

Course Name: HNC Electrical and Electronic
Engineering Year 2

Module Code: PCEE4006

Assignment Title: Diodes and Amplifiers

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Task 1 – Diodes

(i) Identify different types of diode and their uses.

A diode is an electronics component with its most common function being to only allow an electric current to pass in one direction, while blocking it in the opposite direction. A diode is primarily made from a combination of a P-type and N-type semiconductor material, known as a p-n junction. The n-type semiconductor end of the diode is called the cathode and the p-type end of the diode is called the anode. When voltage is applied to the diode through the positive side (anode) the diode becomes a conductor, allowing current to flow, this is called forward bias. If the voltage is applied through the reverse direction and is connected to the cathode, current does not flow and the diode becomes an insulator, this is called reverse bias. (Lowe, 2020)

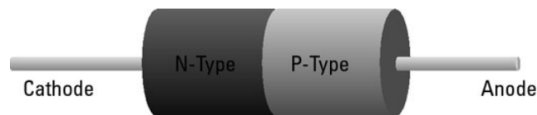


Figure A – A basic diode configuration

A light-emitting diode (LED) are made of two-lead semiconductor light source. It is a P-N junction diode, which emits light when activated. Light is produced when the particles that carry the current combine together within the P-N junction. Within the semiconductor material of the LED, the electrons and holes are contained within energy bands. The separation between these bands determines the energy of the photons that are emitted by the LED. Like a regular diode, when an LED is provided with a reverse bias state it will become dysfunctional. Once the reverse breakdown region has been passed, the LED will become damaged. (Magazine, 2004).

A photodiode is a semiconductor device with a P-N junction that converts light into electrical current. The P layer has an abundance of holes (positive), and the N layer has an abundance of electrons (negative). The difference between a photodiode and other diodes is that when a light is provided to the diode, it results in electron holes within the molecular build up. Depending on the light provided and its intensity, the covalent bonds within the P-N junction material will break, resulting in the conductivity of the photodiode to increase. (Wavelength, 2018)

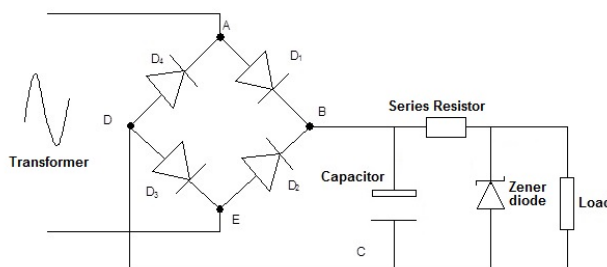
A Zener is not like a normal diode. A normal diode lets current flow in only one direction and needs to be installed in the correct direction. A Zener diode is placed in the opposite direction, against the flow of current. A Zener diode will prevent current from flowing until it reaches a certain voltage, depending on the diode rating. Once this critical value is reached, current is allowed to flow. A Zener diode is able to function within a reverse bias state. This means that a Zener diode is an ideal component to use for voltage regulation. (CircuitBread, 2019)

Commented [RB1]: Good intro

Commented [RB2]: Full stop comes after quoting reference.

Commented [RB3]: Nice explanation of working of three diodes, however pictures of each could've helped.

- (i) Develop the circuit schematic of a full-wave rectifier with capacitor smoothing and Zener diode voltage regulation.



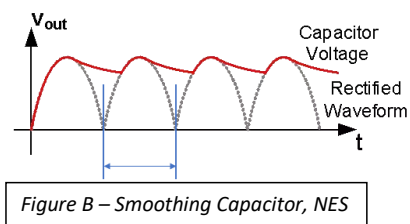
The purpose of this circuit is to convert mains AC to DC voltage. The transformer labelled in the diagram above is called a Stepdown transformer. The purpose of this is to lower the voltage being supplied to the circuit and make it a usable voltage for the Zener diode within the circuit.

The next aspect of the circuit is the bridge rectifier, this consists of four diodes connected together in a specific layout that utilise the fact diodes can only conduct in one direction. The purpose is to convert the negative half of a sine wave input into a positive voltage, this is achieved through forcing the current to travel to the positive side of the diode on the negative and positive half cycle.

Commented [RB4]: Did you mean allowing the current flowing in the same direction in the load resistor?

A capacitor is used and this is regarded as a 'smoothing' capacitor. The purpose of this capacitor is to prevent the output from reaching 0V every half a cycle. The charging and discharging properties of a capacitor mean that when the voltage peaks, the capacitor charges up and as the voltage drops below the volts DC the capacitor discharges, and therefore decreases the voltage ripple occurring. As represented by the graph below.

Commented [RB5]: Good explanation.



A Zener diode is introduced to help reduce the signal ripple on the output. It also acts as a voltage regulator, providing a constant voltage along with additional protection for the circuit.

A BZX55C6V2 Zener diode had been chosen for this circuit. Some of the information required to carry out further calculations had to be found from the associated datasheet; (Rectron, 2006)

$$V_{in} = 9V$$

$$P = 0.5W$$

$$I_{zk} = 1mA$$

$$\text{Zener diode} = 6.8V$$

Commented [RB6]: Units should be Watts

$$I_{zmax} = \frac{P.d}{V_z} = \frac{0.5W}{6.8V} = 0.07 = 70mA$$

Calculating resistance values;

$$R_{min} = \frac{V - V_z}{I_{zm}} = \frac{9 - 6.8}{70mA} = 31.4\Omega$$

$$R_{max} = \frac{V - V_z}{I_{zk}} = \frac{9 - 6.8}{1mA} = 2.2k\Omega$$

A 100Ω resistor was chosen as the resistance had to be between the minimum resistor value and the maximum resistor value. I chose a lower value to avoid any possible heat dissipation.

$$I_R = \frac{V - V_z}{R} = \frac{9 - 6.8}{100} = 22mA$$

$$I_{Lmin} = I_R - I_{zm}$$

$$I_{Lmax} = I_R - I_{zk}$$

$$R_{Lmin} = \frac{V_z}{I_R - I_{zk}} = \frac{6.8}{21mA - 1mA} = 323\Omega$$

$$R_{Lmax} = \infty$$

R_{Lmax} has been rated at an infinite resistance is equal to a no-load condition

Commented [RB7]: Well done, all calculations are right and well presented, however a circuit diagram just showing all these variables could have helped.

(ii) Use Multisim to simulate and test the circuit.

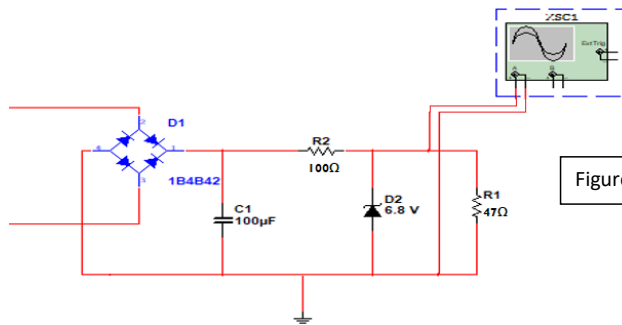
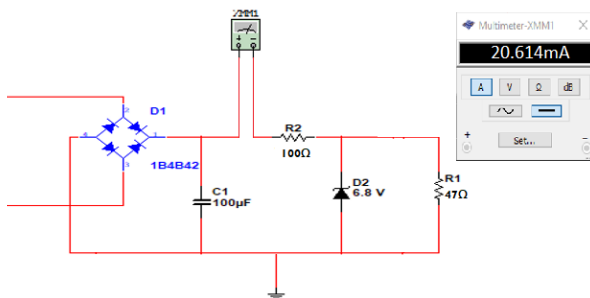


Figure C – Multisim screenshots

Due to unforeseen circumstances, I was unable to retrieve certain screenshots of evidence regarding this task. As shown in figure C, the oscilloscope was connected to the outputs of the circuit to measure the output voltage (V_{out}) produced by the circuit. The output voltage produced was 6.61V. The oscilloscope produced a flat output signal, verifying that the AC input provided to the circuit had been rectified to DC. The output produced was very similar to that shown in figure B.



The above Figure D shows evidence of the current through resistor (R).

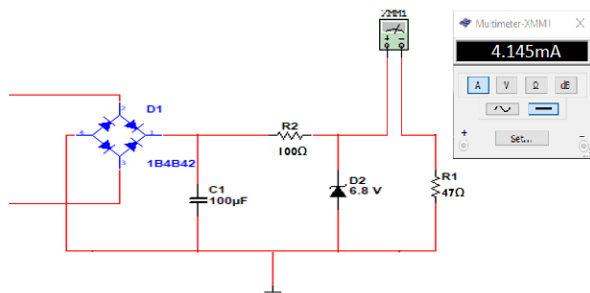


Figure E shows current through RL (I_L)

(IV) Build a prototype of your final circuit.

After simulating the circuit on Multi-sim, the circuit was then made up on a breadboard, replicating the exact circuit that has been shown with the same components and apparatus involved.

The measured values from the built circuit were;

- $I = 21.5\text{mA}$
- $I_L = 4.3\text{mA}$
- $V_i = 9\text{V}$
- $V_{\text{out}} = 6.78\text{V}$

The results produced from this circuit are slightly different to those simulated. The variant in results is minimal and this could be the result of tolerance issues within the built circuit and its components. Multi-sim possesses a perfect environment and this provides the most accurate results as the components used do not possess tolerances, they are exact. The resistors used within college possess a tolerance of $\pm 5\%$, on top of this, the equipment used to measure the circuit such as a multi-meter possesses tolerances that can slightly vary the results recorded. (Lewis, 2017) For the results produced to be so similar, proves that the circuit was a success and was indeed functioning correctly. The output shown on the oscilloscope was as expected, a clear voltage ripple occurred with the smoothing capacitor working as should. Due to unforeseen circumstances, screenshot evidence of the build could not be accessed and used within this report.

(v) Record the output voltage and estimate the voltage ripple for different loads.

The size of the voltage ripple occurring depended on the load resistor that was being used within the circuit. To prove this, I used a range of load resistance values and then measured the voltage ripple on the oscilloscope. The results were;

$47\Omega = 2.1\text{V}$
 $100\Omega = 1.7\text{V}$
 $270\Omega = 1.1\text{V}$
 $3\text{k}\Omega = 0.3\text{V}$

The results measure above show that the higher the load resistance values used, the lower the occurring voltage ripple was. When the resistance is lower, the current within the circuit is more able to be drawn from the capacitor and to the load resistor, resulting in the charging period of the capacitor to increase.

Commented [RB8]: Charging and discharging time depend upon the value of RC, so higher the value of R will increase the time and hence help to smooth out the ripples.

Task 2 – Transistor Amplifier Design and Performance Measurement

A transistor is a semiconductor component that is used to amplify or switch signals. A transistor possesses 3 terminal connections, the base, collector and emitter and they are defined by either

being NPN or PNP transistors. A common emitter configuration is when the signal source and the load share the emitter lead as a common connection point. (AllAboutCircuits, 2020)

Commented [RB9]: Could explain the working of transistor as an amplifier.

a) Designing a common emitter amplifier using a BC108

Below are the calculations made to decipher the required values to construct the circuit and the expected results when measuring the constructed circuit. The h_{fe} was determined through plugging the BC108 transistor into a digital multi-meter. The I_q was found through finding the datasheet online. (Multicomp, 2020)

$$h_{fe} = 308$$

$$V_{CC} = 10V$$

$$I_q = 1mA \text{ (IC)}$$

$$\bullet \quad RC = \frac{V_{CC}}{2I_{IC}} = RC = \frac{10}{2 \times (1 \times 10^{-3})} = \underline{5000\Omega}$$

$$\bullet \quad (RE = IE = IC) = VE = 10\% \text{ to } 15\% \text{ of } V_{CC} \\ = VE = 10\% \text{ OF } 10V = \underline{1V}$$

$$RE = \frac{VE}{IE} = \frac{1}{1 \times 10^{-3}} = \underline{1000\Omega}$$

$$\bullet \quad IB = \frac{IC}{h_{FE}} = IB = \frac{1mA}{308} = \underline{3.25 \times 10^{-6}}$$

$$\bullet \quad V_B = V_E + V_{BE} \quad V_B = 1 + 0.7 = \underline{1.7V}$$

$$IB \times 10 = 3.25 \times 10^{-6} \times 10 = \underline{3.25 \times 10^{-5}}$$

$$\bullet \quad R2 = \frac{1.7}{3.25 \times 10^{-5}} = \underline{52,307\Omega}$$

$$\bullet \quad R1 = \frac{V_{CC} - V_B}{11 \times IB} = \frac{10 - 1.7}{11 \times 3.25 \times 10^{-6}} = \underline{232,167\Omega}$$

b) Constructing the Designed Circuit

When finding relevant components that were required to construct the circuit, some of the calculated resistor values had to be compromised to suit what was available within the department. The circuit designed also included three capacitors; two coupling and a decoupling capacitor. Here are the nearest available that were chosen;

$$R1 = 220K \text{ (232K)}$$

$$R2 = 47K \text{ (52K)}$$

$$RC = 4.7K \text{ (5K)}$$

$$RE = 1K \text{ (1K)}$$

$$C1 = 22\mu F$$

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C2 = 10 μ F
C3 = 10 μ F

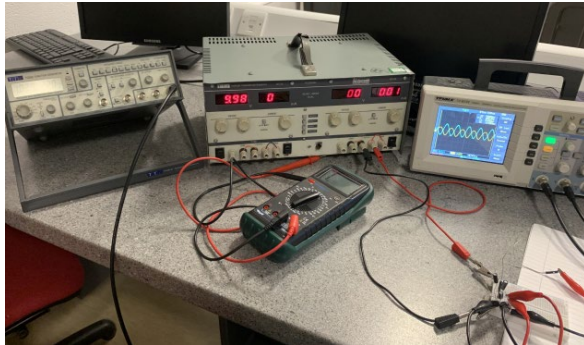


Figure F – Setup

Here is the setup used to produce, test and measure the bridge rectifier circuit. The equipment consisted of a signal generator, power supply, oscilloscope, multi-meter, breadboard and all necessary components involved within the circuit.



Figure G – Oscilloscope

Here is a screenshot provided from the oscilloscope. Two channels were setup on the oscilloscope, one channel measuring the input and the other measuring the output of the circuit to produce a visual impression of the successful amplification occurring. The wave form is showing an inverting wave signal being produced. The phase difference of this sine wave is 180°.

Below are the results that were achieved from the built circuit under DC conditions.

DC Conditions	Results from Built Circuit
VC	4.79V

VB	1.53V
VE	0.9V
VBE	0.6V
IC	1.01mA

Below are the results that were achieved from the built circuit. The amplitude Voltage according to the oscilloscope was 3.09V. To calculate the gain and bandwidth, the frequency applied through the function generator to the circuit was increased and decreased, with the results provided being sequentially recorded to achieve a frequency response.

Frequency(Hz)	Vin(mV)	Vout(V)	Gain(db)	Bandwidth
107	22	1.03	46.81	33.41
145	22	1.58	71.81	37.12
228	22	1.98	90	39.08
393	22	2.53	115	41.21
1k	22	3.09	140.45	42.95
38.27k	22	3.09	140.45	42.95
164.3k	22	2.46	111.81	40.96
205.5k	22	2	90.90	39.17
303k	22	1.5	68.67	36.76
583k	22	1.04	47.27	33.49

Commented [RB10]: Misunderstood, Bandwidth represent the range of frequency not the gain.

c) Constructing the circuit on Multisim

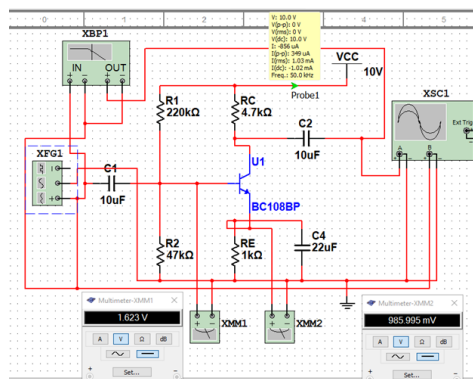


Figure H – Multi-sim screenshot

To try and replicate the circuit constructed on breadboard, the exact same component values were used to make the comparison between both circuits comparable. In the screenshot above, the function generator (XFG1), oscilloscope (XSC1) and a bode plotter (XBP1) have been connected to the circuit. The function generator has been connected to ground and the inputs of the circuit and the bode plotter. The oscilloscope has both the outputs of the circuit going into channel A and channel B.

Below is a table showing the results from my calculations, the measured results from the breadboard construction and the simulated results from Multisim.

	Calculated	Measured	Simulated
VB	1.7V	1.53V	1.62V
VC	5V	4.79V	5V
VE	1V	0.9V	0.98V
IC	1mA	1.01mA	1.02mA

The results provided from the three situations are very similar. I expected to see both the calculated and simulated results to possess less variation due to them both being under the same conditions with no tolerance issues. The greatest differences in measurements are within the 'measured' column, and this was to be expected due to the liability of tolerance issues with both the equipment and components used. (Lewis, 2017) The majority of components such as resistors will have a $\pm 5\%$ tolerance, and on top of this, equipment such as a digital multi-meter will also possess intolerances and this may slightly effect the results recorded (Lygte, 2018)

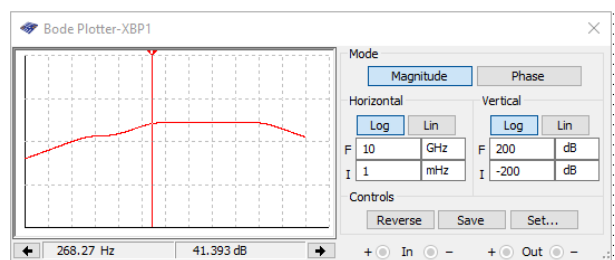
Commented [RB11]: Good explanation to defend the variation in the results.

The bandwidth produced from the Bode plotter can be calculated through subtracting the upper frequency from the lower frequency.

The Lower cut off frequency = 268.27Hz

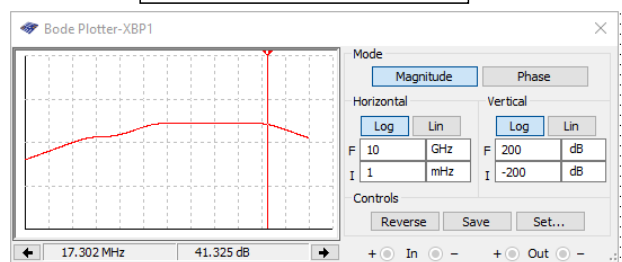
The higher cut off frequency = 17.302MHz

$17.302 \times 10^6 - 268.27 \times 10^3$



Lower Cut-off frequency

Figure I – Bode Plotter findings



Higher Cut off frequency

Commented [RB12]: How did you mark upper and lower cut off frequency on the graph?

Task 3 – Inverting Amplifier

An operational amplifier (Op-amp) is a voltage amplifying device that has been designed to be used alongside other external feedback components such as capacitors and resistors between the output and input terminals of the op-amp. Refer to the basic diagram below of an op-amp. An op-amp is a high-gain electronic voltage amplifier, consisting of a differential input and a single output. An op-amp possesses the ability to carry out mathematical operations such as addition, differentiation and subtraction. (Minj, 2020)

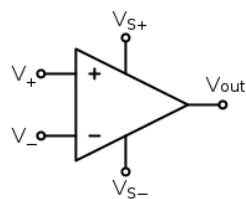


Figure K – Op-amp diagram, Moodle

An op-amp possesses many different applications and so there are multiple different types and configurations of op-amps available. A common configuration would be an inverting op-amp, this is where the inverting input receives feedback from the single output of the amplifier. An input signal is applied to the negative input and the positive is grounded.

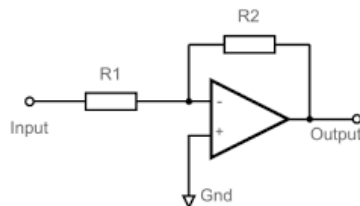


Figure L – Inverting op-amp diagram, Electronics Notes

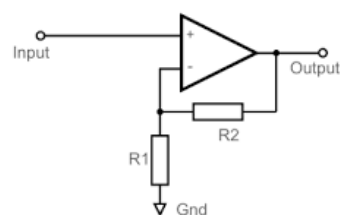


Figure M – Non-inverting op-amp diagram, Electronics

When in a non-inverting op-amp configuration, the input is applied to the positive input and the negative input is grounded, this being the opposite configuration to the inverting op amp shown previously.

These configurations must be used within a closed loop configuration with the use of negative feedback. The negative feedback takes a small amount of the output produced and feeds it back to the input, reducing the total gain and therefore increasing the bandwidth. Negative feedback helps to improve frequency response, linearity, gain stability and step response. The gain of an inverting amplifier will be negative due to the voltage being inverted, however the non-inverting amplifier gain will be positive. To calculate the gain for both the inverting and non-inverting amplifiers the following equations must be used;

$$\text{Inverting amplifier gain} = V_{\text{out}}/V_{\text{in}} = -\frac{R_F}{R_1}$$

$$\text{Non-inverting amplifier gain} = V_{\text{out}}/V_{\text{in}} = 1 + \frac{R_F}{R_1}$$

Commented [RB13]: All nicely explained.

DC Amplification

An op-amp can be used to amplify the DC signal. The amplification produced will depend on the resistors used as R1 and R2 and the gain created within the circuit. For the circuit shown below, the gain would be calculated through using the equation:

$$\text{Gain} = \frac{\text{Negative Resistor}(R_2)}{\text{Resistor}(R_1)} = \frac{10k\Omega}{1k\Omega} = 10dB$$

The output voltage of the circuit shown in figure can be calculated through using the equation;

$$V_{\text{out}} = V_{\text{in}} \times \text{Gain}$$

The output of this circuit will stay constant as the gain is limited by the supply voltage (15V). If 1.1V is supplied, the above Vout equation calculates a Vout of 11V. However if 1.9V is supplied to Vin, the circuit will regulate the voltage to 15V.

Commented [RB14]: Good analysis.

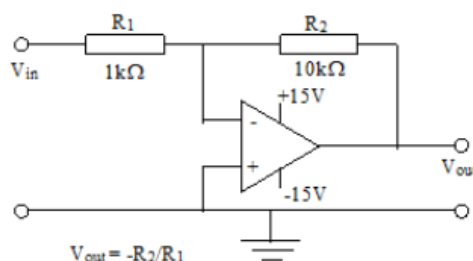


Figure N – Non-inverting op-amp

AC Amplification

With AC amplification applied, the gain produced will be the same as when DC amplification is occurring. Once the frequency has achieved the same value as both the closed loop and open loop gain, the frequency decreases eventually back down to 0dB. The graph below shows the bandwidth of the op-amp and that is defined as the frequency range over which the voltage gain of the amplifier is above -3dB of its maximum output value. (Hub, 2019)

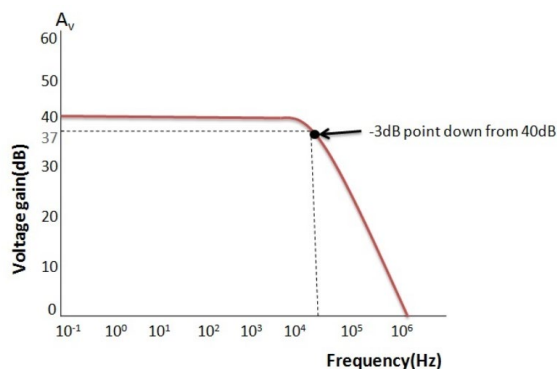


Figure O Operational Amplifier Bandwidth graph, Electronics

The phase angle is the direct relationship between both the input and output sine waves and it can be calculated through using the equation below;

$$\text{Phase angle} = 360 \times F \times \Delta t$$

The F = Input Frequency, Δt = the difference in time between the peak V_{in} and peak V_{out}

Effect of slew rate and input signal frequency on signal distortion and AC amplification

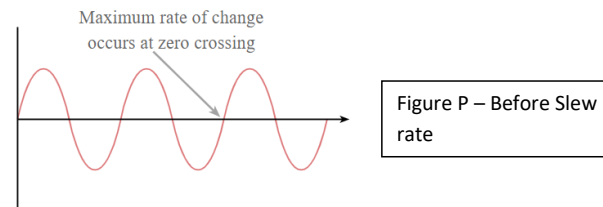
The slew rate of an op amp or any amplifier circuit is the rate of change in the output voltage caused by a step change on the input. Slew rate is measured in voltage change in a given time and this is shown as V/ μ s or V/ms, dependant on the standard of op-amp used. An op-amp may possess a slew rate of 10V/ms and this means that when a step change is placed on the input of the op-amp, it would provide an output of a 10V change in one microsecond. If an op-amp is operating above its defined slew rate limit, the signals associated may become distorted. (ElectronicNotes, 2018)

Commented [RB15]: Not clear

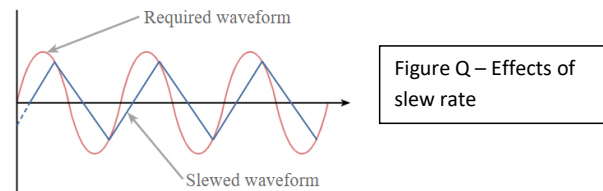
Commented [RB16]: Good definition.

Commented [RB17]: An essential point to be considered in AC amplification. However, you could consider gain bandwidth product as well.

Commented [RB18]: Good point



The maximum rate of change of sine wave occurs at the zero crossing point as shown in the above graph, and this is where slew rate issues are most likely to occur.



As shown by the diagram, when the limit is reached, the op-amp slewing distortion produces a triangular waveform. Increasing the frequency results in the op-amp being less unable, resulting in the amplitude of the output waveform to decrease. (ElectronicNotes, 2018)

The slew rate can be calculated through using the following equation;

$$\text{Slew rate} = 2 \pi f V$$

F= the highest signal frequency, V = the maximum peak voltage of the signal

Commented [RB19]: Here you could conclude this by saying that if the calculated slew rate goes above the internal slew rate, then distortion will be produced in the output signal.

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STUDENT FEEDBACK FORM

This section details the *extent* to which the assessment criteria are demonstrated by you, which in turn determines your mark. The marks available for each category of skill are shown. Lecturers will use the space provided to comment on the achievement of the task(s), including those areas in which you have performed well and areas that would benefit from development/improvement.

Generic Assessment Criteria	Marks available	Marks awarded
1. Engagement with Literature Skills	15	
You have used a wide range of the literature including books and relevant website to provide supporting evidence for your explanations throughout the assignment. Referencing conventions are consistent and right with few inaccuracies.	68% 15	10.2
2. Knowledge and Understanding Skills	30	
You have demonstrated the sound and detailed knowledge and understanding the of the basic underlying concepts of diodes and transistors and Op Amps. Your explanation of each section of the power supply unit, slew rate and bandwidth with pictures in place is worth appreciation. However, for transistor task, you could consider the biasing, DC load line, different operating regions of the transistor and function of different resistor and transistor and capacitors to explain its function as an amplifier in more detail.	68% of 30	20.4
3. Cognitive and Intellectual Skills	15	
You have exhibited sound cognitive and intellectual skills by verifying and simulated and measured results against the calculated values and providing the explanation for any variation in the measured and simulated results. All the calculations are accurate and well presented by stating the formulas at first place. However, you slightly misinterpreted the results of the ripple voltages and misrepresented bandwidth calculations. But overall, your work shows your ability to devise sound arguments using evidence and make appropriate and valid judgements.	68% of 15	10.2

4. Practical Application Skills	25	
While performing simulation and practical work in classroom, you have demonstrated your exceptional ability to use different approaches to find solutions for the encountered problems. I acknowledge that you could not provide the evidence for all simulated and practical activities due to unforeseen closure of the college.	80% 25	20
5. Transferable Skills for Life and Professional Practice	15	
Overall, your work is accurate, coherent, fluent well-structured and organised, except that few times, your sentences could be restructured. Your usage of equation editor and pictures when required to explain the concept deeply is worth appreciation. Your work clearly evident your ability to work effectively and independently or as a part of the group.	70% 15	10.5

Assessment Mark (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)	Late Submission Penalties (tick if appropriate)		71.3%
	Up to 1 week late (40% Max)		
	Over 1 week late (0%)		