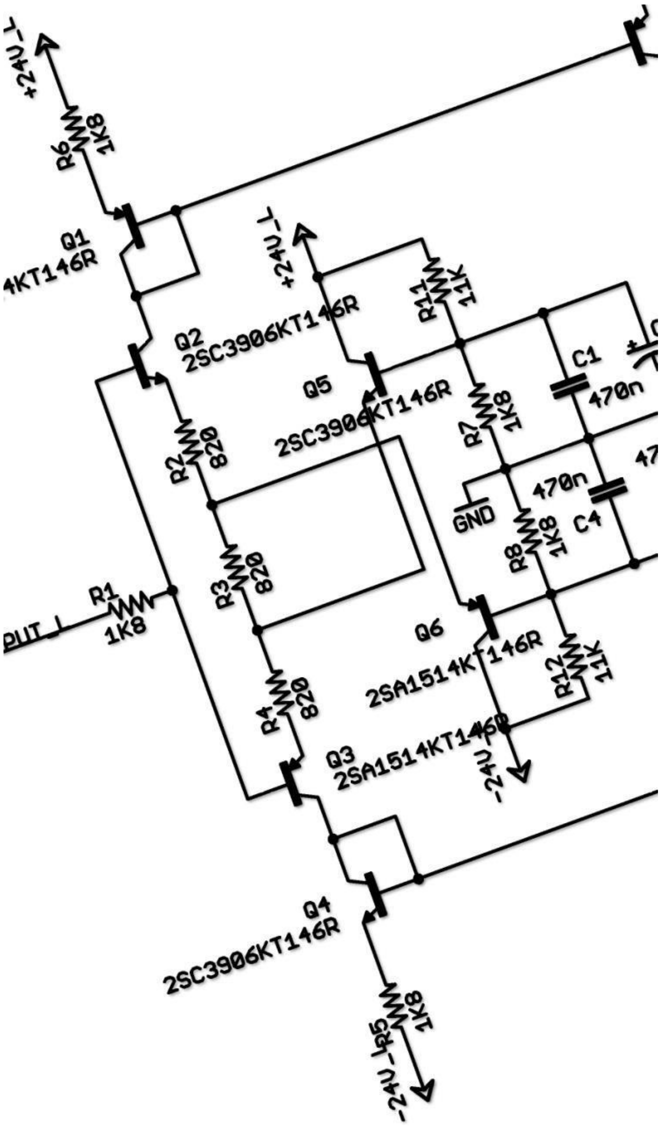
MONASH University
Engineering

ECE2131

Electrical Circuits

Laboratory Notes



2022 Edition

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2022

10 Diode Circuits

10.1 Learning Objectives and Introduction

Diodes are a versatile electronic component that allow current to flow in only one direction. They have a huge number of applications, such as circuit protection, power rectification, voltage multiplication, logic, demodulation, clipping, and clamping. Other varieties of diode are also used as light sources, and for optical communications.

This lab is designed to provide practical experience in working with diodes, introducing you to as many of the different applications for diodes as possible. This lab is also designed to increase your exposure to applications of diodes you may not have considered. If you have time, you should try to ensure you understand as many of the circuits as possible, as many are useful for electronics design problems you may encounter later in your degree and in your career.

By the end of this lab you should:

- Apply simple diode models to predict the outputs of circuits with diodes
- Analyse, build and characterise diode circuits.

10.2 Equipment and Components

- Breadboard.
- Diode 1N4007.
- Resistor 100 Ohm, 100 kOhm.
- Capacitor 470 nF.

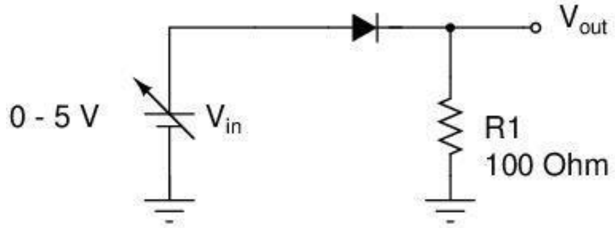
10.3 Important Notes

Pay close attention the diode I-V curve. Applying a voltage source across a diode junction will result in an exponentially increasing current, which can very easily damage the diode. You should therefore always limit the maximum current flowing through the diode, e.g. using a resistor.

10.4 Experimental Work

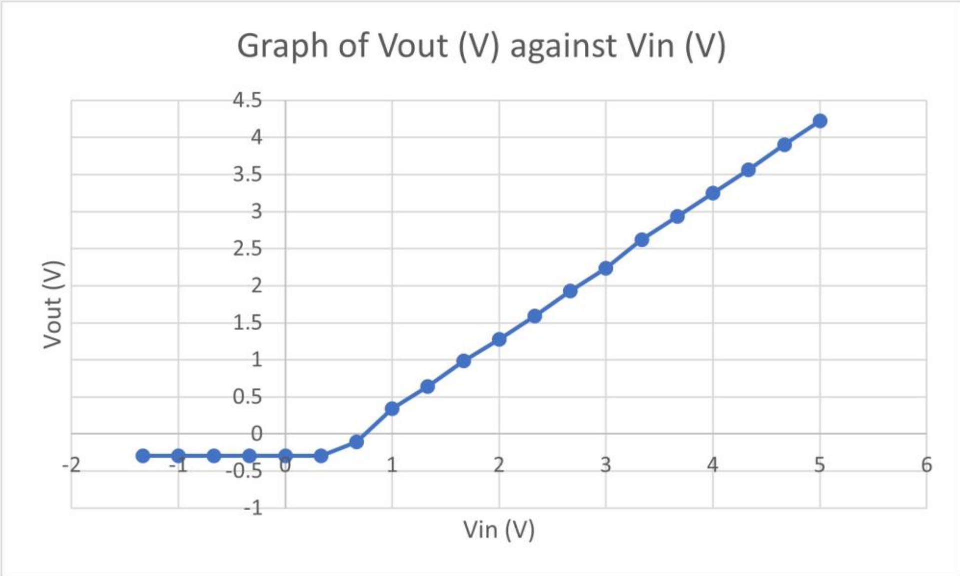
10.4.1 Part A – Diode Characteristic

Construct the following circuit on the prototype board.

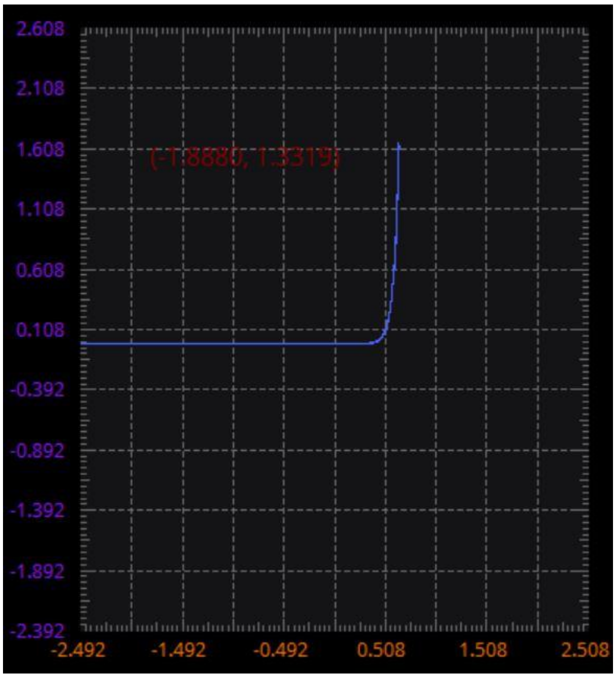


10.4.1.1 Sweep the DC supply voltage manually from 0V to 5V, recording at least 15 points. Measure the output voltage using a multimeter or oscilloscope. Plot the graph of V_{out} against V_{in}.

Graph of Vout against Vin



Graph of Current Against Vout



Is this as expected? How well does this match the simple diode models you have been introduced to?

Table

Point	V_{in} (V)	V_{out} (V)	$V_D = V_{in} - V_{out}$ (V)
1	0.333	- 0.295	0.628
2	0.667	-0.108	0.775
3	1.000	0.342	0.658
4	1.333	0.637	0.697
5	1.667	0.983	0.684
6	2.000	1.279	0.721
7	2.333	1.591	0.742
8	2.667	1.928	0.739
9	3.000	2.237	0.763
10	3.333	2.620	0.713
11	3.667	2.932	0.735
12	4.000	3.249	0.751
13	4.333	3.565	0.768
14	4.667	3.903	0.764
15	5.000	4.224	0.776
		Average Value (V)	0.728

Yes, this curve is expected, and it matches the constant voltage drop model that we have learned in the lectures. The diode will not allow the current to pass through the input voltage until it has reached the value of the turn on voltage which is approximately 0.7 V. Based on our observation of the graph above, there is very small voltages at the positive terminal. The measured value has a negative polarity. This could be due to the systematic error made by humans during the extraction of data from the graph or the error could from Scopy itself. The measured value for the turn on voltage is approximately 0.68 V which is close to the theoretical value (from the graph of current against Vout) and the measured value for the turn on voltage (average value across 15 different points) is 0.728 V which is also quite similar to the ideal turn on voltage of 0.7 V. After the input voltage has exceeded 0.7 V, there will be current flowing through the diode. The diode will be in forward bias.

10.4.1.2 Your measurements should have demonstrated that the forward voltage drop does not change much over a large range of currents, so we can safely *assume a constant voltage drop of approximately 0.7 V* across the diode for bias circuit calculations.

To test this, we want to achieve a diode current of 10mA in the circuit shown in figure 1. Verify your calculations from the preliminary quiz by measuring the diode current experimentally. To do this, choose the nearest resistor to the one you specified in the quiz. What current did you observe? (You may only be able to perform this in the laboratory using a multimeter to measure current)

Theoretical Value

Based on the preliminary result, we will obtain

$$\frac{(5-0.7)}{R} = 10mA$$

430 Ohms as our value of resistor

We do not have a 430 Ohm resistor in the E12 series of resistor. Thus, we will use the value of resistor which is the closest to the 430 Ohm value which is 560 Ohm (resistor available that is given to us).

The theoretical value of current that we should get would be approximately

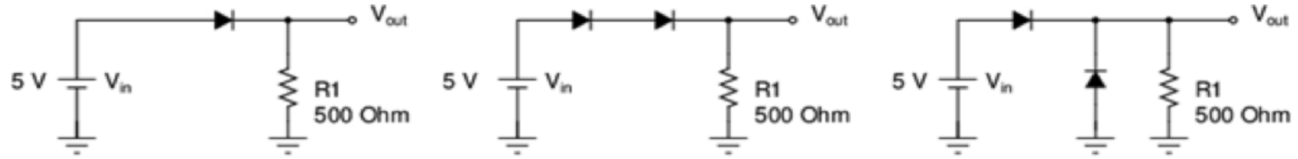
$$\frac{(5-0.7)}{560} = 7.68\ mA$$

Measured Value

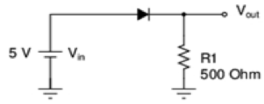
The measured value for the current is 8.065 mA which is close to the theoretical value. There is a difference between the theoretical and measured value as the resistors may not be ideal in this case, causing a larger measured value compared with the theoretical value.

10.4.2 PART B – DIODES IN SERIES AND PARALLEL

Since forward-biased diodes have a relatively constant voltage drop, various combinations are sometimes used in circuits to shift the DC level up or down by a fixed amount or for clipping and clamping purposes. Predict the output voltage and verify with measurements for each of the following circuits. Use the space below to explain your predictions or analysis, as well as write the measured output voltages.



Circuit 1



Theoretical Value

Assuming our diode is in forward bias (consumes 0.7V) in the circuit above, we can use KVL around the circuit to obtain the value of V_{out}.

We will obtain

$$V_{in} - V_D - V_R = 0, \text{ where } V_R = V_{out}$$

Rearranging the equation, we will obtain

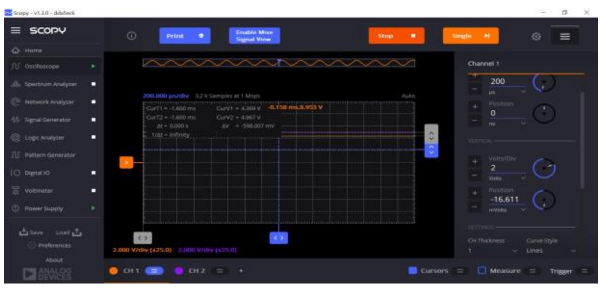
$$V_{in} - V_D = V_{out}$$

Substituting our value where V_{in} = 5V and V_D = 0.7V

$$V_{out} = 5 – 0.7$$

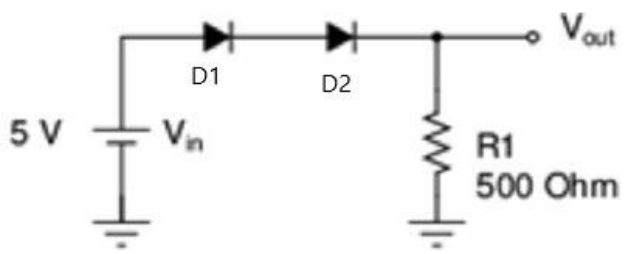
$$= 4.3 \text{ V}$$

Measured Value



The measured output value would be 4.369 V which is very close to the actual value. There is a slight difference due to the systematic error made during the extraction of value from the graph or the inaccuracies rising from Scopy itself. There could also be deviation of voltage as the voltage drop across the diode is not exactly 0.7V. This would result in a larger magnitude of V_{out} obtained.

Circuit 2



Theoretical Value

Assuming that both of our diode (V_{D1} and V_{D2}) is in forward bias (consumes 0.7V) in the circuit above, we can use KVL around the circuit to obtain the value of V_{out}.

We will obtain

$$V_{in} - V_{D1} - V_{D2} - V_R = 0, \text{ where } V_R = V_{out}$$

Rearranging the equation, we will obtain

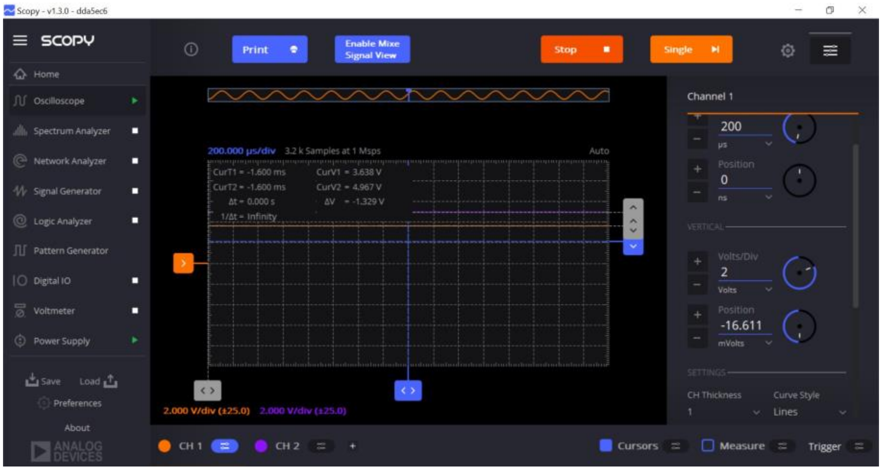
$$V_{in} - (V_{D1} + V_{D2}) = V_{out}$$

Substituting our value where V_{in} = 5V and $V_{D1} = V_{D2}$ = 1.4V

$$V_{out} = 5 – 1.4$$

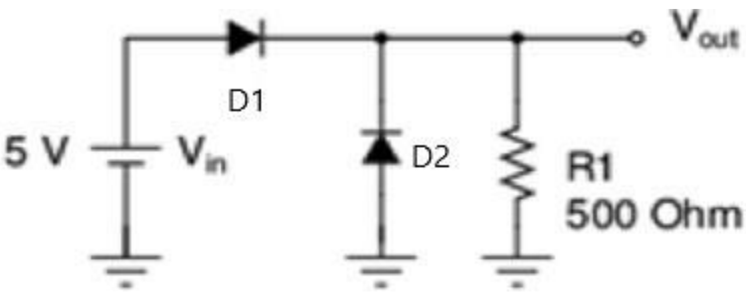
$$= 3.6 \text{ V}$$

Measured Value



The measured output value would be 3.638 V which is very close to the actual value. There is a slight difference due to the systematic error made during the extraction of value from the graph or the inaccuracies rising from Scopy itself. There could also be deviation of voltage as the voltage drop across the diode is not exactly 0.7V. This would result in a larger magnitude of V_{out} obtained.

Circuit 3



Theoretical Value

Assuming diode D_1 is in forward bias (consumes 0.7V) and diode D_2 is in reverse bias (no current passing through the diodes), we can use KVL around the circuit to obtain the value of V_{out}.

We will obtain

$$V_{in} - V_{D1} - V_R = 0, \text{ where } V_R = V_{out}$$

Rearranging the equation, we will obtain

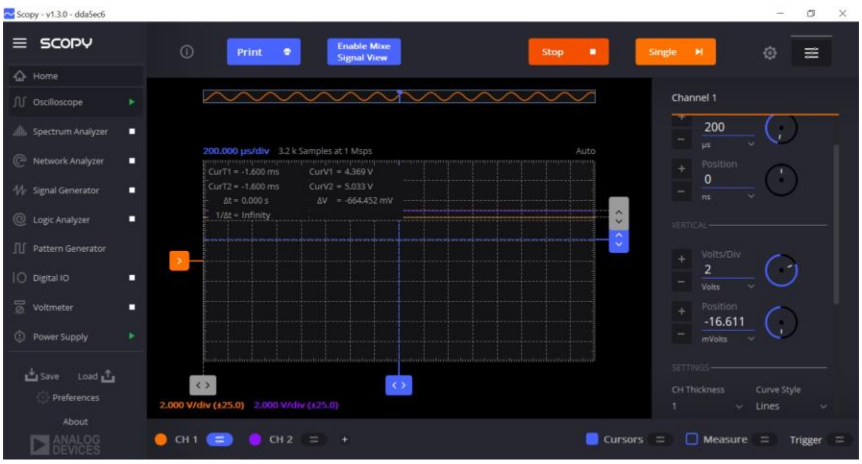
$$V_{in} - V_{D1} = V_{out}$$

Substituting our value where V_{in} = 5V and V_D = 0.7V

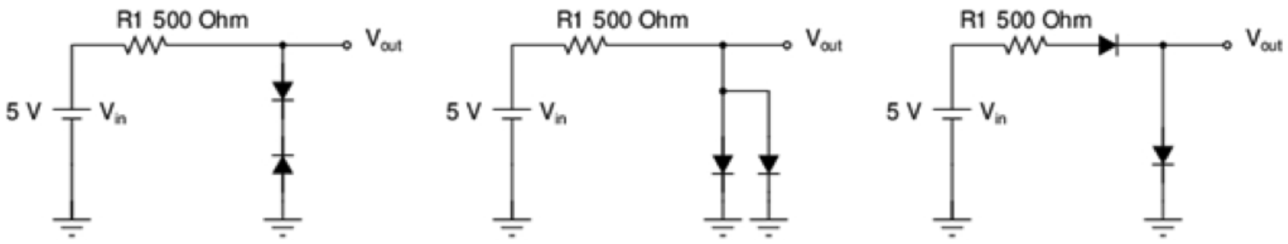
$$V_{out} = 5 – 0.7$$

$$= 4.3 \text{ V}$$

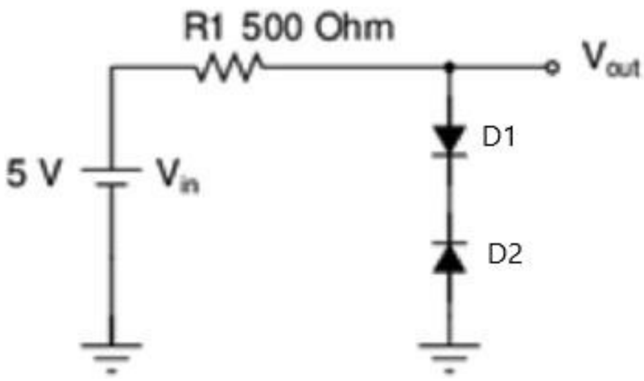
Measured Value



The measured output value would be 4.369 V which is very close to the actual value. There is a slight difference due to the systematic error made during the extraction of value from the graph or the inaccuracies rising from Scopy itself. There could also be deviation of voltage as the voltage drop across the diode is not exactly 0.7V. This would result in a larger magnitude of V_{out} obtained.



Circuit 4

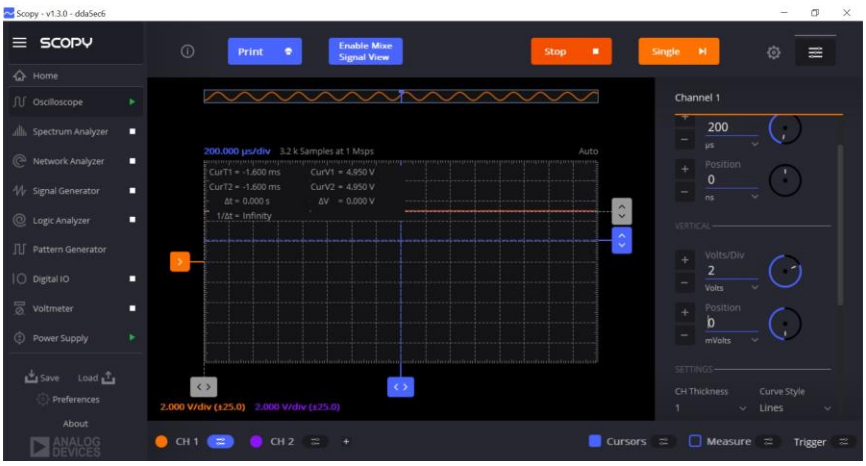


Theoretical Value

As we can observe from the circuit above, we can see that diode D_2 is in reverse bias. This would cause diode D_1 to be zero-bias as diode D_2 would block the flow of current. Thus, we can say that no current will flow through the circuit.

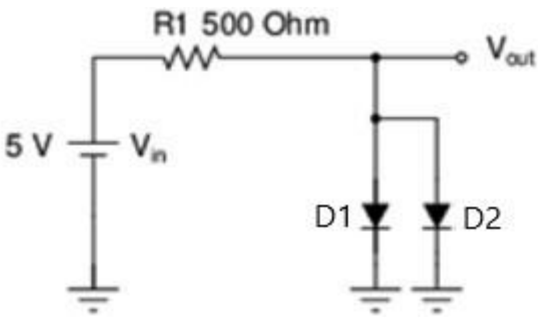
Thus, we can predict that the output voltage will be 5V.

Measured Value



As we can see from the above graph, the output voltage will be equal to our input voltage which is approximately 4.950 V which equates to the magnitude of the input voltage which is our theoretical value obtained from above. There is a slight difference due to the systematic error made during the extraction of value from the graph or the inaccuracies rising from Scopy itself.

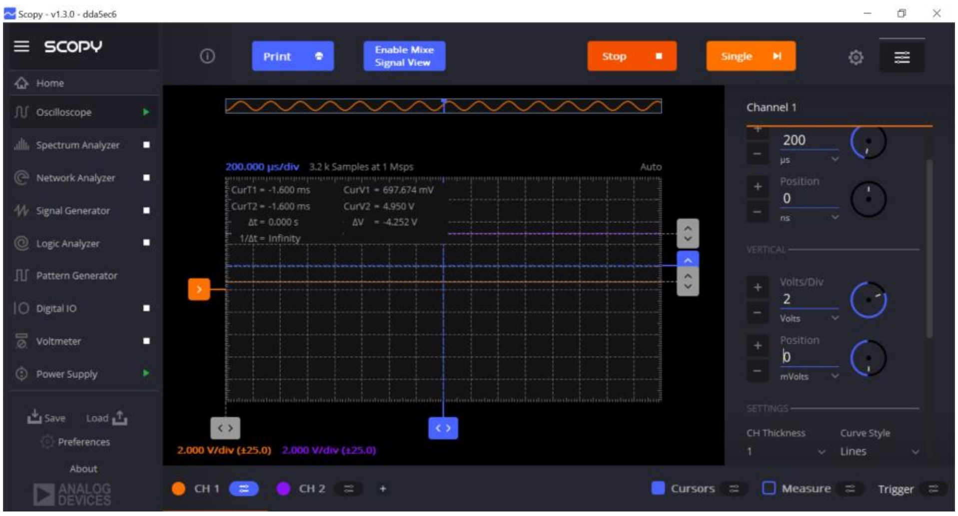
Circuit 5



Theoretical Value

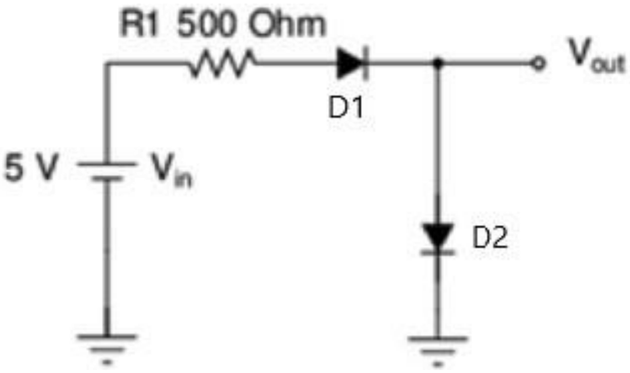
Assuming diode D_1 is in forward bias (consumes 0.7V) and diode D_2 is in forward bias as well, both of the diodes will consume 0.7V. This would also mean that the p junction of the diodes will be 0.7V and the rest of the voltage will be consumed by the resistor. Since Vout is the same as the voltage at the p junction,we can conclude that Vout will be 0.7V.

Measured Value



The measured output voltage has a value of 697.674mV. The measured value is close to the theoretical value obtained from above. The difference in value could be due to the systematic error made during the extraction of value from the graph or the inaccuracies rising from Scopy itself. We can also say that there is a deviation of voltage drop across the diode which does not equate to 0.7V. Thus, there is a slight difference in the measurement obtained.

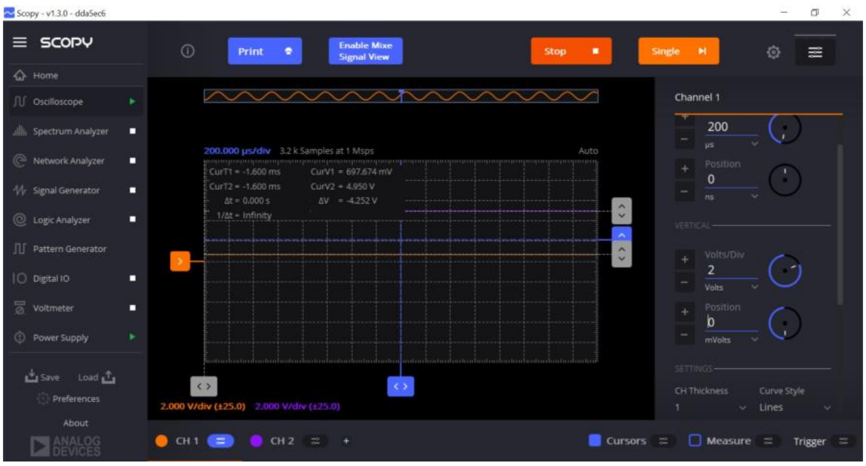
Circuit 6



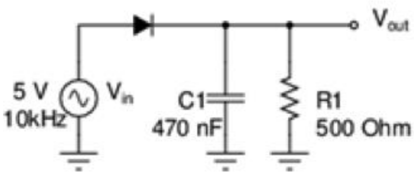
Theoretical Value

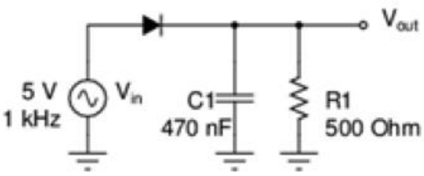
Since the voltage at the p junction of both diodes are higher than the n junction, both diodes will be in forward bias, meaning the diodes will consume 0.7 V each (a total of 1.4 V). This would also mean that the p junction of D_2 will be 0.7 V and 0.7 V more will be consumed by D_1 and the rest of the voltage will be consumed by the resistor. Since V_{out} is the same as the voltage at the p junction of D_2, we can conclude that V_{out} is 0.7 V.

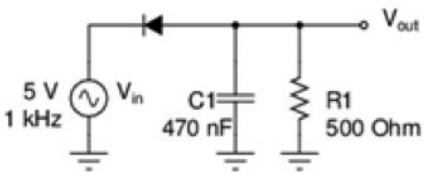
Measured Value



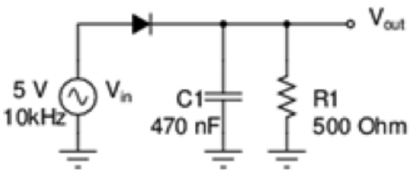
The measured output voltage has a value of 697.674mV. The measured value is close to the theoretical value obtained from above. The difference in value could be due to the systematic error made during the extraction of value from the graph or the inaccuracies rising from Scopy itself. We can also say that there is a deviation of voltage drop across the diode which does not equate to 0.7V. Thus, there is a slight difference in the measurement obtained. We can also notice that we obtain the same graph as the graph obtained in Circuit 5.







Circuit 7 (Assuming 5Vp-p)



Theoretical Value

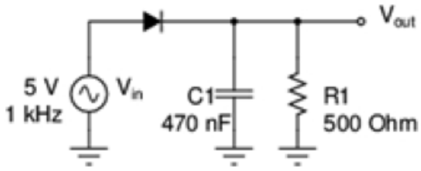
Assuming that the diode is in forward bias (consumes 0.7 V). When V_{in} is larger than 0.7 V and V_{in} is larger than V_{out}, we can say that the input voltage is greater than the capacitor voltage and forward voltage drop. The diode will be in forward bias. When V_{in} is less than V_{out} , we can say that the input voltage is smaller than the capacitor voltage. The diode will be reverse bias.

The output will be a half-wave rectifier with a peak voltage of 1.8 V as the diode will consume 0.7 V out of the inputted 2.5 V (one side of the peak). The output will start to decrease when the input changes direction. The output voltage will be a ripple voltage as the output does not drop to zero immediately.

Measured Value

The measured peak-output voltage would be approximately 1.240 V. There is a slight difference between the theoretical value and the measured value as the voltage drop across the diode will not be exactly 0.7 V. This could also be due to the systematic error by humans during the extraction of value from the graph or errors arising from Scopy itself.

Circuit 8 (Assuming 5V p-p)



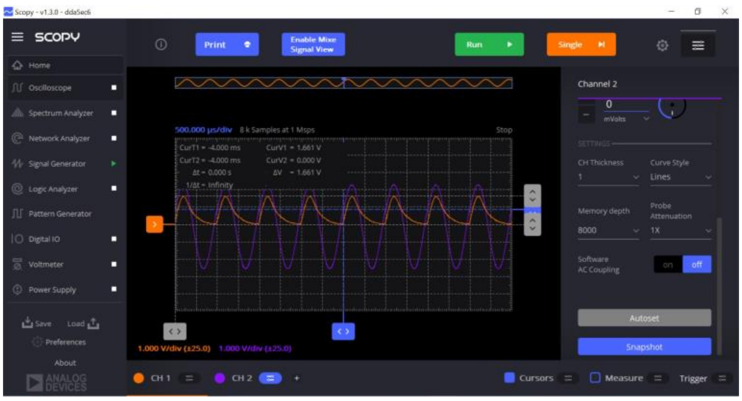
Theoretical Value

For the circuit above, the input voltage will be greater than the capacitor voltage. When the capacitor voltage is larger than the input voltage, the diode in the circuit will be reverse bias. This means that the diode will block the current and the capacitor will drive the current to the resistor during the discharge period. When the input voltage rises again to a specific level (input voltage > capacitor voltage), the capacitor will be recharged to the magnitude of the peak voltage. The process will be repeated. There will be a longer period of discharge as the frequency of the AC source is small, causing a large ripple voltage (in terms of magnitude).

Hence, the output will be a smoothen rectified half-wave.

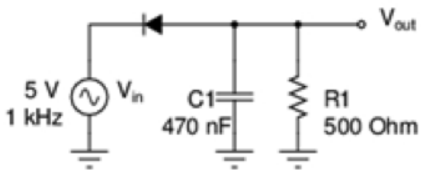
The peak voltage across the capacitor will be 1.8 V as the diode will consume 0.7 V.

Measured Value



The measured peak-output voltage would be approximately 1.661 V. There is a slight difference between the theoretical value and the measured value as the voltage drop across the diode will not be exactly 0.7 V (drop in voltage will not be ideal). This could also be due to the systematic error by humans during the extraction of value from the graph or errors arising from Scopy itself.

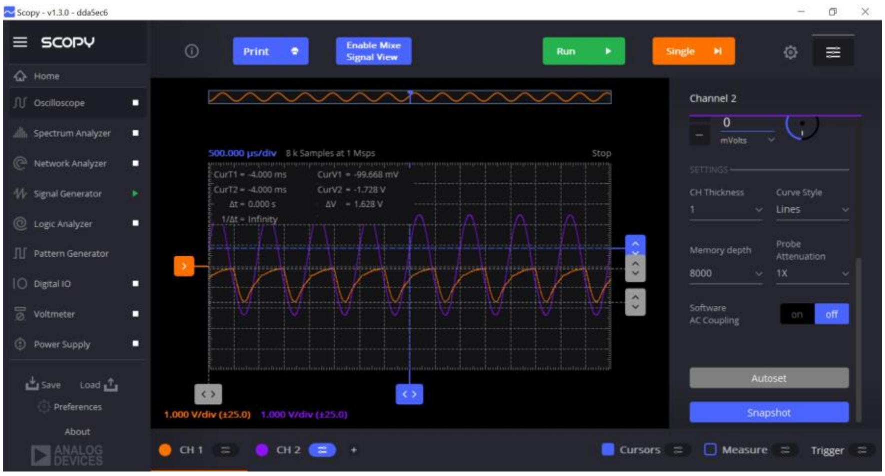
Circuit 9 (Assuming 5V p-p)



Theoretical Value

For the circuit above, the output will be an inverted smoothed half wave rectifier with a negative peak voltage of -2.5 V. As we can see from the circuit above, the diode will be reverse bias. When the input voltage rises, the diode will block the current. The output will charge in the opposing direction towards 0V. As the input voltage drops, the diode will be forward bias, the capacitor will discharge to --1.8V. As the frequency of the voltage source is low, there will be a large ripple voltage as the capacitor can charge for a longer time.

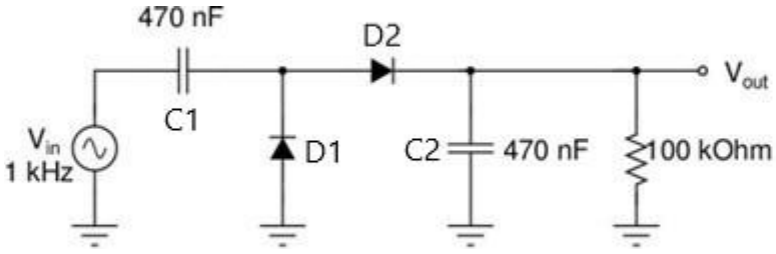
Measured Value



The measured peak-output voltage would be approximately -1.728 V. There is a slight difference between the theoretical value and the measured value as the voltage drop across the diode will not be exactly 0.7 V (drop in voltage will not be ideal). This could also be due to the systematic error by humans during the extraction of value from the graph or errors arising from Scopy itself.

10.4.3 PART C – DIODES IN VOLTAGE MULTIPLIERS

Construct the following circuit:



10.4.3.1 Analyze and measure this circuit. How is it a voltage multiplier, and what is the output voltage V_{out} in terms of V_{in}?

Theoretical Value

When the input voltage is in the negative half cycle, the diode D_1 is in forward bias and the diode D_2 is in reverse bias. The diode D_1 would allow current to flow to the capacitor and charge it. When the input voltage is in the positive half cycle, the diode D_1 is in reverse bias and the diode D_2 is in forward bias. The D_1 diode will block the current flow and the D_2 diode will allow the current to flow to the load resistor.

Now we can analyze the circuit in terms of equations. In the first half of the negative cycle, diode D_1 will turn on (cathode has negative voltage), causing the left capacitor to have a peak voltage drop of $|V_{in}| - V_{diode}$. For the remaining half of this negative cycle, the capacitor voltage will be constant as the increase in input voltage will turn off diode D_1, giving no discharge path. We can look at the time constant for the leftmost capacitor will be 0.047s (found using the equation **τ = RC**). Thus, we can assume that the leftmost capacitor voltage is fixed at $|V_{in}| - V_{diode}$ throughout the period. At peak,

$$V_{out} = |V_{in}| - V_{diode} + V_c$$

$$V_{out} = |V_{in}| - V_{diode} + |V_{in}| - V_{diode}$$

$$V_{out} = 2V_{in} - 2V_D$$

Thus, we can see that the circuit act as a voltage multiplier.

Now let us analyze the circuit mathematically. The capacitor C_1 would charge up to 4.3 V and there would be another voltage drop of 0.7 V due to the D_2 diode, causing V_{out} to be 3.6V. The capacitor C_2 would also charge up until 3.6 V. The voltage across the resistor will also be 3.6 V. In the next cycle (negative cycle), the capacitor C_2 discharges and drives the current to the R_1 resistor in order to smoothen the half-wave. This would convert the AC input voltage to a DC voltage.

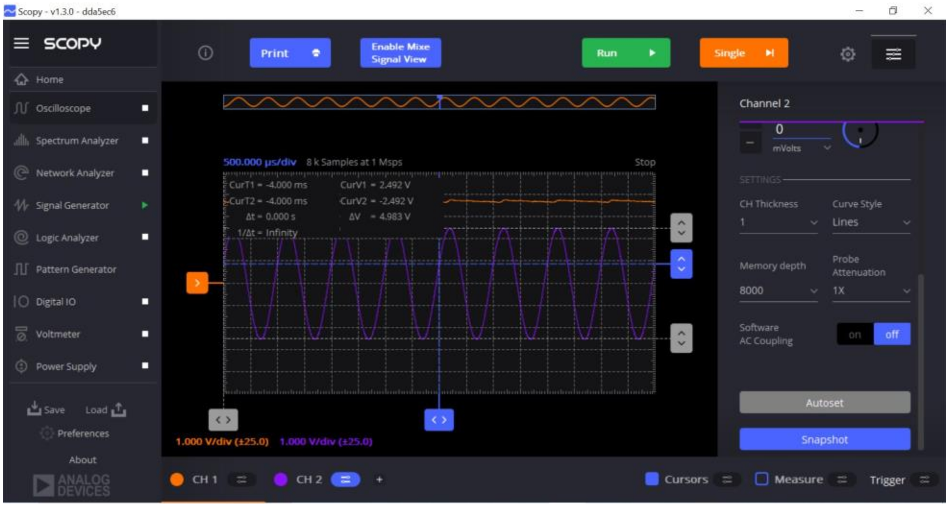
Now, using a 5 (p-p) V in our signal generator, we should get the theoretical output voltage to be

$$V_{out} = 2V_{in} - 2V_D$$

which equates to

$$V_{out} = 2*(2.5) - 2*0.7 = 3.6 \text{ V}$$

Measured Value

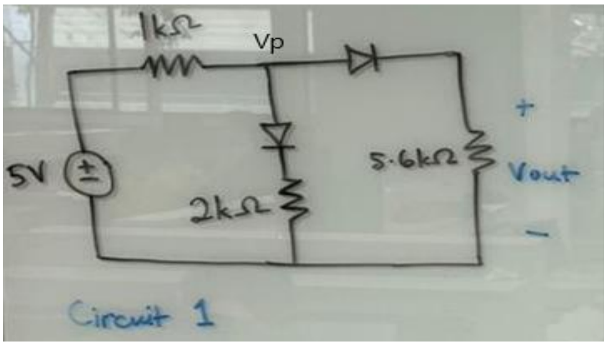


As we can see from the graph above, the measured output voltage would be approximately 3.68 V. There is a slight difference between the theoretical and the measured value as the voltage drop across the diode is unlikely to be ideal (0.7 V) which would explain why the measured magnitude of output voltage has a higher value. This could also be due to the systematic error by humans during the extraction of value from the graph or errors arising from Scopy itself.

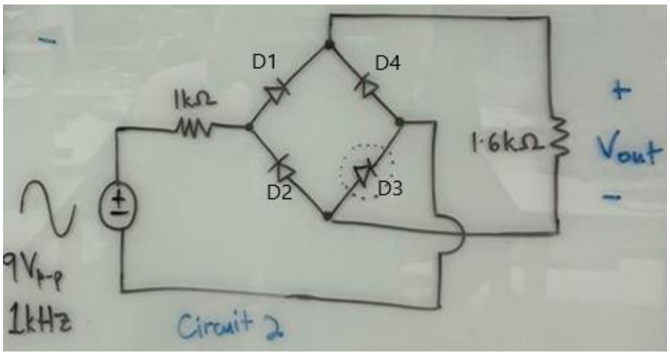
LAB ASSESSMENT

Given Circuit

Circuit 1



Circuit 2



Theoretical Value

Circuit 1

Using KCL (Kirchhoff's Current Law), we can find the value of the voltage at the middle point.

$$\frac{V_p - 5}{1000} + \frac{V_p - 0.7}{2000} + \frac{V_p - 0.7}{5600} = 0$$

We will be able to obtain a more simplified equation

$$5.6\,V_p - 28 + 2.8\,V_p - 1.96 + \; V_p - 0.7 = 0$$

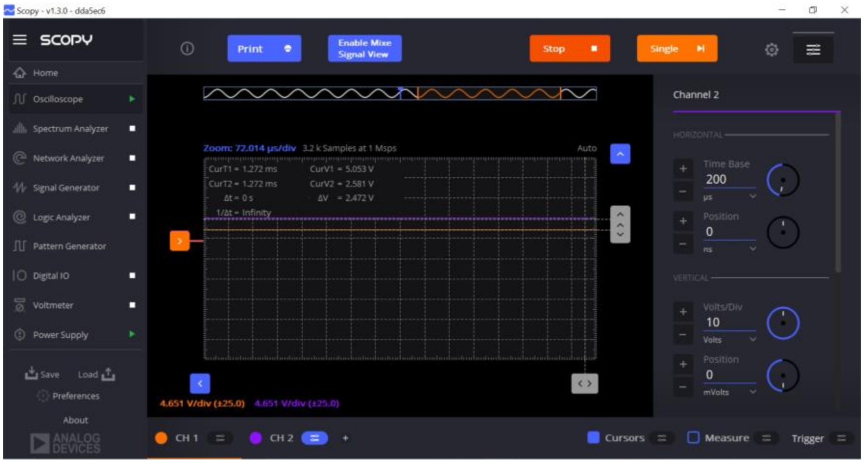
$$9.4\,V_p = 30.66$$

$$V_p = 3.262\,V$$

Once we have found the voltage at point P, we can take the value and subtract by 0.7V. Thus, the value of V_{out} will be 2.562 V.

$$V_{out} = \; V_p - 0.7 = 2.562\text{ V}$$

Measured Value



As we can see from the graph above, the value of V_{out} will be 2.581 V. This measured value is quite close to the theoretical value. This could be due to the systematic error made by humans during the extraction of value from the graph or errors arising from Scopy itself. This could also be due to the fact that the actual voltage drop across the diode is not ideal which would explain the reason the measured value is larger than the theoretical value. The resistor may also not be ideal causing the differences in value.

Circuit 2

Theoretical Value

During the positive cycle when 0 < V_{in} < 1.4 V, diodes 1 and 3 will not have sufficient voltage to turn on. Diodes 2 and 4 will be reversed-biased. Thus, we can say that V_{out} = 0 V.

During the positive cycle when V_{in} > 1.4 V, diodes 1 and 3 will be turned on and diodes 2 and 4 will still be reversed-biased. From here, we can take KVL along the path of the diodes that are forward-biased.

We will obtain the following equation

$$V_{in} - i * 1000 - 0.7 - i * 1600 - 0.7 = 0$$

$$i = \frac{v_{in} - 1.4}{2600} A$$

$$V_{out} = i * 1600$$

Given that the value of V_{in} is 4.5 V, we can find the value of V_{out} which would equate to

$$V_{out} = 1.908 V$$

During the negative cycle when -1.4 V < V_{in} < 0 V, diodes 2 and 4 will not have sufficient voltage to turn on while diode 1 and 3 will be reversed biased. Thus, we can conclude that V_{out} will be 0 V.

During the negative cycle when V_{in} < -1.4 V, diodes 2 and 4 will be forward bias and turn on while diodes 1 and 3 will be reverse-biased. From here, we can take KVL along the path of the diodes that are forward-biased.

$$V_{in} - i * 1000 - 0.7 - i * 1600 + 0.7 = 0$$

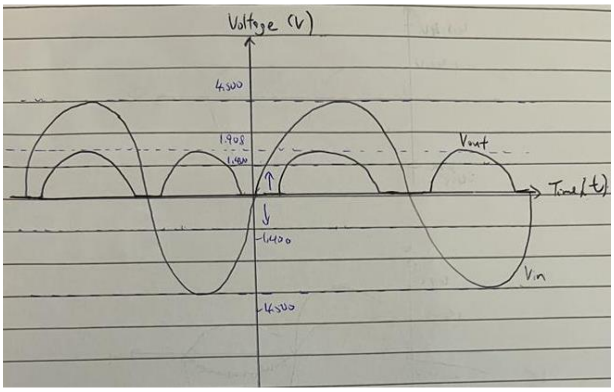
$$i = \frac{v_{in} + 1.4}{2600}\ A$$

$$V_{out} = -i * 1600$$

Given that the value of V_{in} is 4.5 V, we can find the value of V_{out} which would equate to

$$V_{out} = 1.908\ V$$

Graph



The sketch is the predicted output voltage and the input voltage

Measured Value

As we can see from the graph above, the value of V_{out} will be 1.993 V. This measured value is quite close to the theoretical value. This could be due to the systematic error made by humans during the extraction of value from the graph or errors arising from Scopy itself. This could also be due to the fact that the actual voltage drop across the diode is not ideal which would explain the reason the measured value is larger than the theoretical value. The resistor may also not be ideal causing the differences in value. The shape of the waveform of the graph is also quite similar to the theoretical graph that we have drawn above.

ASSESSMENT

Student Statement:

I have read the university's statement on cheating and plagiarism, as described in the *Student Resource Guide*. This work is original and has not previously been submitted as part of another unit/subject/course. I have taken proper care safeguarding this work and made all reasonable effort to make sure it could not be copied. I understand the consequences for engaging in plagiarism as described in *Statue 4.1 Part III – Academic Misconduct*. **I certify that I have not plagiarized the work of others or engaged in collusion when preparing this submission.**

Student signature:________Tan Jin Chun______Date: 19/5/2022

TOTAL: ________(/7)

ASSESSOR: ________