

Diodes and Amplifiers – Oliver Kucyj

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Task 1 – Diodes and full wave rectifier

Diodes

There are many different types of diodes and all of them have different uses and advantages. They all consist of a P-type semi-conductor (Anode) and an N-type semi-conductor (cathode). When current is flowing from anode (positive) to cathode (negative) it is known as forward biasing. When the current is flowing from the cathode to anode it is known as reverse biasing. A diode will only conduct in forward bias, unless the breakdown voltage in reverse bias is reached (Spark notes).

Ideal Diode

An ideal diode shows how a diode would work if components didn't have limitations, however they cannot actually be manufactured to these standards. In forward bias, it acts as the perfect conductor and an infinite amount of current can pass through. In the reverse bias it will act as the perfect insulator and not conduct any current regardless of how high the voltage is, meaning it has no breakdown voltage.

In reality, every component will have an internal resistance, and no component can withstand an infinite amount of current. It also must have a minimum voltage of either 0.3V or 0.7V (depending on the material) to conduct as well as having a current limit. In reverse bias, there will be current leakage, meaning it will not act as the perfect insulator. There will also be a breakdown voltage (Learning about electronics).

Commented [RB1]: Good explanation.

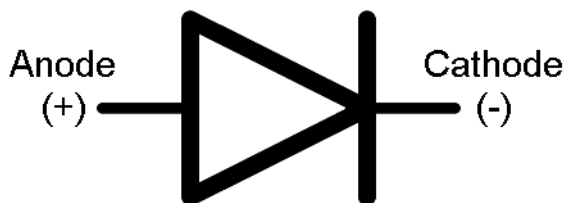


Figure 1 – Ideal diode symbol (Spark fun)

Light emitting Diode (LED)

An LED will convert electrical energy into light energy. They have many uses including lighting, indicators on circuitry, infrared lights and more. They are available in different colours which is determined by the semiconductor material. The different materials will emit photons of different wavelengths, which determines the colour emitted. To work, the LED must be connected in forward bias. The light intensity is directly proportional to the current flowing through it. LEDs are prone to burning out and usually have a current limit of roughly 30mA so they must be protected by a current limiting resistor. LEDs are very efficient sources of lighting as they emit very little heat (Electronic notes).

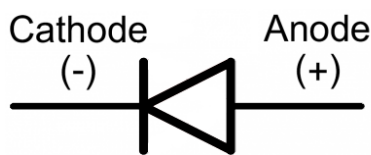


Figure 2 – LED symbol (Spark fun)

Zener Diode

This diode is used in many electrical circuits, such as power supplies for giving a regulated output, AC – DC converters or low current circuits which have voltage limits.

The Zener diode acts the same as an ideal diode, however they are designed with a very precise breakdown voltage which allows them to be used in the reverse bias to maintain a stable voltage. They are available with breakdown voltages anywhere from 2.4V to 200V. Once the breakdown voltage has been reached, the current increases dramatically and the diode begins to conduct as shown in figure 3. After this, the voltage will be maintained regardless of any voltage spikes or drops as long as the current remains between the minimum and maximum values (I_{ZK} and I_{ZM}). When the voltage increases/decreases the current decreases/increases to keep the voltage stable.

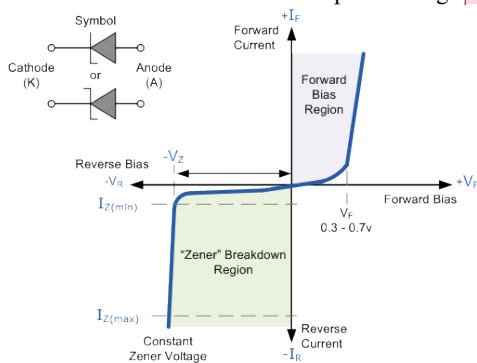


Figure 3 – Zener diode symbol & breakdown voltage graph (Electronics tutorials)

Commented [RB2]: Good explanation of all diodes.

Full wave rectifier

Commented [RB3]: could call it power supply unit

The purpose of this circuit is to convert an AC mains voltage into a DC voltage. The circuit can be broken into 4 different sections, each with their own purpose. These are the step-down transformer, full wave rectifier, the 'smoothing' capacitor and the Zener diode.

Stepdown transformer

This is used to step the mains voltage to a lower voltage suitable for use with the zener diode. The stepdown transformer will consist of 2 coil windings, the primary and the secondary. The input voltage goes to the primary winding and is then outputted from the secondary winding. The transformer will have a turns ratio, which determines how much the voltage is stepped down by. A turns ratio of 2:1 indicates the primary winding has twice as many coils as the secondary winding. This would mean the voltage is reduced by a ratio of 2:1. An input voltage of 240V in this case would be stepped down to 120V (Electronic design).

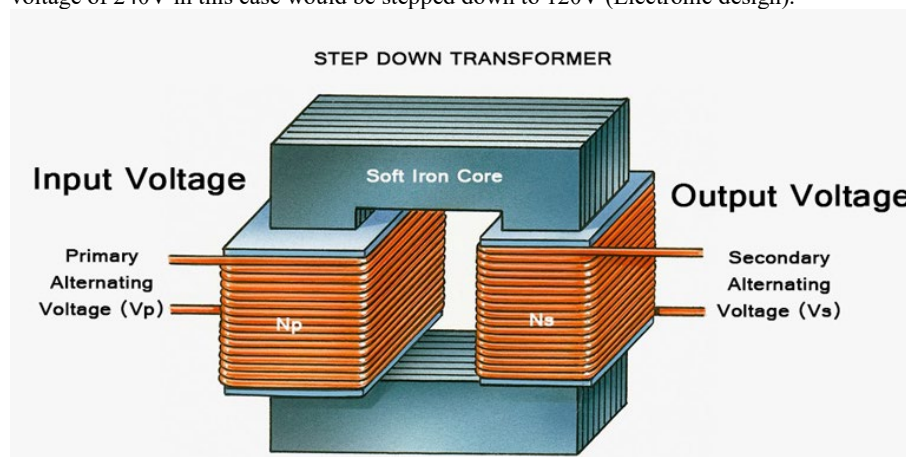


Figure 4 – Step down transformer (Electronic design, 2020)

Bridge rectifier

This circuit (shown in *figure 5*) consists of 4 diodes connected in something commonly referred to as ‘series pairs’. The purpose of this circuit is to convert the negative section of a sine wave input into a positive voltage, providing the output wave shown in *Figure 6*. It utilises the fact that diodes will only conduct in one direction and uses that to force the current to travel to +V on both the negative and positive half cycle (Schubert and Kim, 2015).

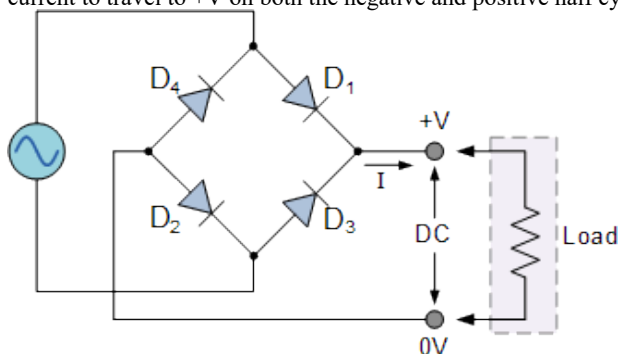


Figure 5 – Bridge rectifier circuit (Electronics tutorials)

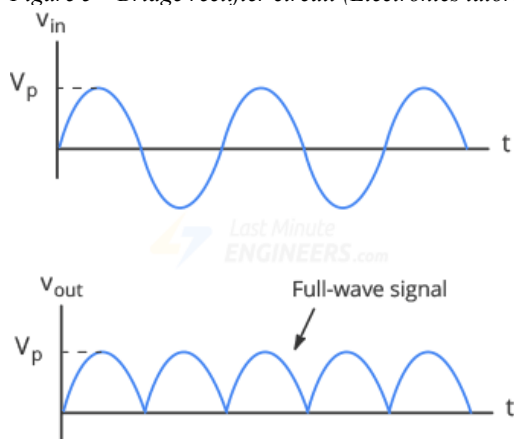


Figure 6 – input signal vs output signal (Last minute engineers)

Smoothing Capacitor

Connecting a ‘smoothing’ capacitor in parallel will prevent the output from dropping to 0 every half cycle. As the supply voltage peaks above V_{DC} , the capacitor is charged up. As the supply voltage drops beneath V_{DC} , the capacitor discharges to minimise the voltage ripple, providing the output shown in *Figure 7*.

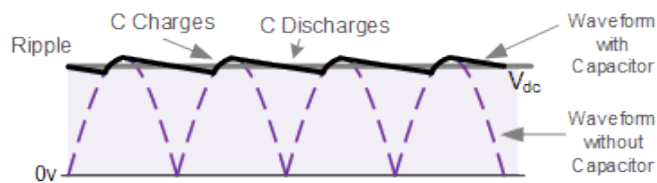


Figure 7 – Output wave with smoothing capacitor vs without (Electronics tutorials)

Zener Diode

The Zener diodes purpose is to reduce the output signal ripple, keep the voltage constant and give the output load more protection. When connected reverse biased in parallel, the Zener diode will maintain a constant voltage regardless of any variations in the input voltage or load resistance as long as the current remains between the minimum and maximum current (I_{ZK} and I_{ZM}). This is done by using a current limiting resistor in series with the Zener diode.

Commented [RB4]: good explanation of working of each section.

Calculations

This section shows the starting values for this circuit and how the other circuit values were calculated.

$$V_i = 10V$$

Zener diode - BZY88C8V2, $V_z = 8.2V$

$$P = 0.5W$$

$$I_{ZK} = 1mA$$

Calculating the current limiting resistor value

$$I_{ZM} = \frac{P}{V_z}$$
$$I_{ZM} = \frac{0.5}{8.2} = 60.98mA$$

$$R_{min} = \frac{V_i - V_z}{I_{ZM}}$$
$$R_{min} = \frac{10 - 8.2}{60.98 \times 10^{-3}} = 29.52\Omega$$

$$R_{max} = \frac{V_i - V_z}{I_{ZK}}$$
$$R_{max} = \frac{10 - 8.2}{1 \times 10^{-3}} = 1.8k\Omega$$

The series resistor value can be anywhere between R_{min} and R_{max} however it should be closer to R_{min} to prevent unnecessary power loss. This circuit will use a series resistor value of 100Ω

The maximum load resistance does not need to be calculated and is equal to infinite. An infinite load resistance would simply be equal to a no-load condition.

Commented [RB5]: good point

Calculating minimum load resistance

$$IR = \frac{V_i - V_z}{R}$$
$$IR = \frac{10 - 8.2}{100} = 18mA$$

$$IR = I_z + IL, \text{ So}$$
$$IL = IR - I_z$$

$$IL_{max} = IR - I_{ZK} - \text{This is the condition where RL draws enough current to drop } I_z \text{ to } I_{ZK}.$$
$$IL_{max} = 18 \times 10^{-3} - 1 \times 10^{-3} = 17mA$$

$$RL_{min} = \frac{V_z}{IL_{max}} = \frac{8.2}{17 \times 10^{-3}} = 482.25\Omega$$

Commented [RB6]: All calculations are correct and well represented.

Multisim circuit

Once these values were calculated the circuit was simulated on multisim (Figure 8). Figure 10 shows a flat 8.2V output signal, proving that the AC input has been converted to DC.

Please note more screenshots were unable to be provided due to the closure of the college.

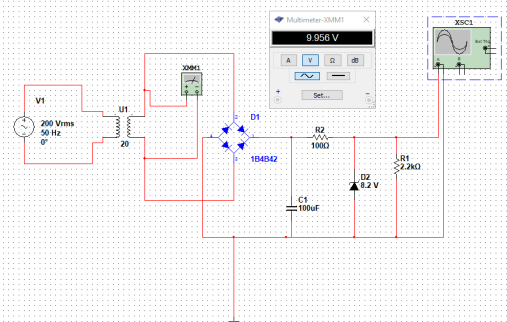


Figure 8 – Multisim circuit with V_i value

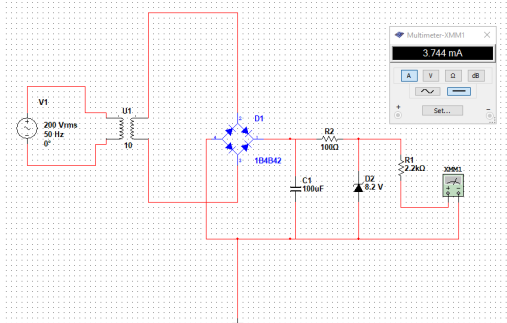


Figure 9 – Multisim circuit with I_L value with $2.2k\Omega$ load

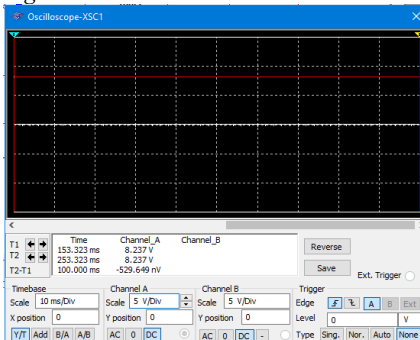


Figure 10 – Multisim circuit DC output

Measured values

This circuit was then created on breadboard. Using a load resistance of $2.2\text{k}\Omega$ the values below were measured.

$$I_R = 17.53\text{mA}$$

$$I_L = 3.83\text{mA}$$

$$V_i = 10\text{V}$$

$$V_{\text{out}} = 8.2\text{V}$$

There are some variations from the multisim and calculated values however they are minimal. The reasons for these slight variations are issues with rounding numbers to 2DP and tolerance in components. The resistors in college have a tolerance of $\pm 5\%$, so a 100Ω resistor could be anywhere between 95Ω and 105Ω which would have an effect on the results

Commented [RB7]: Good point to defend the measured values

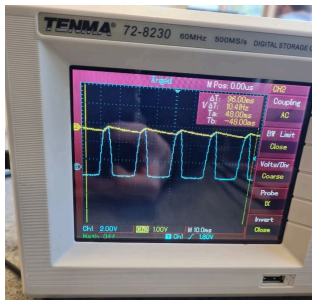


Figure 11 – input and output waveforms.

The size of the voltage ripple will vary depending on the load resistance. This was proven by changing the load resistance and measuring the change in voltage ripple, which resulted in the below values;

$$R_L = 550\ \Omega, \text{ voltage ripple} = 1.6\text{V}$$

$$R_L = 2.2\text{k}\ \Omega, \text{ voltage ripple} = 1\text{V}$$

$$R_L = 2.7\text{k}\ \Omega, \text{ voltage ripple} = 0.8\text{V}$$

These results show that with higher the load resistances the voltage ripple was lower. This shows that the circuit will perform better with a higher load resistance. This is because when the resistance is lower, more current is drawn away from the capacitor and to R_L instead, so the charge time of the capacitor is increased.

Commented [RB8]: ?

Task 2 – Transistors and common emitter amplifier

A transistor is a device with 3 terminals (Emitter, Base and collector) which can be used as an amplifier or a switch. There are 2 types of transistors, NPN and PNP, where P represents P-type material and N represents N-type material. The NPN type transistor is used in the common emitter amplifier, as discussed below.

Common emitter amplifier

A common emitter amplifier (*Figure 12*) is a circuit which utilises a transistor to amplify a very small AC signal. To work correctly, specific values need to be calculated for R_1 , R_2 , R_L and R_E to give the correct voltage and current values. R_L and R_E are there to control the voltages of the collector and emitter legs, whilst R_1 and R_2 are there to control the base current. These resistor values will be different for every individual transistor, as the h_{FE} value can vary between all transistors even if they are the same part number. The h_{FE} is the gain of the transistor and in this application represents the ratio of the current I_B to I_C . The h_{FE} value of the transistor used in this instance 219.

A coupling capacitor (C_1) is used to block DC signals to ensure they are kept separate from the AC signals. C_2 is known as a bypass capacitor. The impedance between the emitter leg and ground will reduce the gain of the circuit, so adding in a bypass capacitor allows higher frequency signals to skip R_E and travel through C_2 instead. The impedance of a capacitor reduces with higher frequencies, so an input with a high frequency will allow for a larger gain. This circuit will also invert the output signal to become 180° out of phase with the input signal (Electronics [tutorials](#)).

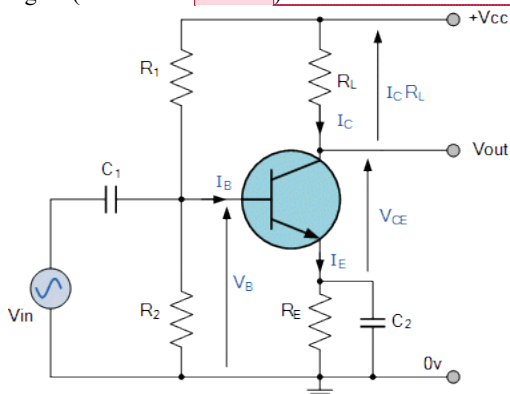


Figure 12 – Common emitter amplifier (*electronics tutorials*)

Commented [RB9]: Good description of all components been used. However, biasing and in what region we need to bias the transistor for its effective operation could be considered.

Calculations

This section shows the calculations used to calculate the values of R1, R2, RC and RE.

$$V_{CC} = 9V$$

$$hFE = 219 \text{ (measured from transistor being used)}$$

$$I_Q = I_C = 10\% \text{ to } 20\% \text{ of } I_{C_{max}} = 1mA$$

Calculating RC

$$R_C = \frac{V_{CC}}{2 \times I_Q} = \frac{9}{2 \times (1 \times 10^{-3})} = 4.5k\Omega$$

Calculating RE

$$V_E = V_{CC} \times 12\% = 9 \times 12\% = 1.08V$$

$I_E = I_C + I_B$, but I_B is a very small value, so as an estimation $I_E = I_C = 1mA$

$$R_E = \frac{V_E}{I_E} = \frac{1.08}{1 \times 10^{-3}} = 1.08k\Omega$$

Calculating R1 & R2

$$I_B = \frac{I_C}{hFE} = \frac{1 \times 10^{-3}}{219} = 0.00457mA$$

$$V_B = V_E + 0.7V = 1.08 + 0.7V = 1.78V$$

$$R_1 = \frac{V_{CC} - V_B}{11 \times I_B} = \frac{9 - 1.78}{11 \times (0.00457 \times 10^{-3})} = 143k\Omega$$

$$R_2 = \frac{V_B}{10 \times I_B} = \frac{1.78}{10 \times (0.00457 \times 10^{-3})} = 39k\Omega$$

It would be difficult to use a resistor exactly the same value as these, so the closest available resistors were used. These were;

$$R_C = 4.7k\Omega$$

$$R_E = 1k\Omega$$

$$R_1 = 150k\Omega$$

$$R_2 = 39k\Omega$$

Multisim circuit

Figure 13 the common emitter amplifier on multisim. Figure 14 shows the output and input signals from this circuit an oscilloscope. The output wave is 180° out of phase from the input wave and has been amplified from 19.99mV to 3.57V, showing that the circuit has worked.

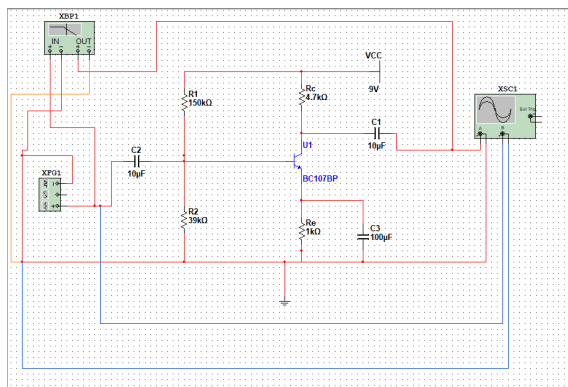


Figure 13 – Common emitter amplifier

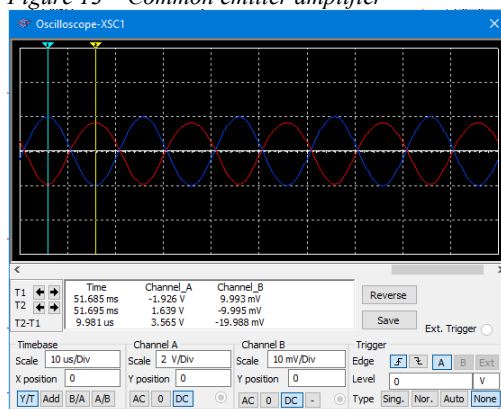


Figure 14 – input and output waveforms

Using a bode plotter the gain and bandwidth can be calculated. *Figures 15 & 16* show the gain compared to the frequency at the upper and lower cut-offs. The gain measured along the flat line is 45dB and represents the maximum gain of the circuit. As shown, the gain will be correct within a certain frequency range and when it drops beneath or above this the gain begins to drop off. **This is known as the bandwidth. It is found by subtracting 3 from the peak gain of the circuit and measuring the higher and lower frequencies in which the gain drops to this value and then using the equation below.**

Commented [RB10]: Bandwidth specifies the range of frequencies for which the gain is above the 70% of its maximum value.

Bandwidth = upper frequency – lower frequency
Lower frequency = 65.692Hz
Upper frequency = 13.455MHz

$$\text{Bandwidth} = 13.455 \times 10^6 - 65.692 \times 10^3 = 13.389\text{MHz}$$

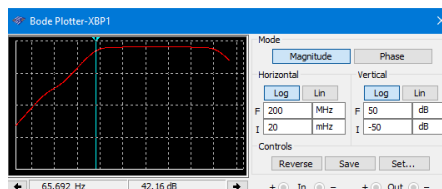


Figure 15 - Lower frequency cut-off

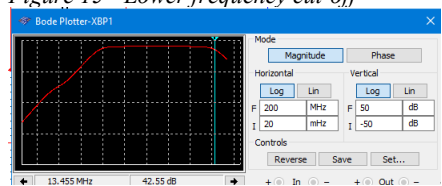


Figure 16 – Upper frequency cut-off

Measured values

This circuit was also created on breadboard, the output wave measured is shown in *figure 17*. The output voltage is 5.4V and the input voltage is 30mA, so the gain can be calculated using the equation below. This result is the same as was measured on multisim.

$$\text{Gain} = 20 \times \log\left(\frac{V_{out}}{V_{in}}\right) = 20 \times \log\left(\frac{5.4}{30 \times 10^{-3}}\right) = 45.1\text{dB}$$



Figure 17 – Input and output signals measured on the oscilloscope

Please note, the frequency response graph could not be completed due to lockdown restrictions.

DC conditions

Figure 18 compares the calculated, multisim and measured values.

DC condition	Calculated	Simulated	Measured
V_B	1.78V	1.73V	2.09V
V_E	1.08V	1.09V	1.04V
V_C	4.5V	3.88V	4.86V
V_{CE}	-	2.78V	3V
V_{CB}	-	2.14V	2.34V
V_{BE}	-	0.64V	0.64V
I_C	1mA	1.09mA	0.9mA
I_E	1mA	1.2mA	1.06mA
I_B	0.00457mA	0.004mA	0.0043mA

Figure 18 – DC conditions table

The values acquired from all 3 sources are very similar. There are variations, which as mentioned in task 1 is down to component tolerances and rounding issues. The calculated values I_B and I_E were estimates too, which could have a slight effect on other values.

Task 3 – Op-amps

Inverting and non-inverting configurations

An op-amp (operational amplifier) is a low-cost microchip which can be used for a range of different applications. As shown in *Figure 19*, it consists of 2 inputs, a single output and 2 ports for an external power supply. Internally, the op-amp is made up of capacitors, resistors and transistors. It is called an operational amplifier because of its ability to carry out mathematical operation, such as subtraction, addition, integration and differentiation.

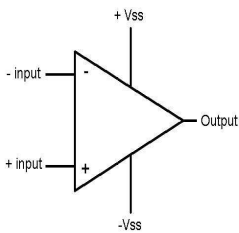


Figure 19 – op amp (Operational amplifiers, Moodle)

When used as an inverting amplifier (*Figure 20*) the op-amp will invert and amplify an AC signal. When used in this configuration, an input signal is applied to the negative input and the positive input is grounded. When used as a non-inverting amplifier (*Figure 21*), the input signal is applied to the positive input and the negative input is grounded (Electronics tutorials).

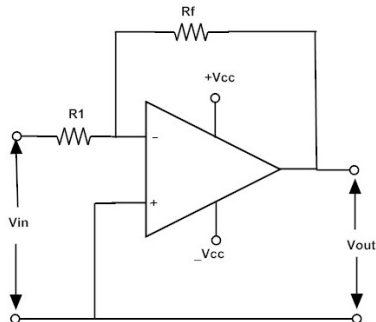


Figure 20 – Inverting amplifier (electronics hub)

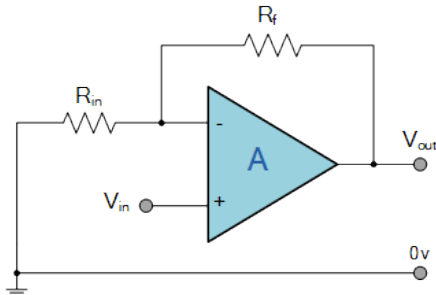


Figure 21 – Non-inverting amplifier (electronics tutorials)

These circuits must be used in the closed loop configuration with negative feedback. This is used rather than the open loop configuration because the gain becomes too high, causing high noise levels and distortion in the output. GBP (Gain Bandwidth Product) = gain x bandwidth, with GBP being constant, so the high gain means the bandwidth is low. A low bandwidth means the circuit will only work effectively over a short range of frequencies. The negative feedback takes a fraction of the output back to reduce the input. This will reduce the overall gain of the circuit, meaning the bandwidth is higher. It will also protect the output from any sudden variations in the input as an increase in the output will mean more negative feedback, improving the stability of the circuit (Electronics [hub](#)).

Negative feedback involves taking a very small voltage back to reduce the input. When used with negative feedback the gain is constant and can be determined based on the values of R_1 and R_F . With negative feedback all resistors must be over $1k\Omega$. The gain of the inverting amplifier will always be negative because it inverts the voltage, whilst the non-inverting amplifier gain will always be positive. The equations for calculating the gain is different for the inverting and non-inverting amplifiers and is shown below;

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

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

Commented [RB11]: Importance of negative feedback is explained.

DC amplification

The op-amp can be used for DC amplification. An example of this is shown below.

Where $R_1 = 1\text{k}\Omega$, $R_F = 10\text{k}\Omega$ and $V_{CC} = 15\text{V}$,

$$\text{Gain} = \frac{R_F}{R_1} = \frac{10}{1} = 10$$

Based on this, the inputs shown in *figure 22* would result in the corresponding outputs.

$V_{in} \text{ (V)}$	$V_{out} \text{ (V)}$
0.1	1
0.2	2
0.3	3
0.4	4
0.5	5
0.6	6
0.7	7
0.8	8
0.9	9
1	10
1.1	11
1.2	12
1.3	13
1.4	14
1.5	15
1.6	15
1.7	15
1.8	15
1.9	15
2	15

Figure 22 – Table showing DC inputs and outputs

The output is consistently 10 times larger than the input until it reaches 15V. The gain then becomes limited by V_{CC} and the output cannot exceed this value.

Commented [RB12]: Good point

AC amplification

The open loop gain in an op-amp reduces as the frequency increases, as shown by the orange line in *figure 23*. This proves that reducing the gain increases the bandwidth and shows how the ratio of gain to bandwidth can be found. Once the frequency reaches the value in which the open loop gain would be the same as the closed loop gain, the gain begins to drop off. The larger the gain, the sooner the blue line will reach the orange line causing the gain to decrease (*All about circuits*).

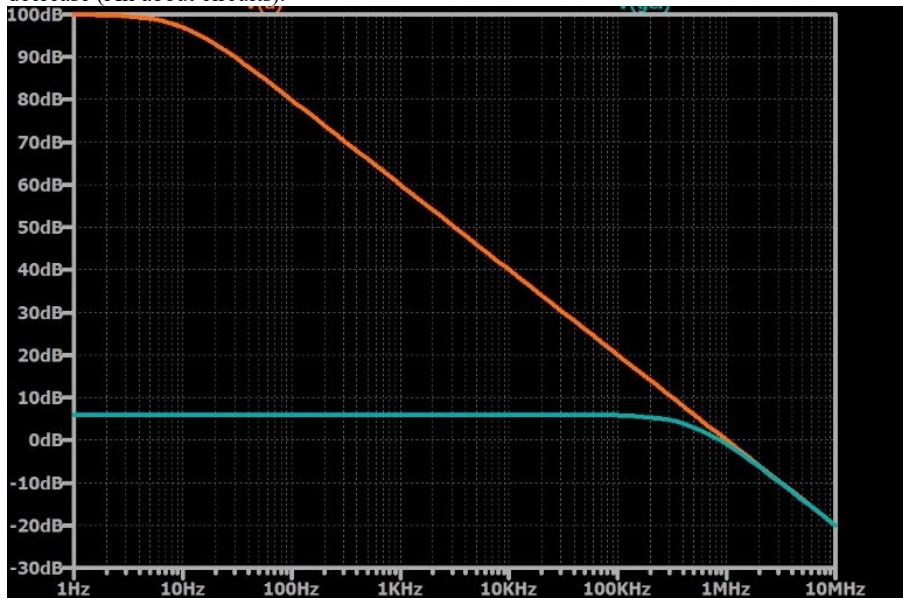


Figure 23 – Frequency response (*All about circuits*)

The phase angle is the relationship between the input and output sine waves. It is calculated using the formula below.

$$\text{Phase angle: } \varphi^\circ = 360 \times f \times \Delta t$$

In this equation, f is the input frequency and Δt is the time difference between the peak of V_{in} and the peak of V_{out} . In an ideal op-amp with a 1kHz input the equation below would apply;

$$\text{Phase angle: } \varphi^\circ = 360 \times 1000 \times 0.5 \times 10^{-3} = 180^\circ$$

Using this same circuit used for DC amplification with a gain of 10 and an AC input of 5V peak to peak, an output of 50V would be expected. However, this output is capped at 15V like with the DC input. The resultant output of this circuit would be something similar to that shown in *figure 24* and is commonly known as **clipping**.

Commented [RB13]: Good explanation

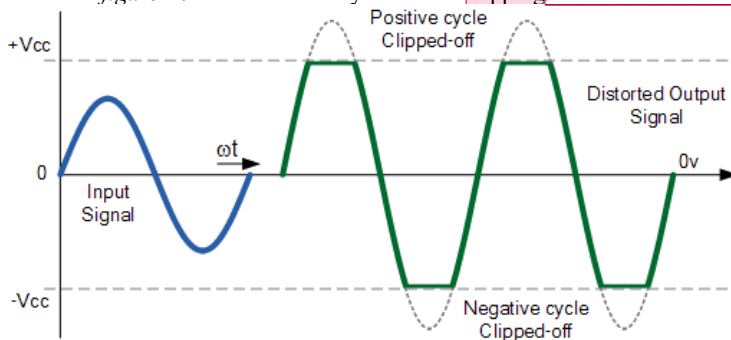


Figure 24 – AC output clipping (Electronic tutorials)

The output can be further distorted depending on the slew rate. The slew rate is the maximum rate which the output of the op-amp can vary. Each op amp will have a slew rate defined in the datasheet. For the 741 op-amp this is 0.5V/μs. The slew rate only becomes an issue if the calculated slew rate exceeds the internal slew rate. It can be calculated using the formula below;

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

The slew rate will increase with frequency and maximum output voltage. The examples below show this. In example 1, the frequency is 1kHz. In example 2, the frequency is 1 MHz.

$$\text{Example 1 slew rate} = 2 \pi \times 1000 \times 50 = 314159 \text{ V/s} = \mathbf{0.314V/\mu s}$$

$$\text{Example 2 slew rate} = 2 \pi \times 1000000 \times 50 = 314159265 \text{ V/s} = \mathbf{314.159 V/\mu s}$$

Example 1 would have no distortion from the slew rate, however example 2 has a calculated slew rate higher than the internal slew rate, so the output would become distorted and look like the output shown in *figure 25*.

Commented [RB14]: Well done, very good example to explain the effect of slew rate on the output.

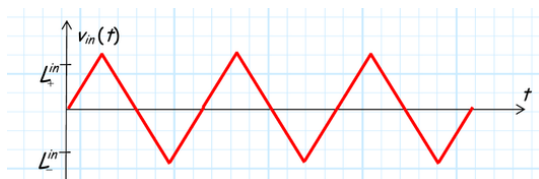


Figure 25 – distorted output from high calculated slew rate (Study Lib)

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Diodes and Amplifiers – Oliver Kucyj

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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 excellent and detailed knowledge and understanding of the basic underlying concepts of diodes and transistors and Op-amps. For each task, you have explained the concept in a comprehensive manner with illustrations in place. Especially, your explanation of the slew rate with example is commendable. However, for transistor task, you could consider the biasing, DC load line and different operating regions of the transistor to explain its function as an amplifier in more detail.	82% of 30	24.6
3. Cognitive and Intellectual Skills	15	
You have exhibited excellent 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. But overall, your work shows your ability to devise sound arguments using evidence and make appropriate and valid judgements.	74% of 15	11.1

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.	85% 25	21.25
5. Transferable Skills for Life and Professional Practice	15	
Overall, your work is accurate, coherent, fluent well-structured and organised, except at 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)		77.7%
	Up to 1 week late (40% Max)		
	Over 1 week late (0%)		