (i.e. not the ground) terminal of the signal generator you have.

There should be enough wire next to the component where the signal is injected into for the crocodile clip to "bite" on. If not then a temporary wire can be placed at that node.

Measurement 1: (see page 12 for diagram)

The test signal should be a sinusoid of 1V amplitude peak-‐to-‐peak (i.e. +0.5V to -‐0.5V).
The starting frequency should be at 0.5Hz and the stop frequency at 10Hz.
Measure in increments of 1Hz.
(i.e. 11 measurements in total: 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 Hz)

Record the dB drop in amplitude of the resulting sinusoid per frequency.

Remember: To find the decibel drop in amplitude you use the formula:

$$dB = 20\times \log\left(\frac{Vout}{Vin}\right)$$

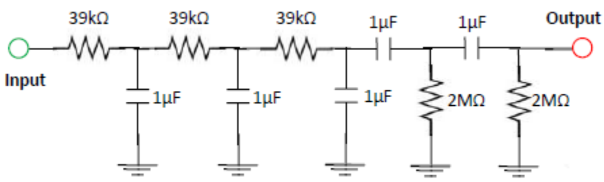
Where *Vout* is the output sinusoid amplitude and *Vin* is the input sinusoid amplitude.

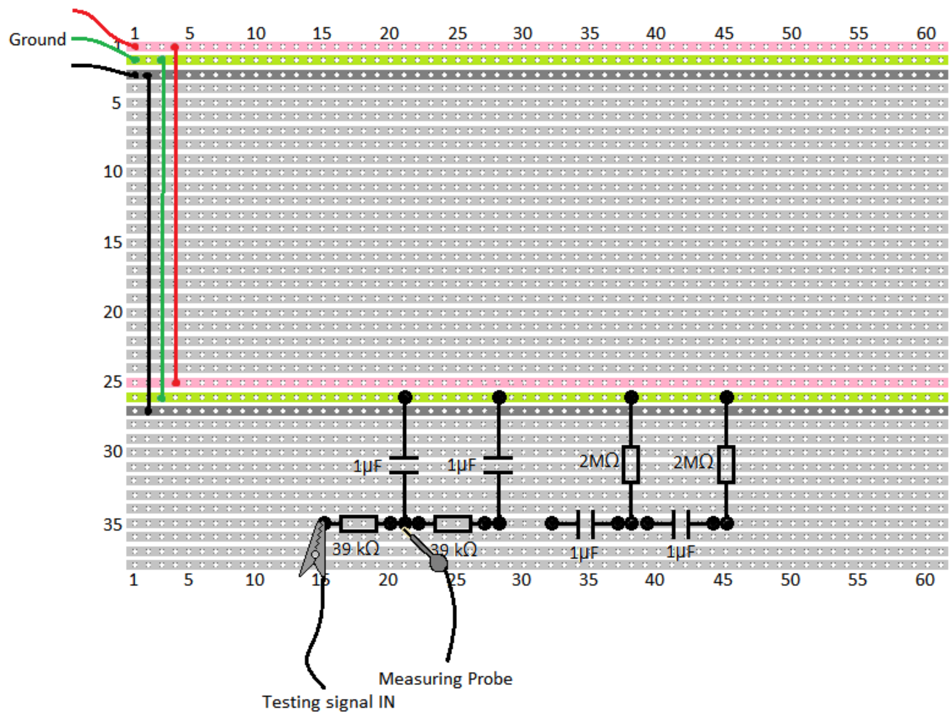
Measurement 2: (see page 12 for diagram)

Repeat the procedure in measurement 1. (Notice the only difference is the measuring point)

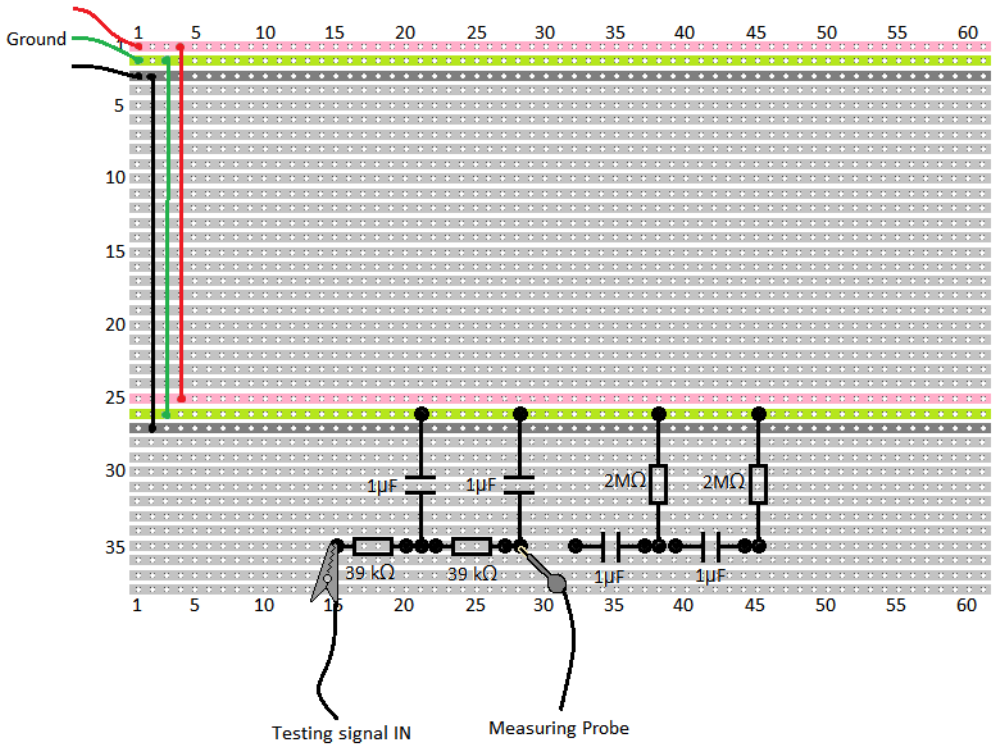
QUESTION 1.2 [5 marks]

a) *Plot the response from the two measurements (one and two) on the same graph, where the y-‐axis is the dB drop and the x-‐axis is the frequency. Comment on these results and explain the difference between the two graphs.*
b) *If the circuit was extended as shown in the diagram below how manydBs/Oct attenuation would you expect between the frequencies of 12Hz and24Hz?*





Measurement 1 Diagram



Measurement 2 Diagram

Measurement 3: *(see page 14 for diagram)*

The test signal should be a sinusoid of 1V amplitude peak---to---peak (i.e. +0.5V to ---0.5V).
The starting frequency should be at 0.05Hz and the stop frequency at 5Hz.
Measure in increments of 0.5Hz.
(i.e. 11 measurements in total: 0.05, 0.5,1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 and 5 Hz)

Record the dB drop in amplitude of the resulting sinusoid per frequency.

Remember: To find the decibel drop in amplitude you use the formula:

$$dB = 20\times \log\left(\frac{Vout}{Vin}\right)$$

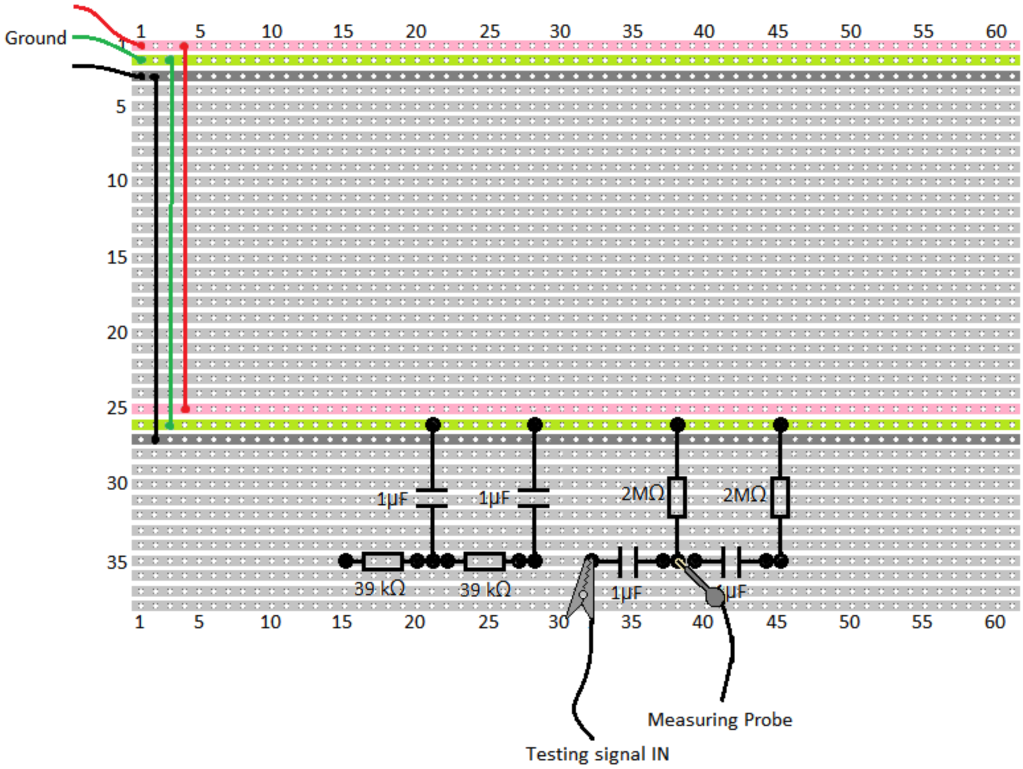
Where *Vout* is the output sinusoid amplitude and *Vin* is the input sinusoid amplitude.

Measurement 4: *(see page 14 for diagram)*

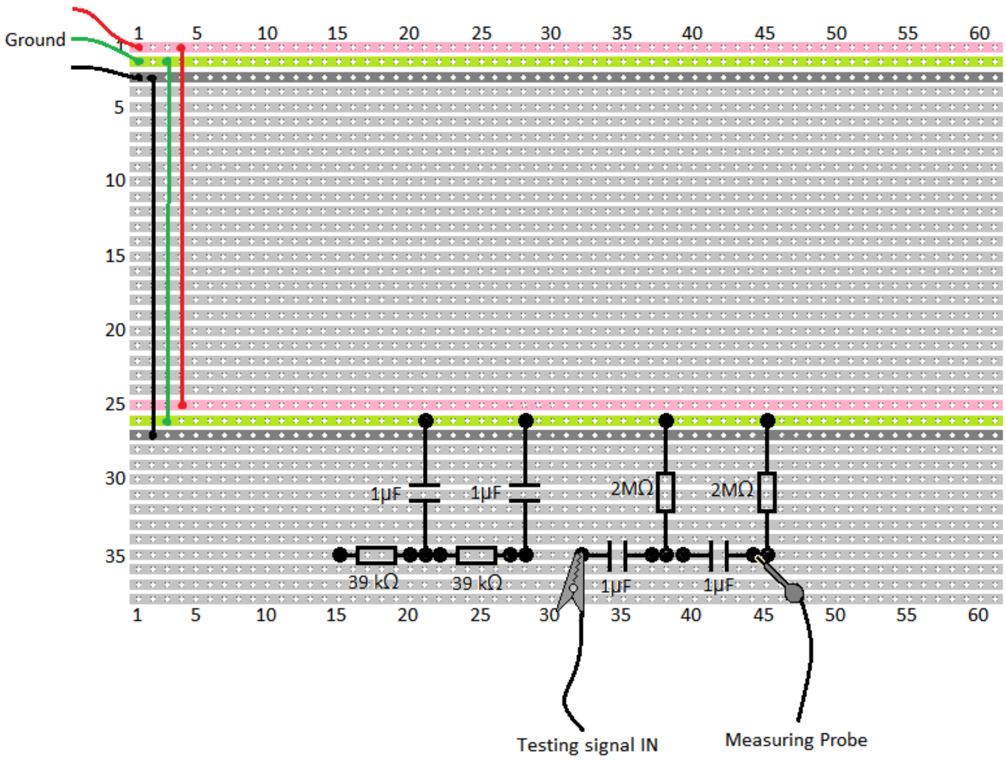
Repeat the procedure in measurement 3. (Notice the only difference is the measuring point)

QUESTION 1.3 [4 marks]

Plot the response from the two measurements (three and four) on the same graph, where the y---axis is the dB drop and the x---axis is the frequency. Comment on these results and explain the difference between the two graphs.

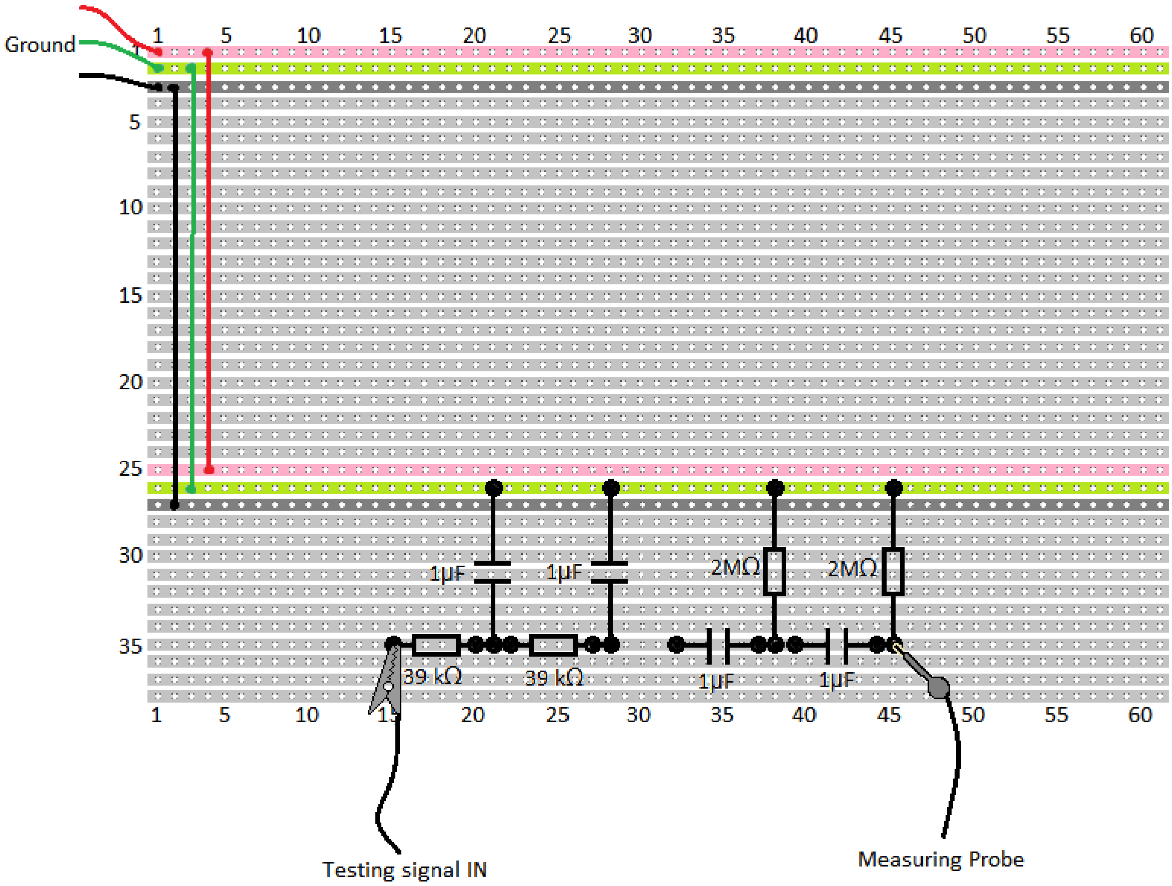


Measurement 3 Diagram



Measurement 4 Diagram

QUESTION 1.4 [4 marks]



If you were to measure the response across the entire circuit as shown in the above diagram, how would you expect the dB drop to be as frequency of the input sinusoid changed and why?

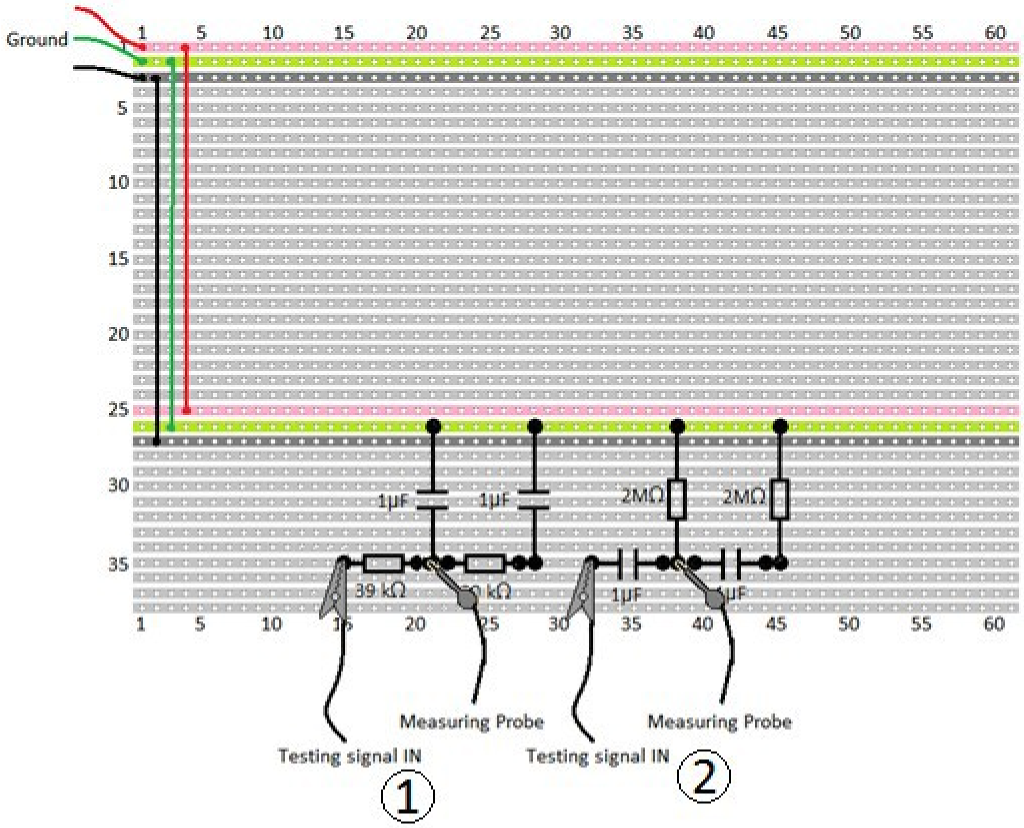
Think of appropriate frequencies to use to make the measurement and prove your point by making your own measurements and show a resulting plot.

Important for coming lab: Measure the frequency at which a 50mV peak---to---peak signal attenuates to 3mV peak---to peak at the output when measuring and testing points are as shown for question 1.4.

Save that frequency number somewhere you will use it in the next lab!

Optional exercise for Lab 1

This is an extra exercise to build a better understanding of this lab. No need to submit anything for this one.



Make two measurements as shown in the above diagram.

In both cases estimate the time constant of the system graphically and compare with the theoretical value. The suggested test signal is a pulse train.

How do you expect the time constant to change if you moved the measuring probe one node to the right?
(i.e. for measurement 1 taking both resistors in line and for measurement 2 taking both capacitors between test and measure)

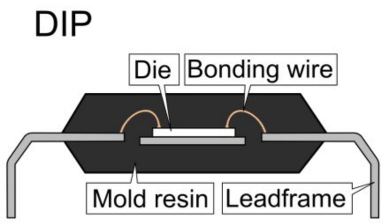
End of Lab 1

Lab 2 Op‑amp amplifier [15 marks]

Introduction – The op‑amp

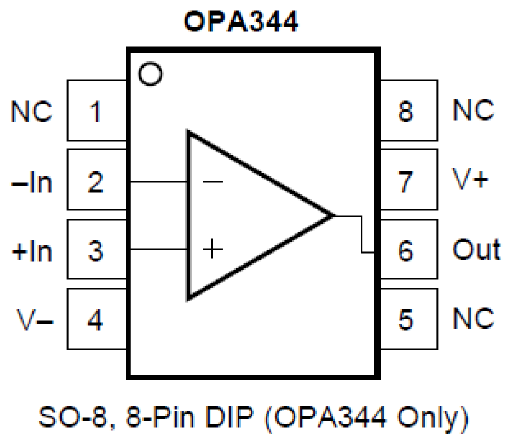
For this lab you will built an active circuit. The op‑‑‑amp you are going to use is the Texas Instruments OPA344PA. Its datasheet can be found in the appendix. Go over the datasheet and read the specifications for this op‑‑‑amp.

The first thing that you most probably will notice about the op‑‑‑amp is that it is not triangular! The DIP (Dual In Line) package that holds the op‑‑‑amp has a rectangular shape with eight pins.



A cross section through the DIP package will look similar to the above diagram. A very small die has the IC topology that makes the op‑‑‑amp in micro‑‑‑size silicon architecture. Bonding wires attach where the different inputs and outputs are to the micro silicon architecture and those bond with the legs that stick out that we can interface with. Black resin protects and holds everything together. Also allows for heat dissipation so the die and wires don't melt when current pusses through.

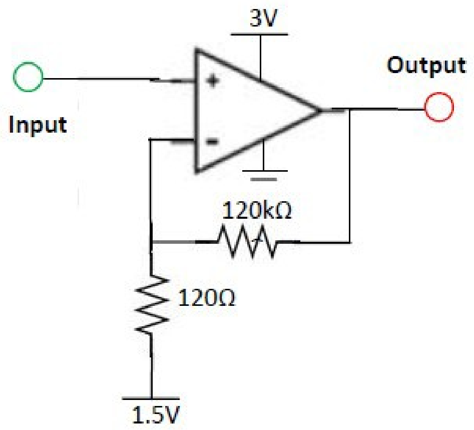
The OPA344PA schematic is:



- **NC** = Not connected to anything. It is only a support.
- **‑In** = The negative terminal of the op‑amp
- **+In** = The positive terminal of the op‑amp
- **V‑** = The negative power supply.
- **V+** = The positive power supply.
- **Out** = The op‑amp output.

Note: There is a dot next to the pin with number one. This pin is also noticeable on the op-amp package. Its purpose is to know which way around the plastic package corresponds to the schematic. Kind of trivial but extremely important to know!

Circuit for Lab 2

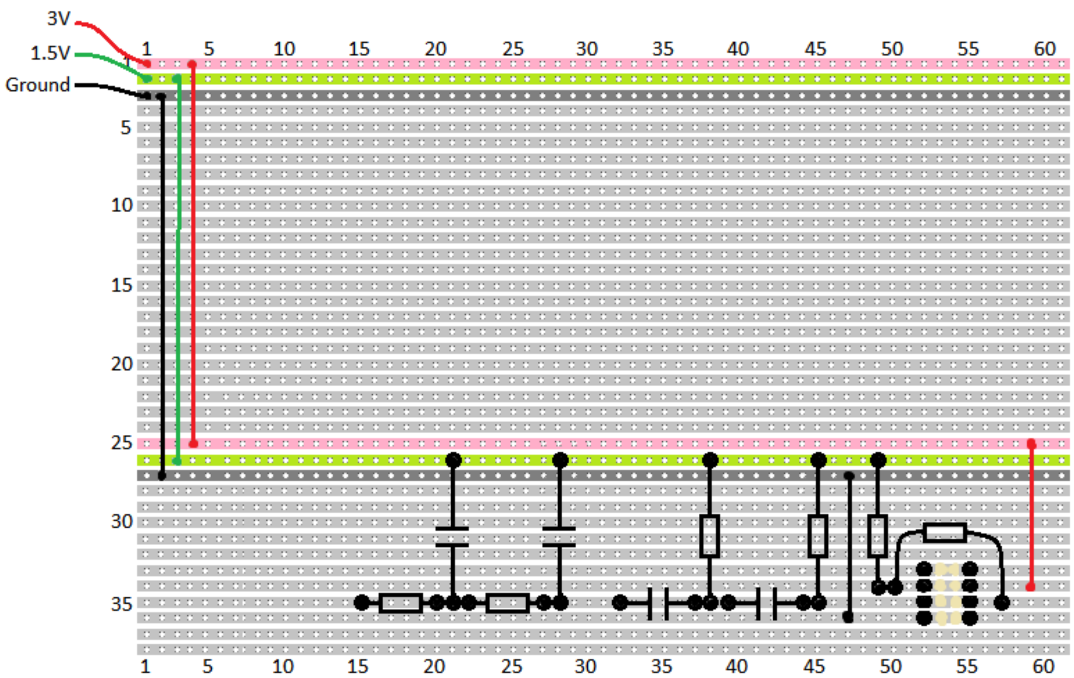


QUESTION 2.1 [2 marks]

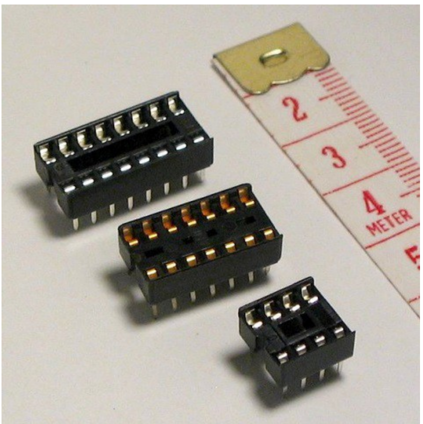
What function does this circuit perform? Can you derive the transfer function?

Again as before there are many ways to place the components on the strip board to perform the function of this circuit.

A suggested topology which follows from the previous lab is:



Usually when IC (Integrated Circuits) is placed to the stripboard they are not directly soldered since the heat generated from the molten solder can deteriorate the function of the IC. Instead a socket package is soldered on the stripboard and the IC can be slotted into place.

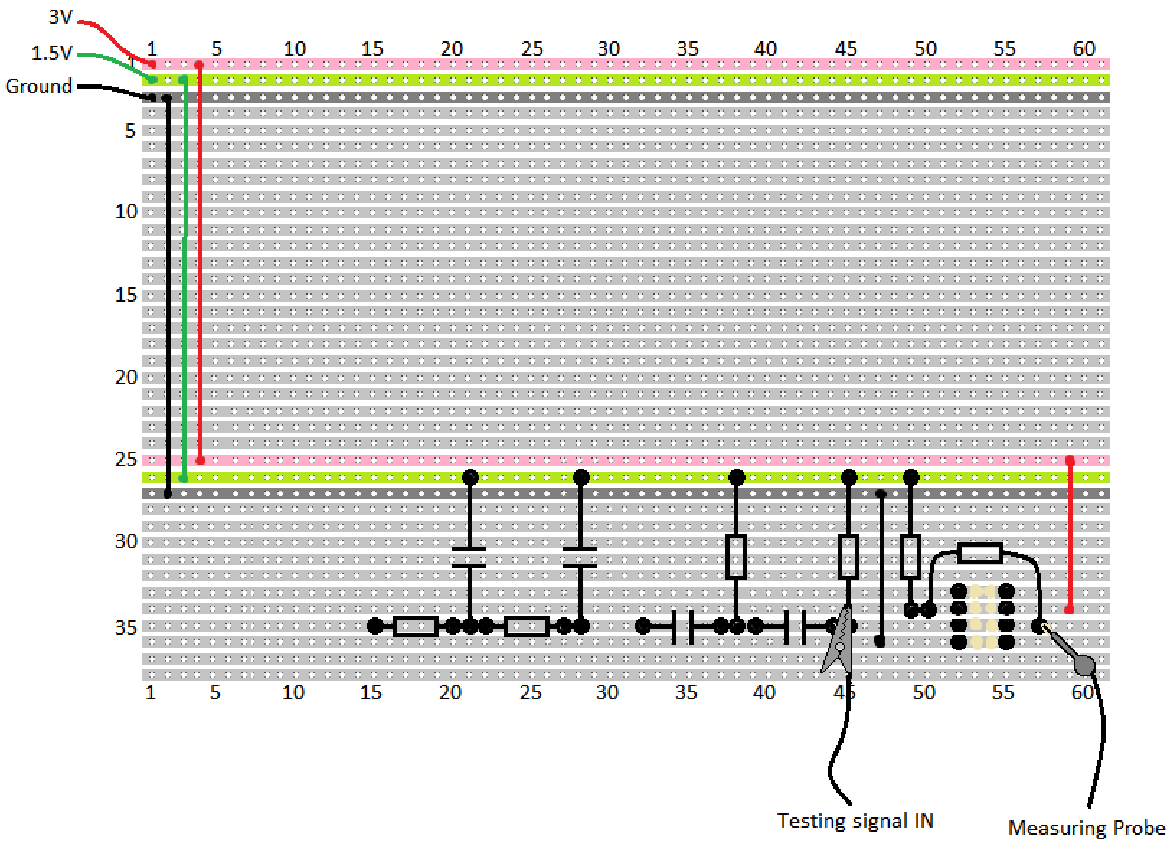


The picture to the left shows a collection of three socket packages. Bottom is an eight socket package similar to the one we are using in this lab. In the middle is a 14 socket package and top is a 16 socket package.

Note: The middle space between the socket---pins must be striped of copper otherwise the IC will just have adjacent pins short circuited.

Measurement of the circuit:

Place the crocodile clip on the wire shown in the diagram of the next page. Notice that the node we are connected on is connected to the **+In** terminal of the op---amp. To double check how correct the connection is place one probe of the multimeter on the crocodile clip and the other probe of the multimeter on the third leg of the IC. If the multimeter is set to check for diode connection it should make a sound if the connection is correct.



Four different measurements are to be made:

Measurement 1:

Let the testing signal be 1V peak to peak sinusoid at 1 kHz with zero DC offset. Record the output.

Measurement 2:

Let the testing signal be 1V peak to peak sinusoid at 1 kHz with DC offset of 1V. Record the output.

Measurement 3:

Let the testing signal be 1V peak to peak sinusoid at 1 kHz with DC offset of 1.5V. Record the output.

Measurement 4:

Let the testing signal be 1V peak to peak sinusoid at 1 kHz with DC offset of 2V. Record the output.

Measurement 5:

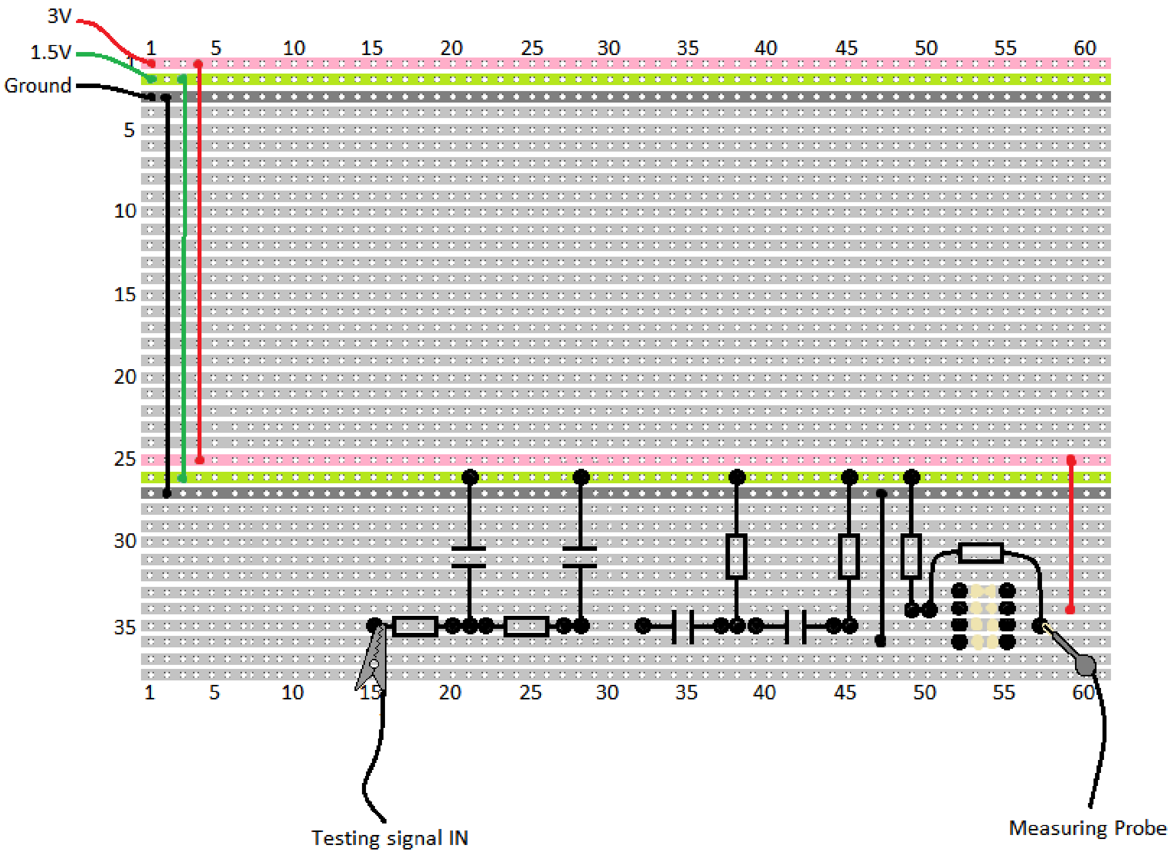
Let the testing signal be 1V peak to peak sinusoid at 1 kHz with DC offset of 2.5V. Record the output.

QUESTION 2.2 [5 marks]

Show the outputs of the above measurements. Why do we observe this? Why is the DC offset so important?

Combinations of circuits / systems:

Place the electrodes as shown in the following diagram.



Note: Leave the circuit on for some time before attempting these measurements. You should observe a transient period; record this transient or start up period.

Measurement 5:

Use as a testing signal a sinusoid **without** any DC offset with amplitude 50mV peak to peak. The frequency should be the frequency recorded at the end of the previous lab (see page 15). Record the output.

Measurement 6:

Maintain the same frequency and amplitude as the previous measurement. Change the DC offset of the signal first at 1V then at 1.5 and lastly at 2V as before and record the outputs.

Measurement 7:

Set the DC offset back to zero. Keep the amplitude at 50mV and vary the frequency by increasing +10Hz of the recorded value. Record the output.

Now decrease the frequency by 10Hz of the recorded value. Record the output.

QUESTION 2.3 [8 marks]

a) *Show the outputs of the above measurements.*

b) *For measurement 5, can you explain the output?*
Hint: Read again the last part of page 15 for the property of the frequency we used.

c) *For measurement 6 is the DC offset important in this case? If it is different from before why is this?*
Why do we need to wait before we measure anything? Hint: Use the transient or start up period plot to explain this.
Hint Question: What is the long term behaviour of a capacitor in DC conditions?

d) *For measurement 7, can you show the different sub---systems that make up the full circuit and hence can you explain the output?*

Optional Exercise for Lab 2

Measure the slew rate of the opamp and its DC offset and compare with the datasheet in the appendix.

End of Lab 2

Lab 3 **[35 marks]**

It is strongly suggested you go back to page 2 and read again "The basic mechanism of impedance pneumography" so you have clear in your head the concept of **amplitude modulation** and how it works.

This lab is separated into two parts. It is important you read through the entire lab before you start. Preferably work on Part Two **before** the lab session.

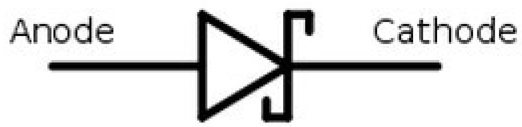
------------ If you arereading this <u>before</u>thelab session skip to Lab 3 Part Two. ------------

Lab 3 Part1: Non--Linear circuits

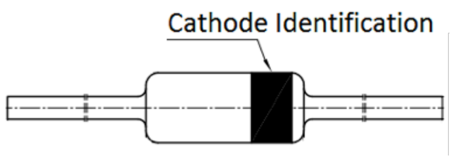
Introduction

The concept of non linearity in circuits is a vast topic and can be an entire course on its own. A quite abstract definition can be that a non---linear circuit does not obey the superposition principle; in the sense that the linear combination (i.e. addition) of individual independent inputs doesn't always equal the linear combination (i.e. addition) of their corresponding outputs.

The non linear component introduced today is the Schottky diode. The model to be used is the Vishay Semiconductor – BAT83S – TR Schottky Diode, 30mA forward. Its datasheet can be found in the Appendix.



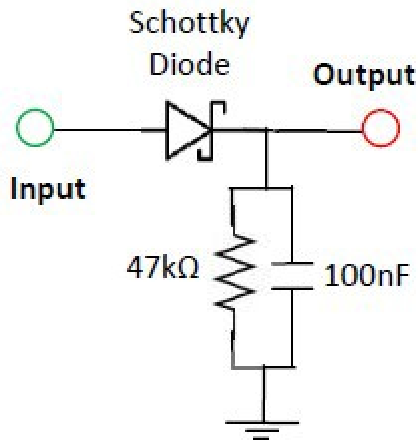
Symbol for Schottky diode.



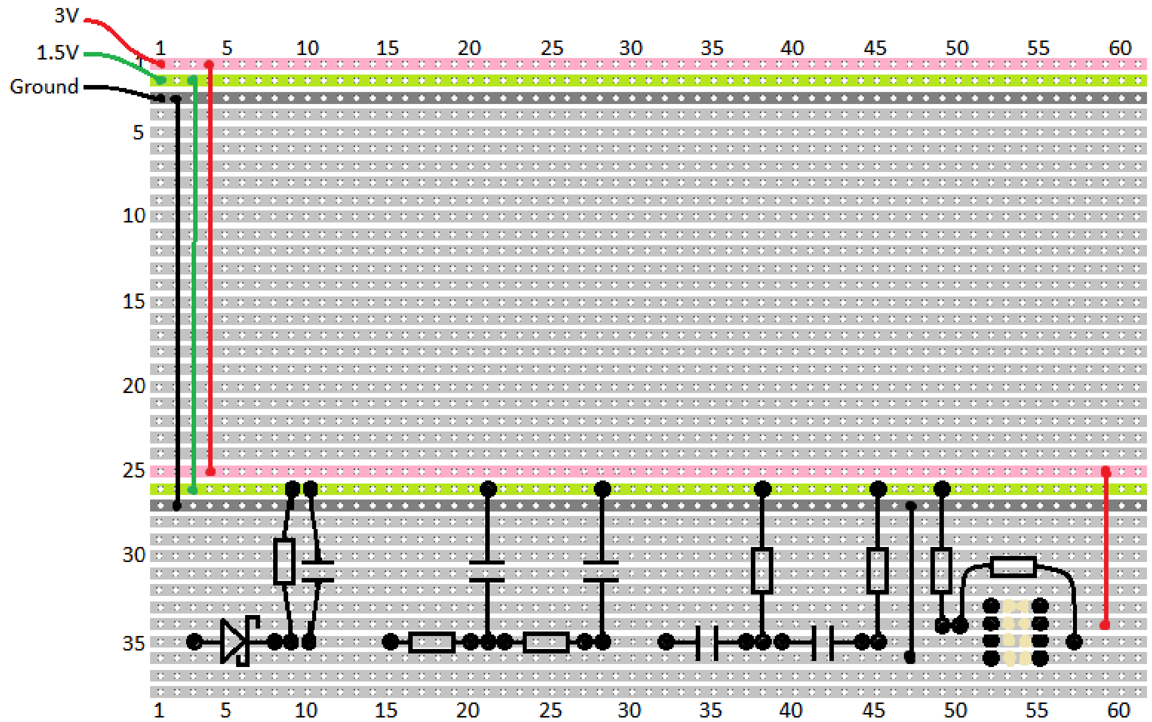
The component used in this lab.

The very first thing to be noticed is that the diode is a directional device. If it placed backwards in the schematic it will **not** work as indented. See the two diagrams above and make sure you identify which is the anode and which is the anode on the component you have for the Schottky diode.

Circuit for Lab 3 Part 1

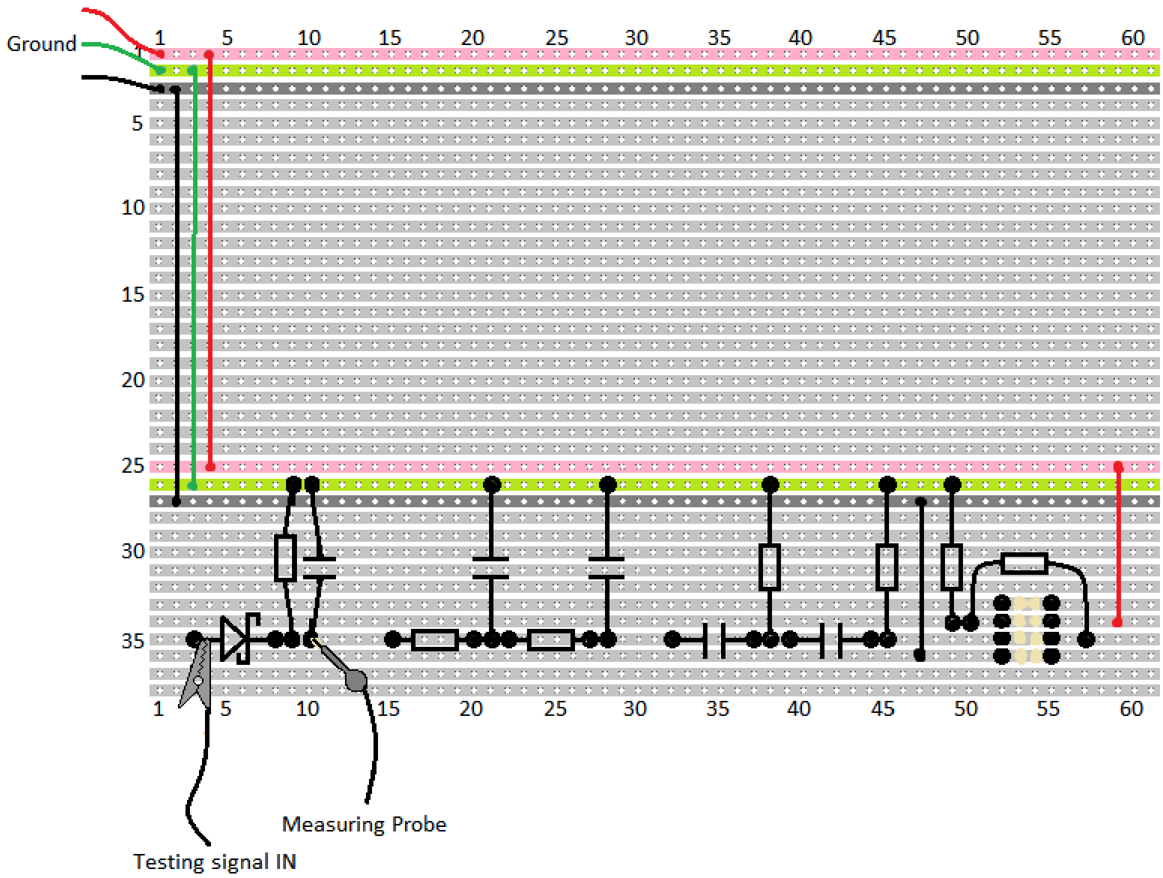


A suggested topology which follows from the previous lab is:



Measuring the circuit

<u>(Notice the Ground connection!)</u>



Measurement 1:

Let the testing signal be a sinusoid with frequency of 10 Hz and 2V peak-to-peak.

--- Start with no DC offset. Record the result.

– Change the DC offset to -1V and record the result.

--- Change again the DC offset to +1V and record the result.

Measurement 2:

Let the testing signal be a sinusoid with frequency of 10 Hz and 2V peak---to---peak, and with zero DC offset.

--- Start with the frequency at 10 Hz. Record the result.

--- Change the frequency to 100 Hz and record the result.

--- Change the frequency to 1 kHz and record the result.

--- Change the frequency to 10 kHz and record the result.

QUESTION 3.1 [8 marks]

a) *What are the outputs of the above measurements?*

b) *For measurement 1 how is the DC offset important in the operation of the diode?*

c) *For measurement 2 what is the effect of changing the signal frequency? Can you estimate a time constant?*

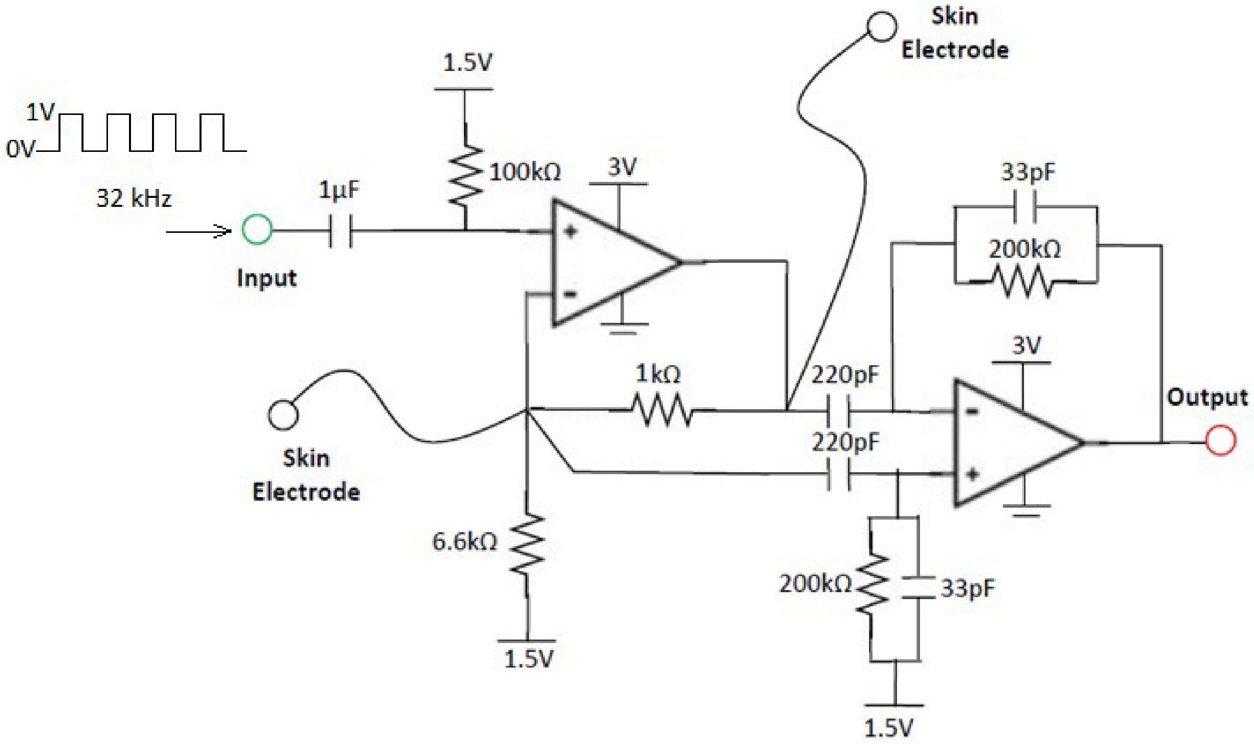
End of Lab 3 Part 1

Lab 3 Part2: Unguided Design

Introduction

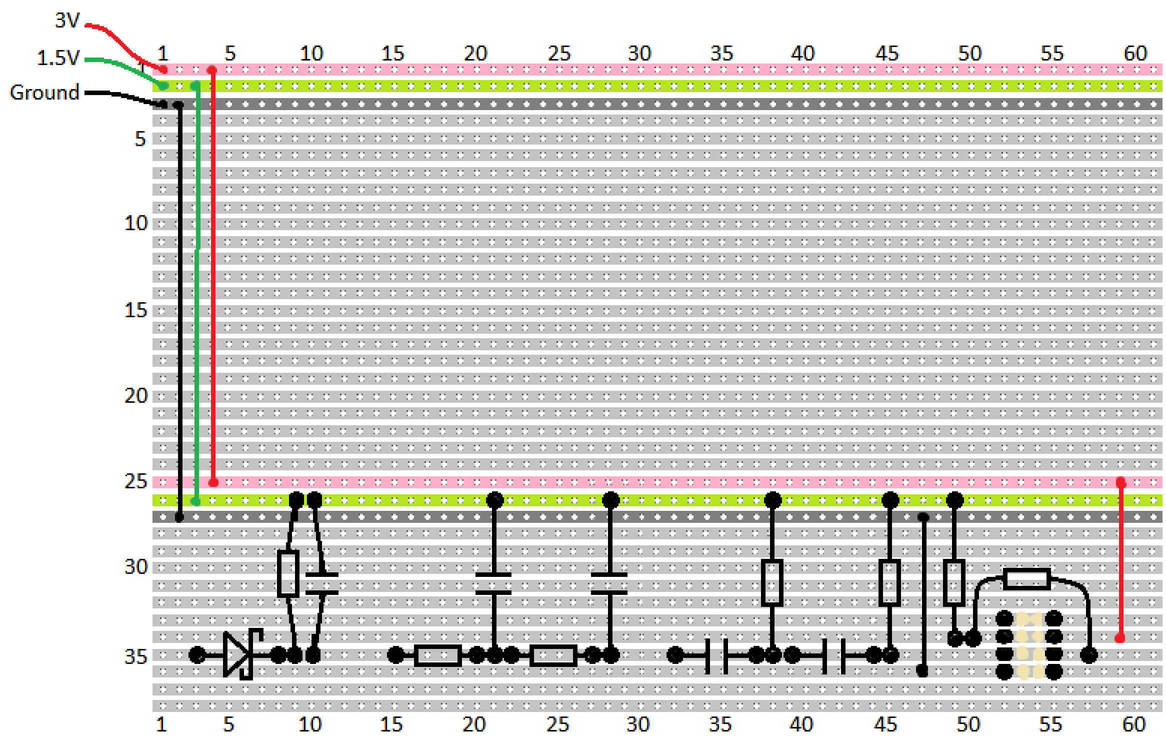
As the title suggests this lab will allow you to design your own topology of components upon the stripboard given the circuit schematic.

Circuit for Lab 3 Part 2:



Lab3---DesignQuestion:

Your stripboard should look something like this if you followed the steps suggested in these labs.



You have the top space of the stripboard to design the circuit given in the previous page. It is strongly suggested you design first using the extra printouts of the above figure given in the last page of the lab notes, and after you get the OK from an invigilator start soldering. As mentioned before, mistakes are very time wasteful.

You will need to submit the page [4 marks] with your design (last page of the report) together with your final report.

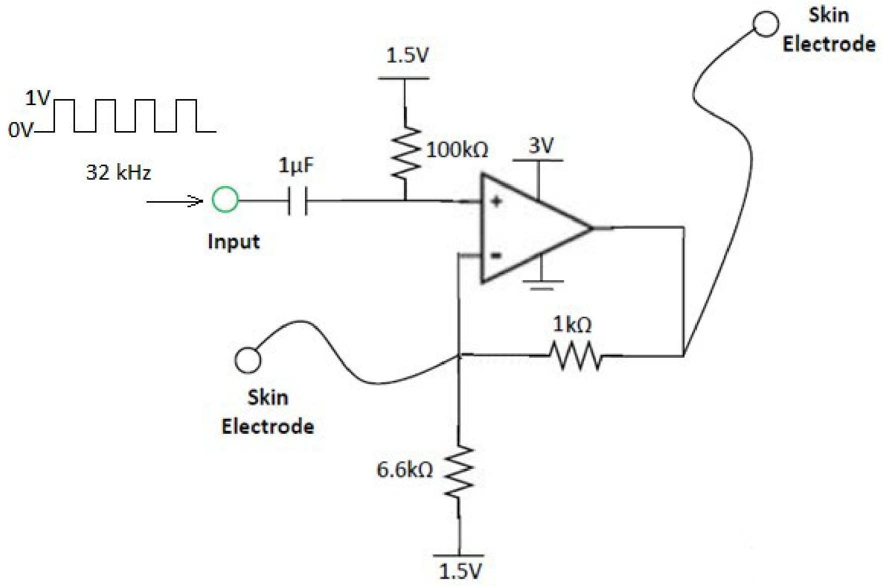
<u>Design Hints:</u>

- When placing resistors and diodes along a strip take care to leave at least 4 holes between the two terminals so the component physically fits on the board.
- A good design is one which takes advantage as much as possible the strips on the board and has the least cuts on the copper and soldered jumping wires.

NOTE: You also need to connect the new circuit that you design on the top half of the stripboard to the existing component topology at the lower half to link the two circuits, and thus complete the circuit given in page 5.

QUESTION 3.2 [8 marks]

a) *What is the purpose of the two 220pF capacitors in the circuit in page 27?*



b) *If a square wave from zero to one volt and of frequency 32 kHz is given as input as shown in the above diagram how does this affect the current flow through the wires that attach to the electrodes?*

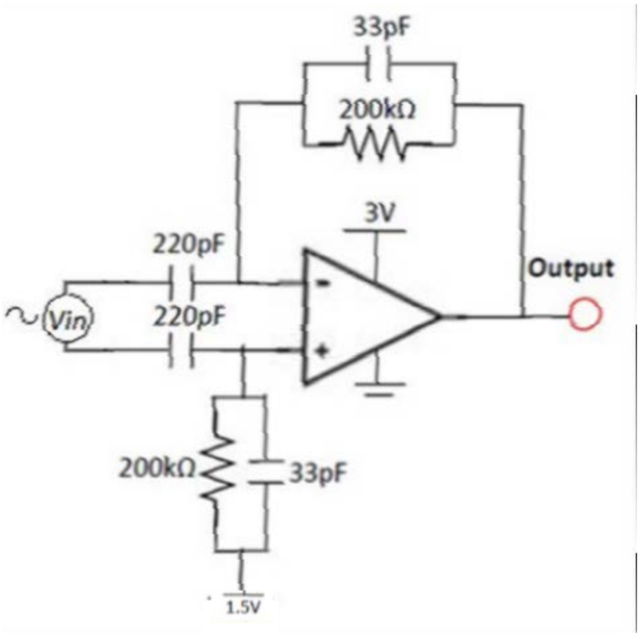
<u>Hint:</u> Assume that there is a resistance of 1 kΩ joining the two wires that are labelled "skin electrode".

c) *Hence can you explain what function does the circuit in the below diagram perform? How is it useful in the impedance respirometric system?*

<u>Hint:</u> Go back to the introduction and read again the "Impedance Pneumography as a system" section.

QUESTION 3.3 [9 marks]

a) *Derive the transfer function of the following circuit:*



b) *What function does this circuit perform?*

c) *How is it useful in the impedance respirometric system?*

QUESTION 3.4 [6 marks]

a) *Measure the common mode attenuation of the above circuit.*

b) *Measure the differential gain of the above circuit.*

c) *Hence find the common mode rejection ratio.*
Look up in the datasheet and compare the value given for the CMRR of the opamp with the measured. Why is it so different?

End of Lab 3 Part 2

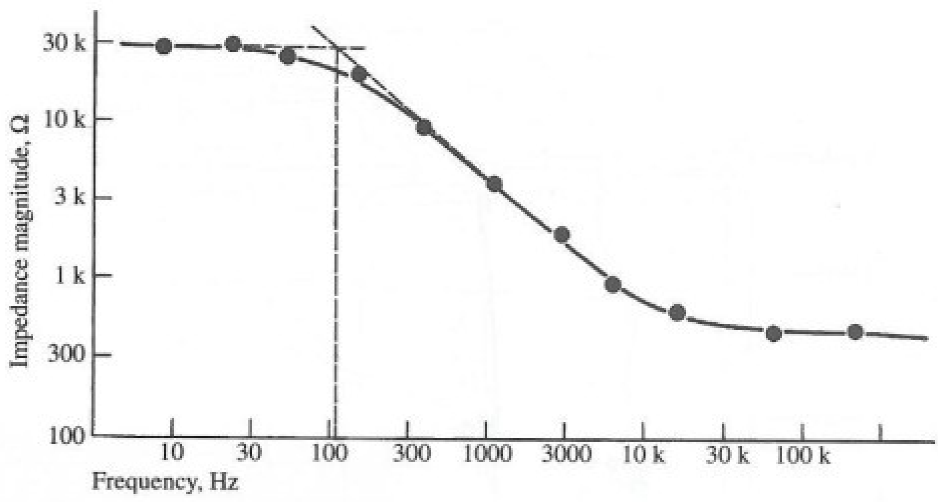
Final Lab [15 marks]

Introduction

For this lab you will need to have the circuit completed. It is the final test of your circuit by connecting it to a patient simulator and recording the respiration output.

There is a risk involved in the measurement from direct placement of electrodes on the skin due to the fact that there is a current injection and the recording path crosses a very important electro---active tissue; the human heart!
The injected current frequency will be at 32 kHz. There are two main reasons for choosing this high frequency.

1) The high frequency gives us a low impedance "window" into the human tissue.

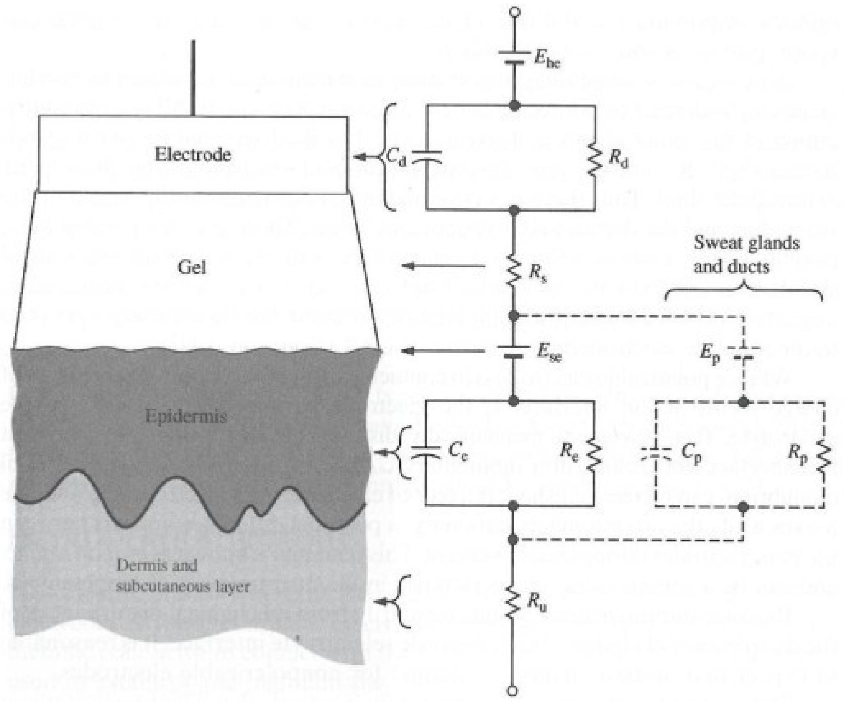


The above figure gives the experimentally determined magnitude of impedance as a function of frequency for electrodes. We see that below 100 Hz the impedance magnitude across the two electrodes is around 30 kΩ. After 100 Hz the impedance magnitude decreases and thus making the tissue more conductive as frequency increases.
It is observed that around 30 kHz and onwards there is a plateau of impedance change with increasing frequencies.
This allows us to choose the 32 kHz as our current inject frequency and for that value the impedance magnitude is around 1kΩ. Keep in mind that this value greatly varies per person depending on fat levels, hydration of the skin, oil secretions etc.

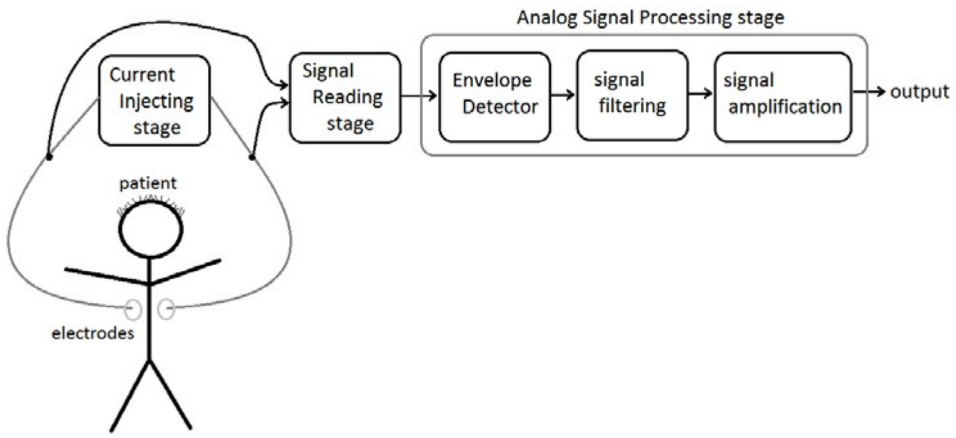
2) Any frequency of injected oscillating current that is comparable to the cardiac rate (i.e. 0.5Hz < f < 3Hz) has the potential to cause arrhythmias and cardiac dysrhythmia and in extreme cases cause cardiac arrest. The injected frequency of 32 kHz is high enough to not cause any interference with the cardiac rhythm, but if a low frequency envelope somehow develops it can be very dangerous.

QUESTION 4 [5 marks]

Using this electrical analogue model of the electrode---skin interface, can you explain why the impedance decreases as injected frequency increases?



QUESTION 5 [10 marks]



Looking at this diagram (also on page 5) can you compare it to the electrical circuit that you have built and identify the circuit that performs each function of every box? Based on your lab experience elaborate on the crucial design aspects of each block and how these might affect the system-level performance. How would you improve the specific design?

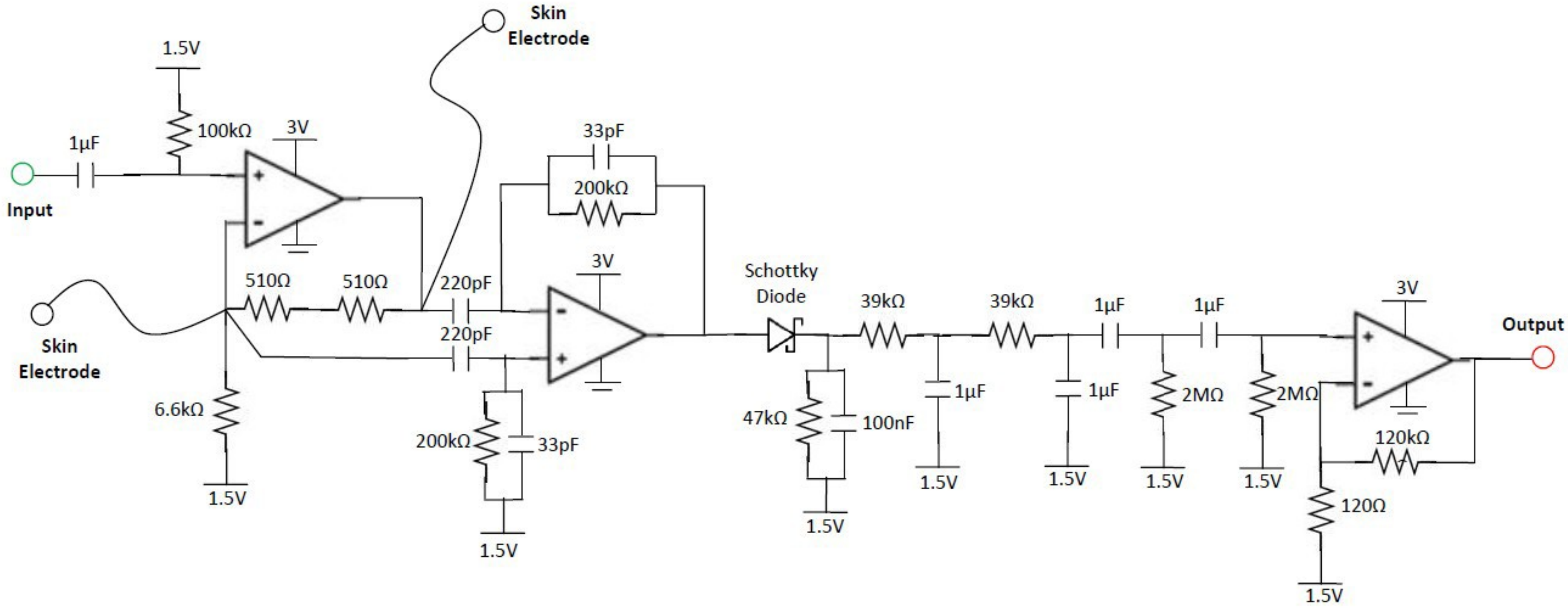
Note: The full circuit is also on page 35

Together with your report you will need to submit the board that **you** have designed (one board per person) with your name and CID written on it.

A working prototype board corresponds to **[15 marks]**.

USEFUL SOURCES

- The impedance pneumography circuit.
- The Impedance Pneumography. Authors: Geddes La., Hoff H, Hickman D, Moore A, From Aerospace Medicine, 1962 Jan Volume 33.
- Texas Instruments OPA344PA Datasheet
- Vishay Semiconductors BAT83S Datasheet



Skin
Electrode
1.5V
100kΩ
3V
1μF
Input
510Ω
510Ω
220pF
220pF
Skin
Electrode
6.6kΩ
1.5V
33pF
200kΩ
3V
200kΩ
33pF
1.5V
Schottky
Diode
39kΩ
39kΩ
1μF
1μF
47kΩ
100nF
1.5V
1μF
1μF
2MΩ
2MΩ
1.5V
1.5V
1.5V
1.5V
3V
Output
120kΩ
120Ω
1.5V

NAME: ____________________

____

CID: ______________________