PHYC30300- Advanced Laboratory I

Electronics

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Exercise 5

Theory

A resistor–capacitor circuit or RC circuit, is an electric circuit made up of resistors and capacitors. A first order RC circuit is an RC circuit consisting of one resistor and one capacitor. RC circuits can be used to filter a signal by blocking out certain frequencies and passing others. Simple examples of these RC filters are high-pass filters and low-pass filters.[1]

Circuit

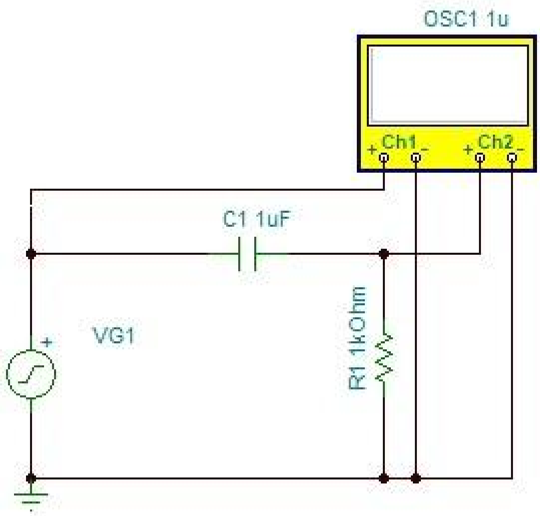
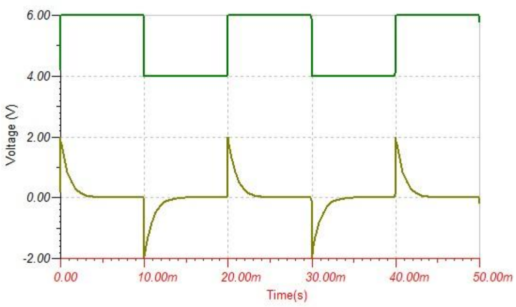


Fig 5.1 Circuit diagram for exercise 5. This is an example of a high pass filter.

The circuit above is an example of a high-pass filter. This means it passes the high-frequencies above their cutoff frequency while attenuating frequencies below the cut-off frequency. The reactance of the capacitor is high at low frequencies so the capacitor blocks any input signals until the cut-off frequency is reached. Above this cut-off frequency the reactance of the capacitor has reduced enough as to now allow all of the input signal to pass through to the output.

Analysis & Discussion



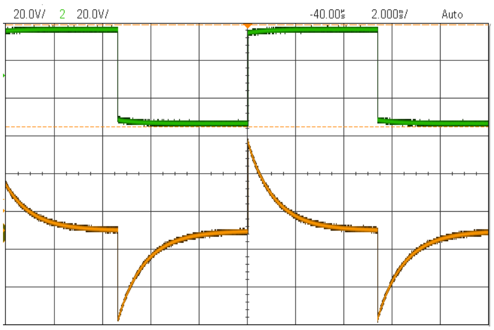


Fig5.2(a) and (b) show the input square wave compared to the output voltage versus time for simulation and measurement, respectively.

Fig5.2(a) and Fig5.2(b) show the input and output voltage for both simulated and measured RC high-pass filters. It can be seen that low-frequency signals have been blocked, however we can see a decaying curve after each of our spikes. This is due to the charging and discharging of the capacitor. The decay constant of this curve is equal to the RC combination of the circuit. The spikes themselves are caused by the changing AC current. When input voltage changes from 5V to -5V for example, this change is a high frequency event causing a spike.

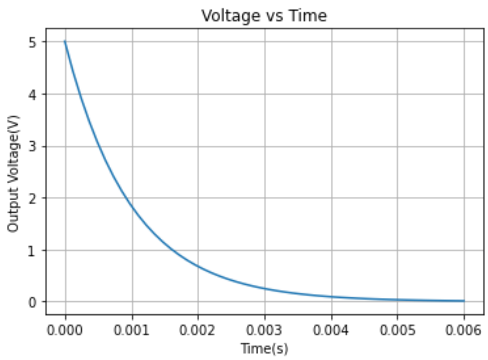


Fig 5.3 shows the theoretical decaying curve for a high pass filter

Our theoretical, measurement and simulation graphs all agree having all the same time decay constant. Each graph takes 5.5ms to decay from the peak to zero.

Exercise 7

Circuit

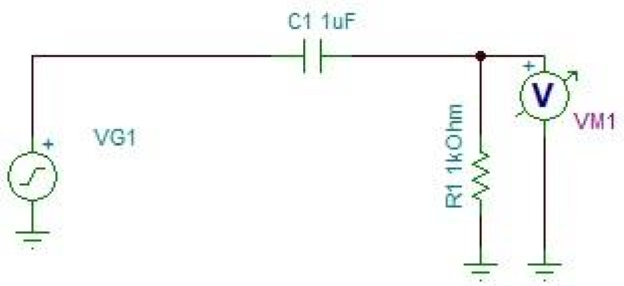


Fig 7.1 Circuit diagram for exercise 7

Similarly to the circuit in Exercise 5, the combination of capacitor and resistor in the circuit acts as a high-pass filter. In this exercise we will explore the frequency response curve for a high-pass filter.

Analysis & Discussion

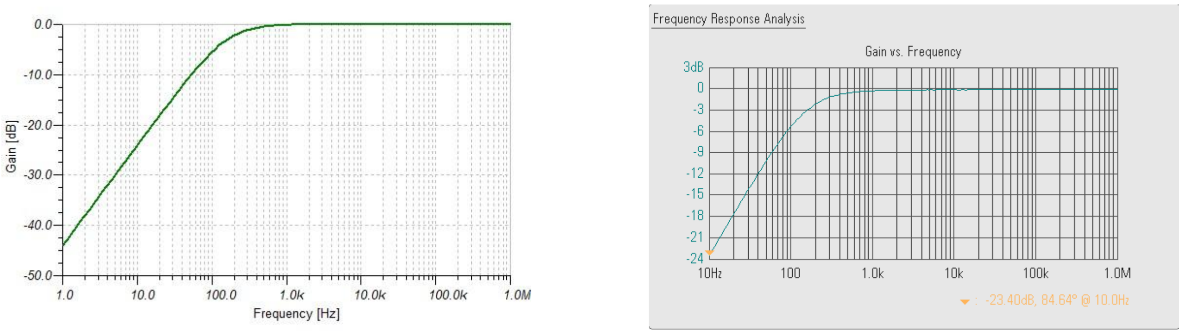


Fig7.2(a) and (b) show the gain vs frequency for simulation and measurement, respectively.

We can see in this circuit, the signal is damped at low frequencies with the output increasing at 20dB per decade until the cut-off frequency is reached. The region from the initial point to the cut off frequency is known as the stop band while the frequency range above this point is the pass band. This region can be seen to end at -3db or at ≈159 Hz which is our measured cut-off frequency. We can also see from the frequency response analysis that the phase angle is equal to 45 degrees at our frequency cut-off point ≈159 Hz.

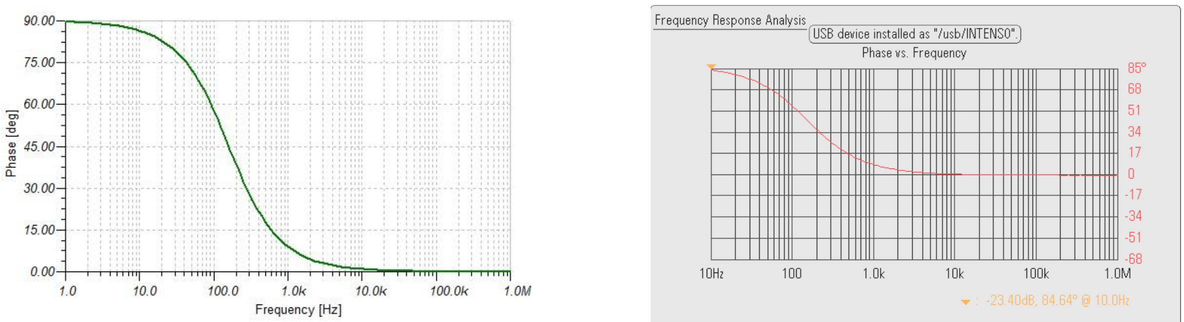


Fig7.3(a) and (b) show the phase angle vs frequency for simulation and measurement.

When attempting to calculate the theoretical frequency response curve to compare to our simulated and measured plots, the plots did not agree. Both the gain and phase response do not agree with what is expected. I believe that this is due to a computational error of my own and have included both plots in the appendix for Exercise 7.

Exercise 12

Theory

A diode is an electrical component that allows the flow of current in only one direction. The most common diode uses a p-n junction.[2] In this diode, one material in which electrons are charge carriers is in contact with a second material where holes are charge carriers. Where they meet, a depletion region is formed. Across this depletion layer, electrons move to fill holes in the p-side. This stops the further flow of electrons. When this junction is forward biassed, when a positive voltage is applied to the p-side, electrons can move across the junction to fill the holes, and this causes a current to flow through the diode.[2] When the junction is reverse biassed, when a negative voltage is applied to the p-side, the depletion region widens and electrons cannot move across.

Circuit

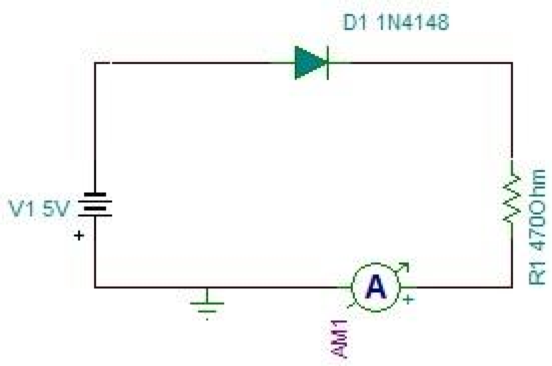


Fig12.1 Circuit diagram for exercise 12

The function of the diode in this circuit is rectification of AC to DC. When a diode is forward biassed, current will pass current. When the diode is reverse biassed, the current is blocked. The PN junction then needs a bias voltage of a certain polarity and amplitude for current to flow. [2]This bias voltage controls the resistance of the junction and in turn, the flow of current through it.

Analysis & Discussion

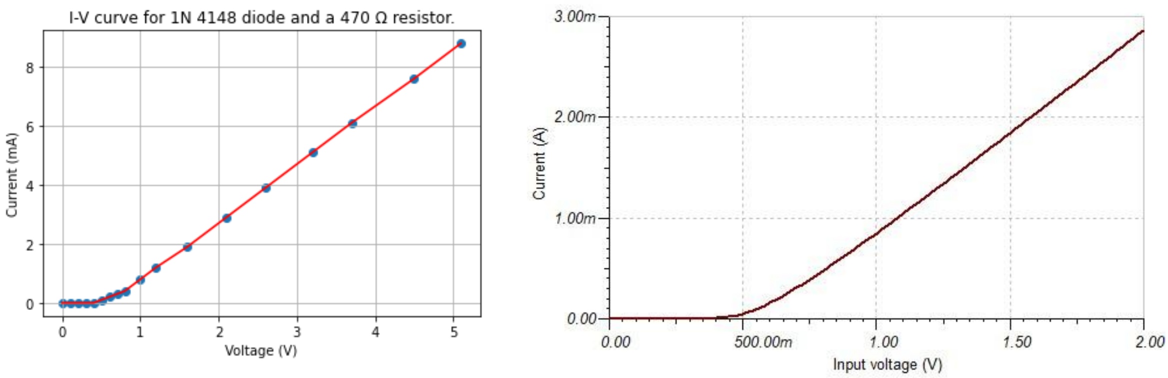


Fig12.2(a) and (b) show the IV curve for forward bias for both simulation and measurement, respectively

Starting at the origin, current and voltage are extremely small or zero.
When the forward voltage exceeds the diode's bias voltage, which was found to be ≈ 0.4V, the forward current increases rapidly for a very short time producing a small curve in voltage.
This is consistent with our findings both in the simulation and measurement.
When the diode is reversed biassed, the diode blocks current except for an extremely small leakage current. The diode continues to block current flow until the voltage becomes greater than the diode's breakdown voltage resulting in a sudden increase in reverse current.
We were unable to plot a measured reverse IV curve in the laboratory as we could not measure to a small enough degree in order to get accurate measurements for reverse current.

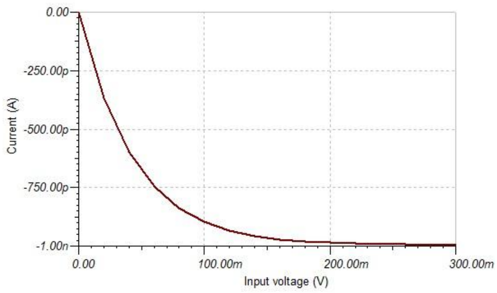


Fig12.3 shows the IV curve for reverse bias for simulation.

Exercise 12b

Theory

As previously mentioned in exercise 12, the function of the diode in the circuit is rectification of AC to DC. When a diode is forward biassed, current will pass current. When the diode is reverse biassed, the current is blocked. Therefore when passing an AC sine wave through the circuit, the diode allows the positive half-cycle of the input AC signal and blocks the negative half-cycle of the input AC signal. The output voltage waves will have positive peaks but will be zero where negative peaks would be. This is a type of half-wave rectifier. However, this pulsating direct current changes over a short period of time. However, a capacitor can be used to convert the pulsating DC to pure DC.[3]

Analysis & Discussion

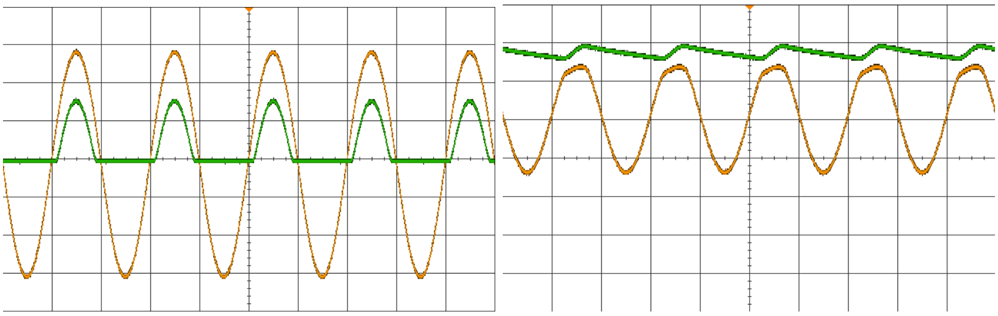


Fig.12b(a) and (b) show the input (orange) and output (green) voltage for half-wave rectifiers without and with a capacitor filter.

As we can see from Fig.12b(a), the diode allows the positive half-cycle of the input AC signal and blocks the negative half-cycle of the input AC signal. The output voltage waves will have positive peaks but will be zero where negative peaks would be.
In Fig.12b(b) we can see that the output voltage has significantly smaller ripples due to the capacitor filter. The remaining ripples are caused due to the capacitor charging up and discharging on the way down. [3]

Exercise 19

Theory

An npn transistor consists of a piece of p-type material, doped at both sides as n-type
If we apply a voltage to an npn transistor a current will flow into the n-type material and out the p-type middle. If this ptype middle is sufficiently thin, charge carriers will move through to the second n-type layer. [4]They are now free to move toward the second, even more positive, voltage source. If we reverse the bias on the p-n junction at the start, no current can flow into the p-type layer in the centre and no current will flow into the n-type layer on the end. This is the current amplification property of a transistor.[4]

Circuit

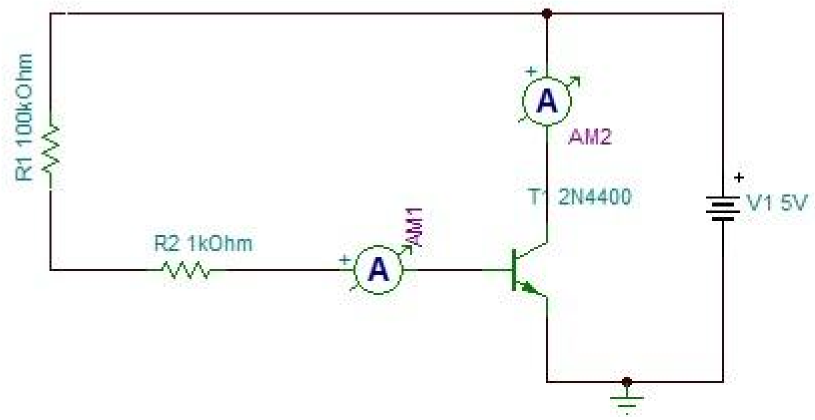


Fig19.1 Circuit diagram for exercise 19

From our ammeters placed in the circuit, we can measure the current before and after it gets to the transistor. This way we can see how much the transistor has an effect on the current.

Analysis & Discussion

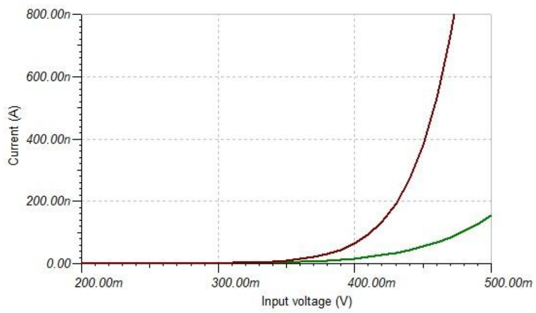


Fig.19.2 shows the input (green) and output (red) current for a transistor acting as a current amplifier.

As we can see from Fig19.2, the current is indeed being amplified by the transistor. By taking measurements of both input and output current at various input voltages, we were able to find the gain to be a factor of ≈ 6.9.

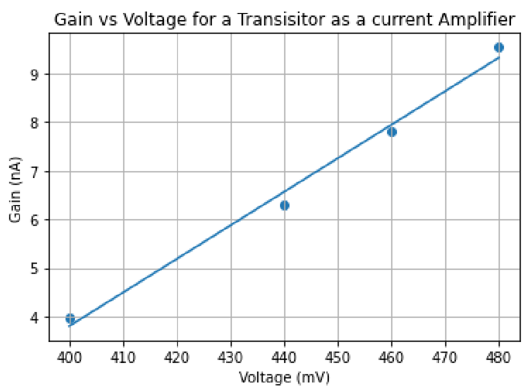


Fig.19.3 shows the gain vs input voltage for a transistor acting as a current amplifier.

Exercise 20

Theory

The response curve of this circuit can be divided into three stages. [1]The first stage is when the transistor is off and the voltage is 5V due to no collector voltage flowing. The second stage is when the transistor is partly on and the voltage across the load resistor increases, therefore the output voltage drops. The third stage is when the transistor is fully on and is said to be saturated. [1]The higher the load resistance is the quicker the voltage output drops and the transistor switches on.

Circuit

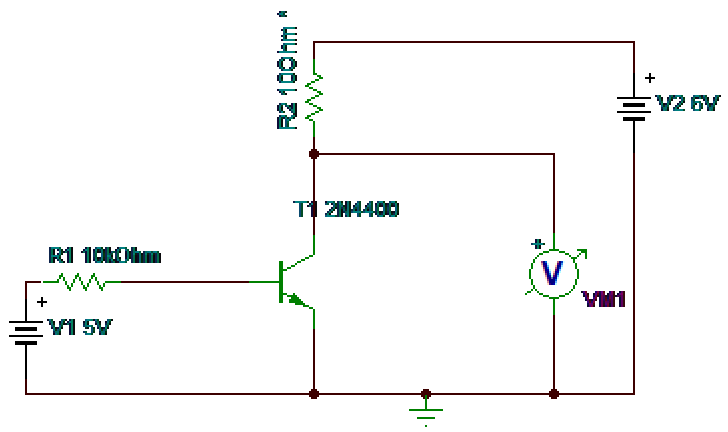


Fig 20.1 Circuit diagram for exercise 20

By changing the value of the load resistor, we are able to find the effect of its value on the switching action of the transistor. The higher the load resistance is the quicker the voltage output drops and the transistor switches on.

Analysis & Discussion

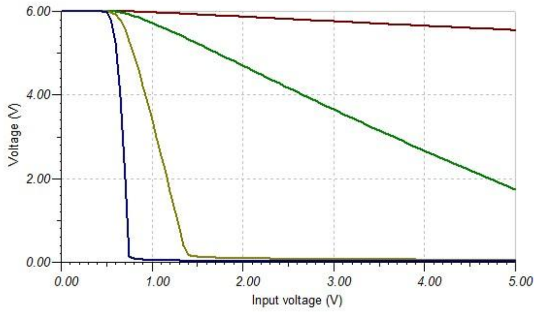


Fig.20.2 shows the response curve for various different load resistor values. Blue (10k ohms), Gold (1k ohms), Green (100 ohms), Red(10 ohms)

As we can see from Fig 19.3, the higher the load resistance value is the less input voltage required to turn the transistor fully on. We can also see the three stages in the response curve of each of the load resistor values.

Exercise 21

Theory

A light-dependent resistor or LDR, is a photo-conductive cell made from a semiconducting material, and its resistance changes in an inversely proportional manner to the light intensity falling upon it.[5] This material becomes an insulator in the dark as the material does not have enough electrons in order to conduct. However, when in the light, photons fall upon it and release electrons which allow it to conduct. The more electrons it has, the more it will conduct, thus lowering its resistance. By using this type of resistor to bias a transistor, we can make a transistor switch power to an LED depending upon the light conditions. [5]

Circuit

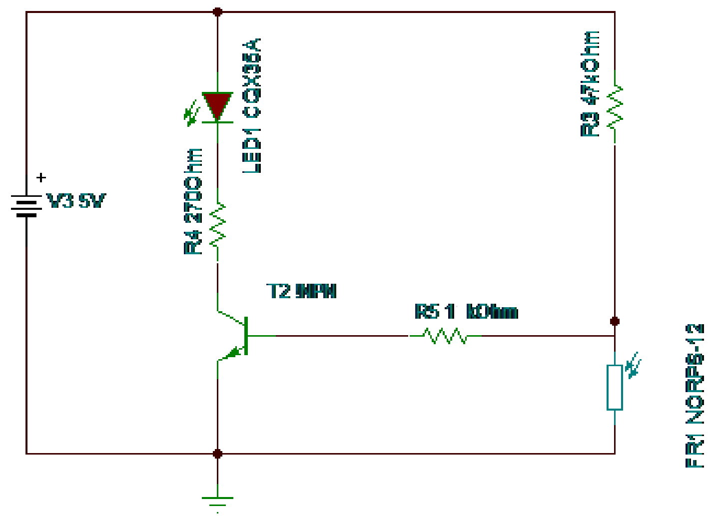


Fig 21.1 Circuit diagram for exercise 21

In this circuit, the bulb is on in the light, and off in the dark. When light falls on the LDR, its resistance drops, and so does the voltage across it, however the voltage across R3 increases. The voltage across the base junction is not sufficient to make the transistor conduct. In the dark, the LDR resistance increases, and the voltage across it increases too. This increase in voltage across the base junction thereby causes the transistor to conduct, switching on the bulb.
Choosing components was extremely important in this exercise as we wanted to have R3 be lower resistance than the LDR in the dark and higher resistance in the light. In bright light the LDR's resistance was 8 kΩ, however, in the dark its resistance increased to around 1 MΩ.

This meant that there was a wide range of values that could be suitable for R3. However, through trial and error, I found that 47kΩ was the most suitable. For the other resistors in the circuit it was important we chose resistors high enough so that they would protect the LED and transistor and ensure they got the right voltage.

Analysis & Discussion

Additional Question;

In order to calculate the cost of running the circuit over the course of a year, we must calculate how much power is drawn through the circuit both in the daytime and at night time.

$$Power = V \times I = \frac{V^2}{R}$$

For the Day;

There is no current flowing through the base or the LED. Just R3 and the LDR.

$$Power = \frac{V^2}{R} = \frac{25V}{47k + 8k} = 0.455mW \times 12\, hours = 5.45\, mWh \times 365\, days = 1.989\, kWh$$

For the Night;

There is zero current flowing through the LDR and only 1/100 of the current flowing through the resistor as it is fully switched on. Power is only used by a transistor that is partly on.

$$Power = V \times I = 5 \times 5.05 = 25.25mW \times 12\, hours = 303\, mWh \times 365\, days = 110.95\, kWh$$

$$112.584\, kWh \times €\, 0.18 = €\, 20.265$$

Exercise 25

Theory

An Operational Amplifier, or op-amp, is a voltage amplifying device designed to be used with external feedback components such as resistors and capacitors between its output and input terminals.[6] These feedback components determine the resulting function or operation of the amplifier and of the different feedback configurations whether resistive, capacitive or both. In this circuit, the input voltage signal is applied directly to the non-inverting input terminal which means that the output gain of the amplifier becomes positive in value The result of this is that the output signal is in-phase with the input signal. [6]

Circuit

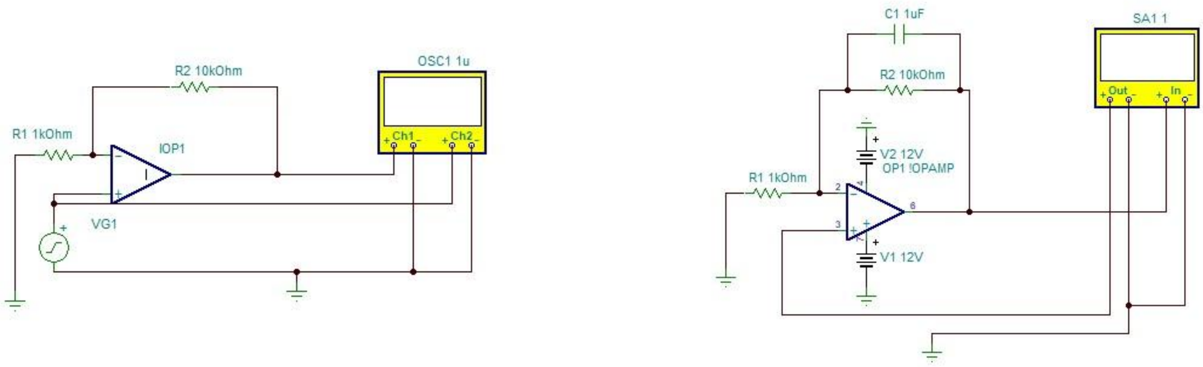


Fig25.1 Circuit diagram for exercise 25 and exercise 25(b)

Feedback control of the non-inverting operational amplifier is achieved by applying part of the output voltage back into the inverting input terminal using a Rf- R2 voltage divider network, producing negative feedback. [6]
The components were specifically chosen to provide a closed-loop gain of 20 db or a factor of 10. The closest we could come to this, using the components available in the lab, was a factor of 11. This was calculated using the formula; [1]

$$Gain = 1 + \frac{R_F}{R_2}$$

For part (b), a capacitor was added across R_F

Analysis & Discussion

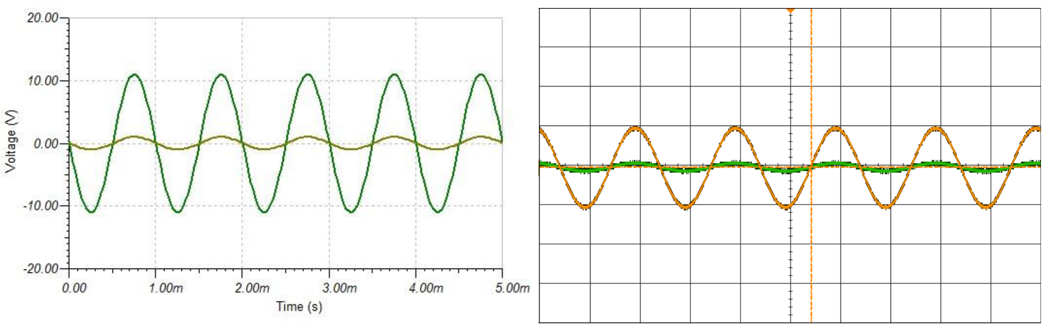


Fig.25(a) and (b) show the input and output voltage for non inverting amplifier

As we can see from both Fig.25(a) and (b) our input voltage has been increased by a gain of 20db or a factor of 10 in both our simulation and measured plot. This was as expected.

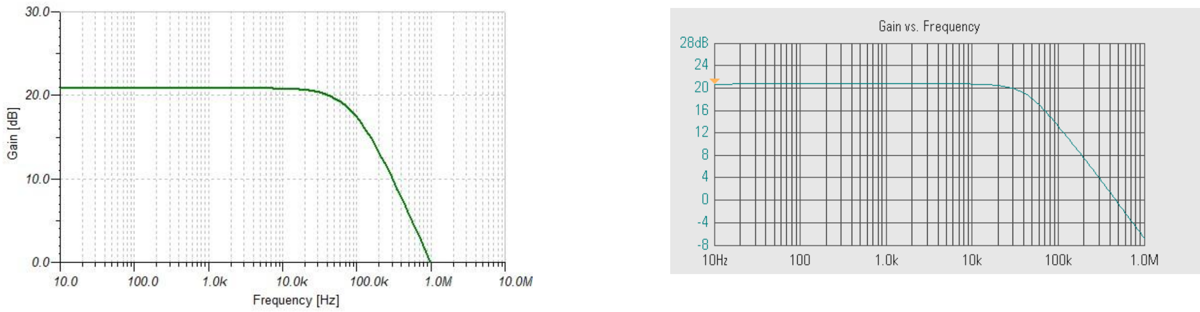


Fig.25(a) and (b) show the frequency response curve for a non-inverting amplifier

As we can see from both Fig.25(a) and (b), both plots start at a gain of around 20 db and reach their unity gain frequency at 1MHz as 0 db is equal to a gain of 1. The frequency response of our op amp has a low-pass characteristic. It passes on low-frequency signals and attenuates on high-frequency signals.

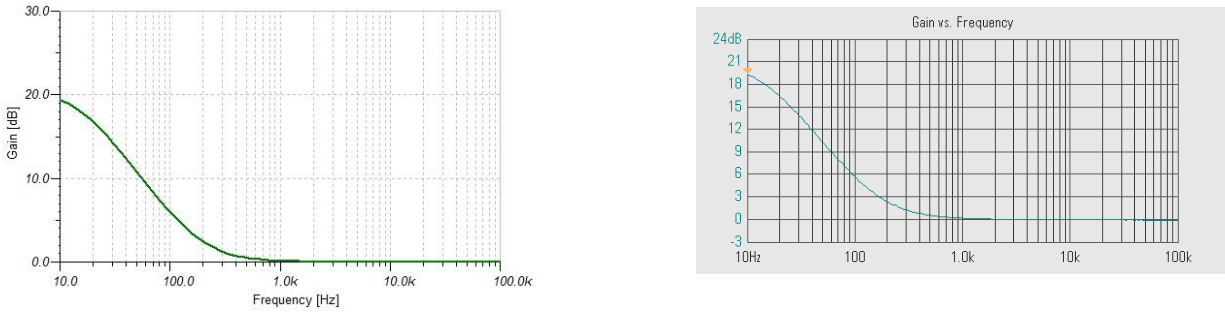


Fig.25(a) and (b) show the frequency response curve for a non-inverting amplifier with a capacitor

As can be seen from the figures above, the frequency response of our op amp has a low-pass characteristic. It passes on low-frequency signals and attenuates on high-frequency signals.

Exercise 27

Theory

DAC, or Digital to analog converter, takes digital inputs and generates the output which is equivalent to the analog signal.[7] A Summing amplifier sums up the currents running through the input branches and the resulting current runs through R_F, which is R5 in Fig 27.1. The output voltage is a linear combination of each of the input voltages, determined by the values of the resistors on each branch, determining the amplification. [1]

$$V\,out \;=\; -R_F\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \;+\; ..... \;+ \frac{V_n}{R_n}\right)$$

Circuit

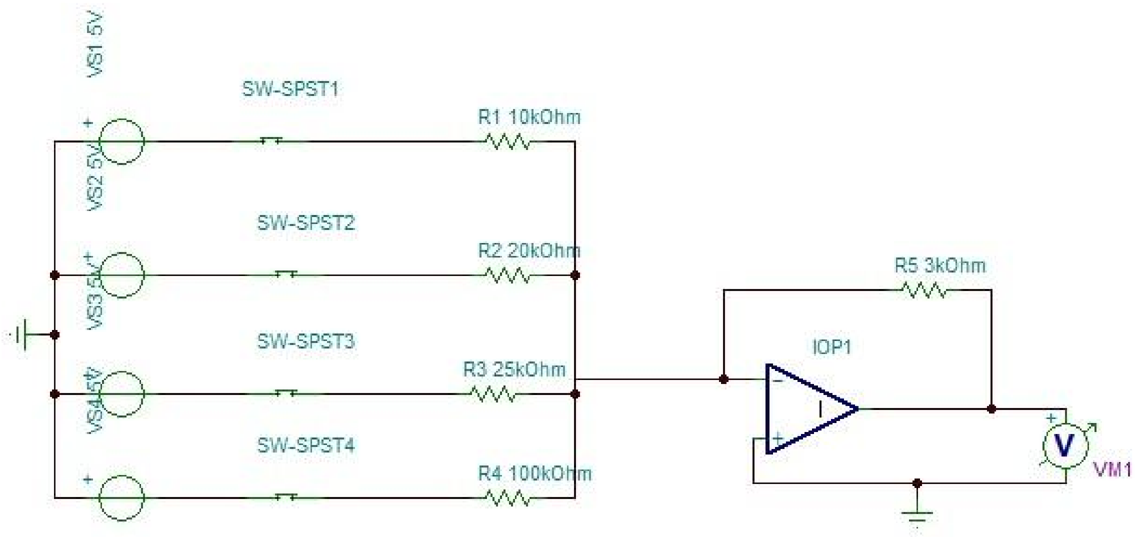


Fig.1 Circuit diagram for exercise 27

In each of the branches when the switch is closed, 5V flows and when open 0V.
The output of this circuit depends on two main factors, the first one is the value of the feedback resistor and the second is the combination of the input voltages.

Analysis & Discussion

In the table below, 1 stands for the switch being closed and 0 means it was left open. The full-scale of this circuit was -3V

Branch 1	Branch 2	Branch 3	Branch 4	V out
1	1	1	1	-3V
0	1	1	1	-1.5V
0	0	1	1	-750mV
0	0	0	1	-150mV
0	0	0	0	-60mV
1	0	0	0	-1.5V
1	1	0	0	-2.2V
1	1	1	0	-2.85V
0	1	0	0	-750mV

0	0	1	0	-600mV
0	1	1	0	-1.35V

References

[1]3rd Year Electronics Laboratory Dr John Quinn∗ Department of Experimental Physics, National University of Ireland
[2]diode- Definition, Symbol, Types, & Uses, Encyclopedia, Erik Gregersen Britannica,https://www.britannica.com/technology/diode
[3]Capacitor Filter using Half Wave and Full Wave Rectifiers, ElProCus - Electronic Projects for Engineering Students,
[4] TRANSISTORS AND AMPLIFICATION, Galileo.phys.virginia.edu, http://galileo.phys.virginia.edu/classes/241L/transist/transold.htm
[5]Peter Vis, Transistor as a Switch Using LDR,https://www.petervis.com/GCSE_Design_and_Technology_Electronic_Products/Transistor_as_a_Switch/Transistor_as_a_Switch_Using_LDR.html
[6]Non-inverting Operational Amplifier, ElectronicsTutorials, https://www.electronics-tutorials.ws/opamp/opamp_3.html
[7] Kamal Raj,4 bit DAC using op-amp - Circuit Fever,Circuitfever.com,https://circuitfever.com/4-bit-dac-using-op-amp

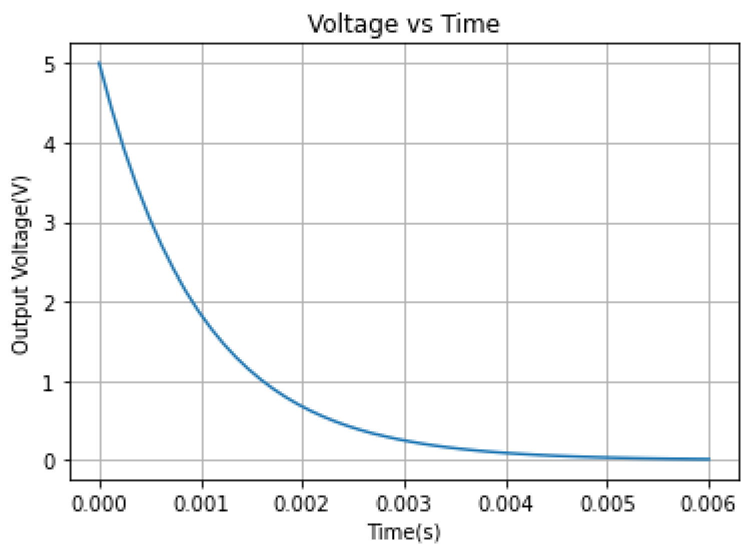
In [16]:

```
import numpy as np
from matplotlib.widgets import Cursor
import matplotlib.pyplot as plt
import scipy.optimize
import pandas as pd
V,I = np.loadtxt("IV.txt", unpack=True)
volts,A , B  = np.loadtxt("gain.txt", unpack=True)
```

Exercise 5

In [40]:

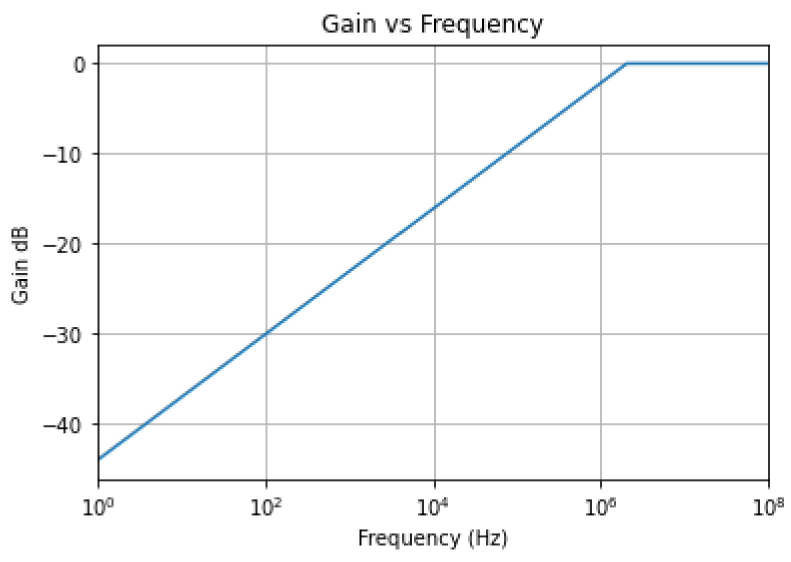
```
def V_ex5(V,R,C,t):
    return V*(np.exp(-t/(R*C)))
t = np.linspace(0,6/1000)
plt.plot(t,V_ex5(5,1000,1/1000000,t))
plt.ylabel("Output Voltage(V)")
plt.xlabel("Time(s)")
plt.title("Voltage vs Time")
plt.grid(True);
```



Exercise 7

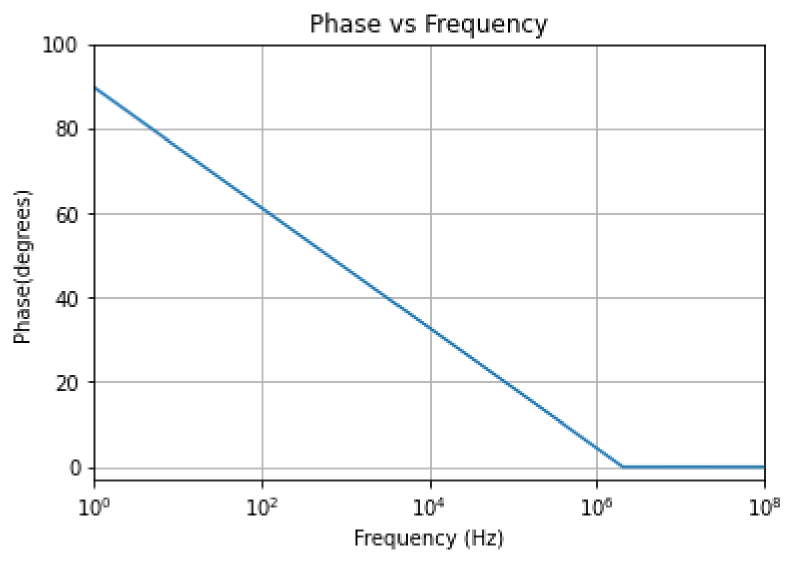
In [142…

```
def v_out(v_in,R,C,freq):
    return v_in*(2*np.pi*freq*R*C)/((1+((2*np.pi*freq)**2)*(R**2)*(C**2))**(1/2))

v_in=1
freq = np.linspace(1,10**8)
plt.plot(freq,(20*np.log10(v_out(v_in,1e3,1e-6,freq)/v_in)))
plt.ylabel("Gain dB")
plt.xlabel("Frequency (Hz)")
plt.xscale('log')
plt.title("Gain vs Frequency")
plt.grid(True);
plt.xlim([1, 1e8]);
```



In [141…

```
def phase(v_in,R,C,freq):
    return 360/(2*np.pi) * np.arctan(1/(2*np.pi*freq*R*C))

v_in=1
freq = np.linspace(1,10**8)
plt.plot(freq,phase(v_in,1e3,1e-6,freq))
plt.ylabel("Phase(degrees)")
plt.xlabel("Frequency (Hz)")
plt.xscale('log')
plt.title("Phase vs Frequency")
plt.grid(True)
plt.xlim([1, 1e8])
plt.ylim([-3,100]);
```

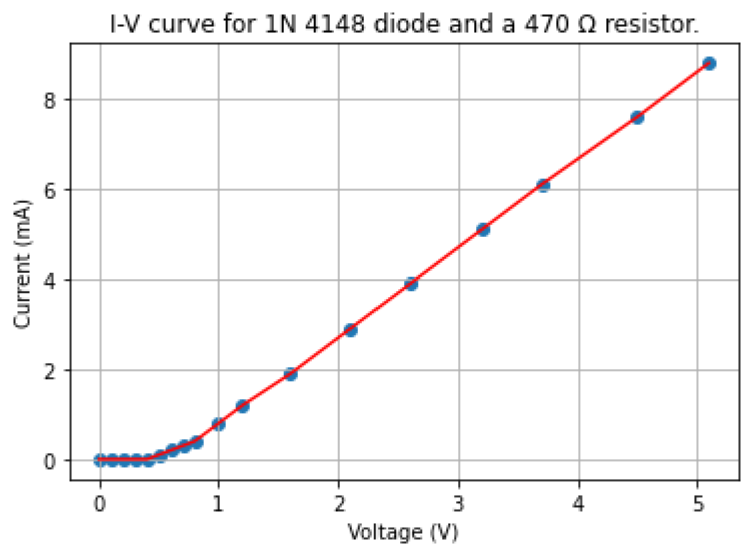


Exercise 12

In [150…

```
plt.scatter(V,I)
plt.plot(V,I, color = "r")
plt.ylabel("Current (mA)")
plt.xlabel("Voltage (V)")
plt.title("I-V curve for 1N 4148 diode and a 470 Ω resistor.")
plt.grid(True)
;
```

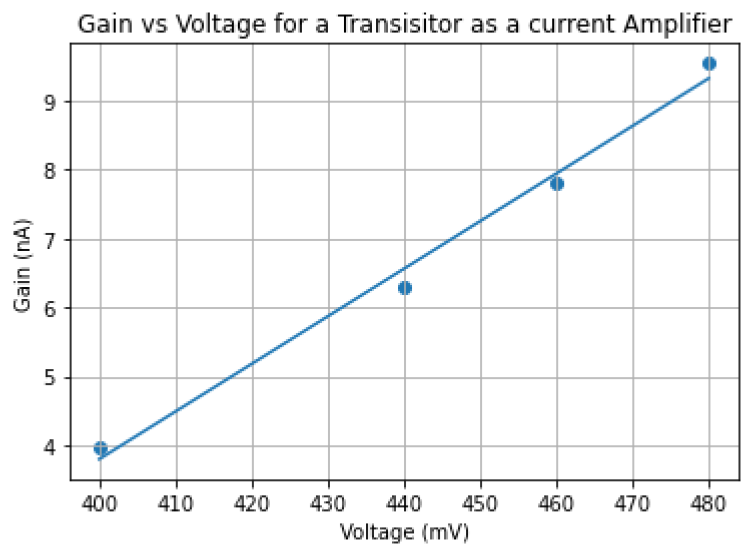
Out[150… ''



Exercise 19

In [151…

```
plt.scatter(volts,A/B)
m, c = np.polyfit(volts, A/B, 1)
plt.plot(volts, m*volts+c)
plt.ylabel("Gain (nA)")
plt.xlabel("Voltage (mV)")
plt.title("Gain vs Voltage for a Transisitor as a current Amplifier")
plt.grid(True)
```



In [ ]: