**Feedback Cover Sheet**

Complete at least one item and up to three items in each section

**Section One**

Reflecting on the feedback that I have received on previous lab reports, the following issues/topics have been identified as areas for improvement:

1. Making the report flow

**Section Two**

In this assignment, I have attempted to act on previous feedback in the following ways:

1. Tried to link things together to help the flow

**Section Three**

Feedback on the following aspects of this assignment (i.e. content/style/approach) would be particularly helpful to me:

1. conclusions

**ECDE Lab Report**

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**You must complete this checklist. Otherwise, your report will not be marked.**

|  |  |
| --- | --- |
| * All members of the group have made contribution to the laboratory work and this report. | Yes |
| * The report is written in my own words with data taken and graphs drawn by myself. No material has been copied from the lab sheet or elsewhere without proper reference. | Yes |
| * The report is produced using Word processors without any handwritten content. | Yes |

### Abstract

Lab 1 looked at the non-linear characteristics of an Op-amp circuit. It was found that a 4.15% discrepancy was found between the theoretical and experimental values for the switching time. Lab 2 focused on capacitors and charge and was found that in circuit containing a capacitor, adding a capacitor to the outside of the circuit affected the voltage across the internal capacitor. It was concluded that increasing the external capacitance increased the voltage measured across the internal capacitor. The aim for lab 3 was to investigate a differential amplifier. The finding from this lab was a difference in 1.2 between theoretical and experimental voltage gain and a maximum discrepancy of 2.5% from the measured results to the theoretical results. In lab 4, the aim was to simulate a two-stage amplifier. It was found that their was a large difference of 40% between the simulation and calculation. This being due to the current gain being used for each being a different value.

### Introduction

In this lab, the aim was to investigate a non-linear op-amps, in this task, the aim was to investigate a simple half-wave rectifier using a diode, 1 kΩ resistor, input voltage of 6 V peak to peak and frequencies of 50 Hz, 500 Hz and 5 kHz. The main interests were the switching time, and the difference in the input and output voltage

### 1. Lab 1 – Task 4

### Diagram, schematic Description automatically generated1.1. Circuit diagram and pre-lab

*Figure 1: Circuit sketch of half wave precision rectifier drawn on Multisim*

The theoretical switching time was worked out using the equation below:

(1)

From the data sheet [1], the slew rate was noted as 0.5 V/µs and the input voltage was 13.8 V assuming the diode would not conduct until the input voltage had reached 0.6 V. This gives us a switching time of 27.6 µs.

### Chart, histogram Description automatically generated1.2 Results and discussion

*Figure 2: Oscilloscope graph when input voltage has a frequency of 50 Hz. Yellow line represents the input voltage, red line indicated output voltage*

Chart, line chart, histogram

Description automatically generated

*Figure 3: Oscilloscope graph when input voltage has a frequency of 5 kHz. Yellow line represents the input voltage, red line indicated output voltage. (Text at bottom indicates that time elapsed between the two cursors is 26.53 µs.*

As can be seen in figure 2, when the input voltage goes into the negative region, the output voltage drops to – 15 V. This is due to the diode restricting the current when in the negative direction. It is also shown by figure 2 that the input and output voltage signals are very similar when in the positive region, with a difference of 165 mV between the input and output voltages in the positive region. The switching time was recorded as 26.53 µs at 50Hz. This is 1.1 µs smaller than the theoretical value that was obtained. This could be due to the diode only starting to conduct when the input voltage is higher than the estimated value used. However, this is an acceptable switching time as the percentage error is only 4.15 % so can be considered as an accurate representation.

### 2. Lab 2 – Task 3

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Cext (F) | 0.1µ | 0.047µ | 0.022µ | 0.01µ | 4700p | 2200p | 1000p | 470p | 220p |
| Vint (V) | 2.48 | 1.52 | 0.87 | 0.44 | 0.22 | 0.11 | 0.054 | 0.029 | 0.014 |

In this task, the aim was to investigate how adding a capacitor externally to a circuit that has a capacitor already affects the distribution of charge and the overall output voltage. The external capacitor (Cext) was connected in parallel to another capacitor (Cint) in a circuit. The value of the Cint was kept constant with a value of 10-7 F. 5 V was put across Cext before connecting the two capacitors. Cext was varied from 0.1 µF to 220 pF and the voltage across Cint was measured using a voltage meter.

*Figure 4: Table of measured external capacitance against the measured voltage across the internal capacitor*

These values were compared to two theoretical equations that predict the voltage across Cint. These are:

As seen in figure 4, the measured voltages and the theoretical voltages from equation 1 are very similar so can be used to approximate the voltage across Cint over a large range of values. As for equation 2, the calculated values only become accurate when the external capacitance was below 0.01 µF. This shows that equation 2 is accurate when the ratio of Cint/Cext is 100 or above. Therefore, it can be said that equation 2 is accurate only when Cint is 100 times or more larger than Cext.

*Figure 5: Graph of capacitance against voltage across the internal capacitor gathered experimentally (Orange), theoretically using Equation 3(Black) and theoretically using Equation 4(Blue)*

### 3. Lab 3 – Task 2

The aim of this lab was to investigate a differential amplifier. In this specific task, the aim was to do a quiescent analyse of the differential amplifier and compare the theoretical quiescent values to those gathered through experimenting.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Theoretical calculation | Measurement | Calculation using measurements |
| VE (V) | -0.5 | -0.576 | - |
| IE (mA) | 0.48 | - | 0.481 |
| IC (mA) | 0.24 | - | 0.246 |
| VOUT1 (V) | 12.6 | 12.6 | - |
| VOUT2 (V) | 12.6 | 12.6 | - |
| gm (S) | 0.0096 | - | 0.00984 |
| vOUT1/(vIN1-vIN2) | -48 | - | -49.2 |
| vOUT2/(vIN1-vIN2) | 48 | - | 49.2 |

The theoretical values were gathered as such:

*Figure 6: Table of theoretical and measured values for the quiescent analysis of a differential amplifier.*

VE was given as -0.5 V; we can calculate IE:

From this, we can calculate IC1 and IC2:

VOUT1 andVOUT2was found by using the collector current and the collector resistance to work out voltage drop from the +VS of 15 V:

The mutual conductance gm was calculated by:

From all the above, the gain was calculated using the following equations:

Subbing in the values gives: and

As can be seen in figure 5, the measured output voltages match those from the theoretically calculated values. Also, the emitter current calculated from the measured data is only 0.001 mA higher than the theoretical emitter current giving a 0.208 % discrepancy between the two values. The experimental collector current is also only 0.006 mA above the theoretical collector current giving it a 2.5% discrepancy. From the mutual conductance from the experimental data had a 0.00014 difference from that of the theoretically calculated one and a 1.2 difference in the gain. All these values are accurate with the highest difference being a 2.5% difference. These differences could be due to many factors. Some of which include extra resistance in the wiring and breadboard, the equipment picking up noise which will interfere with the results and not all components can be considered ideal so will have their own resistance.

### 4. Lab 4

### 4.1. Pre-lab workout

Current Mirror calculations:

Using the diagram in figure 6 as a reference, we can say that the current flowing through R1 is:

Assuming that VBE is 05 V.

From theory, we can say that:

Using the given current gain (β) of 300.

Diagram

Description automatically generated

*Figure 7: Circuit diagram of current mirror used in simulation experiment [2]*

From the calculations above, we know that the collector current (IC1) drawn from the current mirror is 0.1mA. Using this and the circuit shown in figure 6 we can say that:

So:

We also assume that

We can say that the voltage flowing through R2 is 0.5 V since the voltage between base and emitter is 0.5 V, the voltage at node A is 8.5 V so the only voltage flowing through R2 is 0.5 V

This means that the current drawn by the resistor is:

Looking at node A, we can say that:

Using the equation below:

We can say that IC5 = 300 x 40 x 10-6 = 12 mA

Using equation 17, we can calculate gm to be 0.002 S for the first amplifier.

From this we can calculate the input and output impedance for the first amplifier:

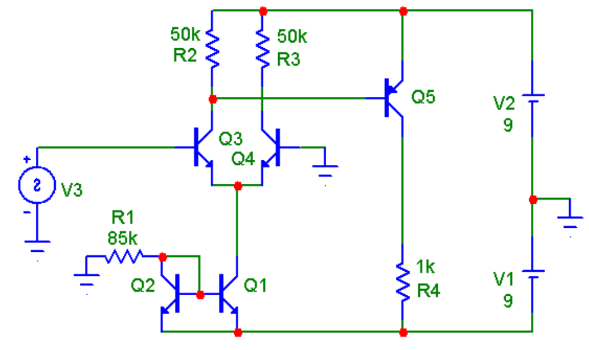
We can now calculate the mutual conductance of the second amplifier using equation 16 again. This means that the

We can also calculate the input and output impedance for the second amplifier using:

Using all the gathered information, we can calculate the gain for each of the amplifiers and the overall gain.

The gain of the differential amplifier and second stage amplifier can be calculated respectively using:

Therefore, the overall gain can be calculated as:



Node A

*Figure 8: Circuit diagram of two stage amplifier used during simulation experiment [2]*

### 4.2. Results and Discussion

A screenshot of a computer

Description automatically generatedA screenshot of a computer

Description automatically generated with medium confidence

*Figure 9: Multisim results for two stage amplifiers under AC analysis (top) and DC analysis (bottom)*

As shown in figure 9, the output voltage decreases from the collector of Q5 as frequency decreases when an AC input signal is set as the input. However, when under DC analysis, the voltage stays at a constant -10 V when the input voltage is below -100 mV. The voltage then increases linearly from -10 to 7 V between the range of -100 to 100 mV, where it stays at 7 V after that. The voltage gain at 1 kHz is -177.83. This significantly lower than the theoretically calculated value of voltage gain of -296.3. The percentage error between the two values is 40%. This large difference may be due to several factors. One of these could be that Multisim used a different current gain value. Another being that the transistor currents and voltages are not the same as the calculated values since some equations used were approximated.

### Reflection and conclusions

Lab 1:

From this lab, a deeper understanding of non-linear Op-amp applications have been achieved. This includes understanding how a half wave precision rectifier works and how slew rate affects the output voltage.

As discussed in the lab 1 section of the report a there was only a small percentage error between the theoretical and experimental value of switching time. The objective of the experiment was to explore practical amplifier circuits and precision rectifiers as well as discover any non-ideal aspects. From the difference in switching time, it can be concluded that a non-linear aspect has been discovered.

Lab 2:

From this lab, an understanding of charge, capacitance and of how an electrometer works have been gained.

From the results gathered in lab 2, we can say that the capacitance of an external capacitor impacts the voltage supplied by the internal capacitor. If the external capacitance increases, the voltage across the internal capacitor increases. We can therefore say that a better understanding of parallel plate capacitors in circuits has been achieved

Lab 3:

This lab aimed to introduce the differential amplifier configuration and investigate the quiescent and small signal analysis of the circuit.

During this lab, the dc current gain of a transistor was measured as well as the construction and testing of a differential amplifier. The measured values from experiments and the theoretical values only had a maximum difference of 2.5% showing the accuracy of the theory and a difference between the gains of 1.2.

Lab 4:

Things taken away from this lab is the knowledge surrounding a multi-stage amplifier and an introduction to circuit simulation software.

The findings from this experiment show a large discrepancy between the simulated and calculated current gain. This was because the voltage gain used in each was different resulting in different end results. From this, we can say that a deeper understanding of the of two stage amplifiers was achieved.

### References

[1] LM741 Op-amp datasheet - <https://www.ti.com/lit/ds/symlink/lm741.pdf>

[2] Lab4 Multi-stage Amp Simulation\_Multisim.docx - <https://canvas.bham.ac.uk/courses/56040/pages/lab-4-multi-stage-amplifier-simulation?module_item_id=2233251>