

PSDE 4004, Assignment 1

by Ethan Howells

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HNC ELECTRICAL & ELECTRONIC ENGINEERING

ETHAN HOWELLS

ELECTRICAL AND ELECTRONIC ENGINEERING

ANALOGUE CIRCUIT DESIGN

SUBMISSION DATE: 17/12/2017



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Introduction, Aims and Objectives

The aim of this assignment is to develop an understanding of the various types of Amplifiers and Oscillators, and compare and contrast their properties. It will also look at the different types of feedback and the application for each.

It will then aim to design a sine wave oscillator, which should operate at 150KHZ and produce a output of $1V_{rms}$.

Research into Amplifiers and Oscillators

Amplifiers are electronic devices that are used to convert a small input signal, into a larger output signal, (Tutorial, 2017). There are three classes of transistor amplifiers available, these are:

- Class A
- Class B
- Class C

Class A

This type of transistor amplifier is the most commonly used; as it allows the output signal to be an amplified replica of the input signal. This is because the transistor is perfectly biased within the active region, therefore allowing full swing and avoiding the cut off regions. There is also very little distortion in this amplifier. The disadvantage of using this amplifier, is that it has a low efficiency of around 20%. (Tutorial, 2017)

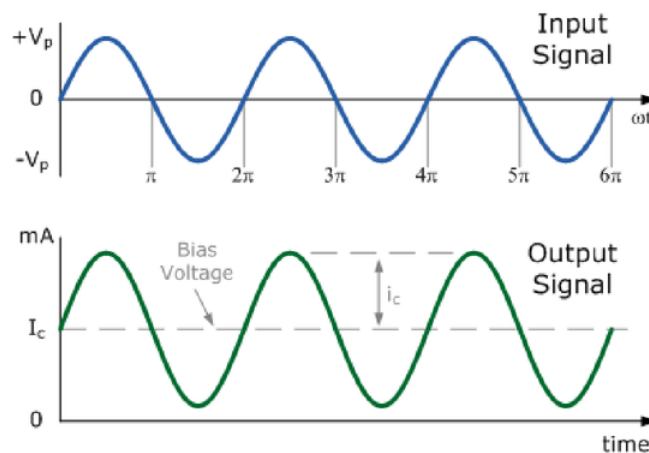


Figure 1 – Class A Amplifier (Tutorial, 2017)

Class B

This amplifier consists of two complimentary transistors. One transistor will conduct for one-half of the signal, and the other transistors will conduct for the opposite half of the signal waveform. Each Transistor will then spend half its time in the active region, and the other half in the cut-off region, which then means the input is only amplified by 50% (Tutorial, 2017). This is because when the transistors are switched off for half cycle, they dissipate less power therefore improving the efficiency of the amplifier. The efficiency of a Class B amplifier is around 78.5% (Today, 2014)

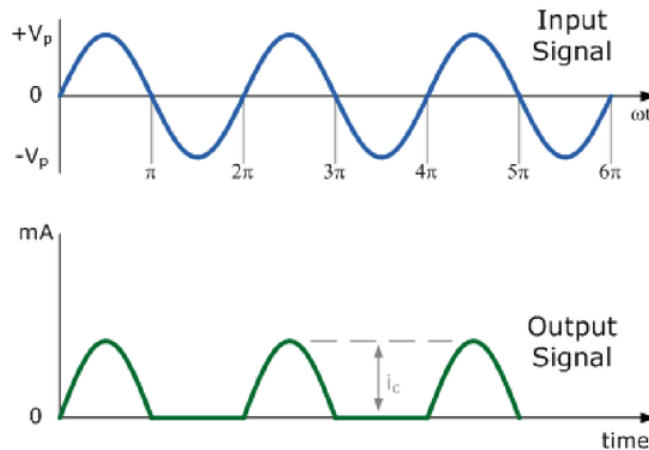


Figure 2 - Class B Amplifier (Tutorial, 2017)

Class AB

This amplifier is a mixture of the Class A and Class B amplifier, this is also the most used amplifier. The amplifier allows both transistors to conduct at the same time, allowing the waveforms to create a cross over point, which reduces distortion. The two transistors in a class AB have very small bias voltage, which is roughly about 5-10% of the quiescent current. This Amplifier also has an efficiency of around 50-60%. (Tutorial, 2017)

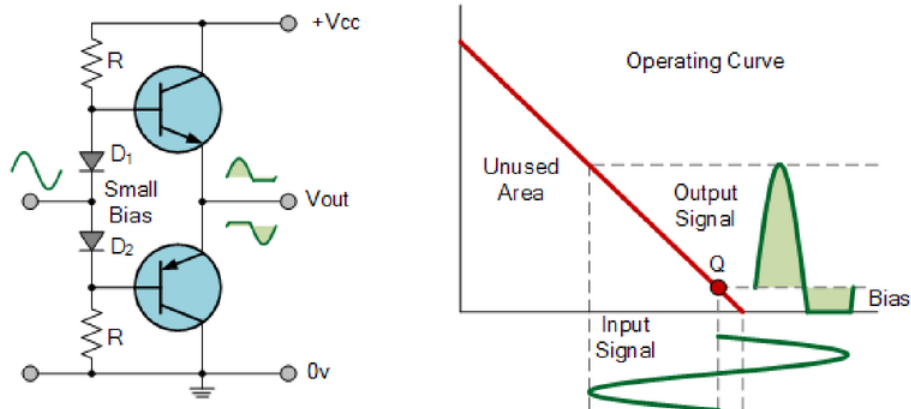


Figure 3 – Class AB Amplifier (Tutorial, 2017)

Oscillators

An Oscillator is an electronic circuit that converts the direct current from a power supply, to alternating current. The two most common signals used in oscillators are; sine and square wave, (Agarwal, 2015). The output waveform can vary from very low to very high frequencies. Oscillators can be split into sinusoidal or Non-sinusoidal oscillators.

Sinusoidal Oscillators consist of:

- Tuned Circuit Oscillators – These consist of inductors and capacitors, which are used to generate high frequencies up to 30Mhz. (Notes, 2017)
- RC Oscillators – These are made up of resistors and capacitors, which generate low frequency signals, which are used in audio signal generators and electronic musical instruments. (Notes, 2017)
- Crystal Oscillators – This oscillator is made up of quartz crystals, which generate a highly stabilized output signal, with the frequency up to 10 Mhz. The electrical signals come from the vibration of the crystal. These are commonly used in clocks, radios and also in test equipment such as signal generators (Notes, 2017)
- Negative-resistance Oscillators – This oscillator works on a negative resistance property where an increase in voltage in 2 points will lead to an decrease in current. (Point, 2017) This uses negative-resistance characteristics of the devices, for example a tunnel diode. These are commonly used for high frequency generation (Notes, 2017)

Non-sinusoidal Oscillators produce a square output waveform. These oscillators can produce an output frequency from 0 to 20 Mhz. (Notes, 2017)

Choice of Active Device

There are a variety of different devices that can be used in an amplifier circuit. These devices include:

- Bipolar Transistor – This is a semiconductor device that is mostly used in amplification, and can amplify both analogue and digital signals. They can be used to switch signals at high speed and are commonly used in wireless transmitters and audio equipment.
- Field Effect Transistors – these are voltage operated devices as they allow voltage to the gate which then controls the current flowing, which is proportional to the input voltage. It has an instant operation, high efficiency and are also very cheap. They can also be used to replace bipolar transistors in electronic circuits. (ElectronicsTutorials, 2016) They are generally used in integrated circuits, as they are able to use low levels of current. (Poole, 2017)
- ICs – Integrated circuits are semi-conductor devices which can be used as an oscillator, amplifier, counter, timer and microprocessor. IC's can be split into linear or digital devices dependent on its intended application. Linear IC's consist of a linear output, which is linear with the input signal. These are used in audio and radio frequency, but are most common in amplifier devices. Digital ICs only operate a few defined states and are used in frequency counters and computer networks. The fundamental building blocks of digital ICs are logic

gates, which then allows the circuit to be able to work with binary data, which consists of two different states: High (logic 1) and low (logic 0). (Rouse, 2015)

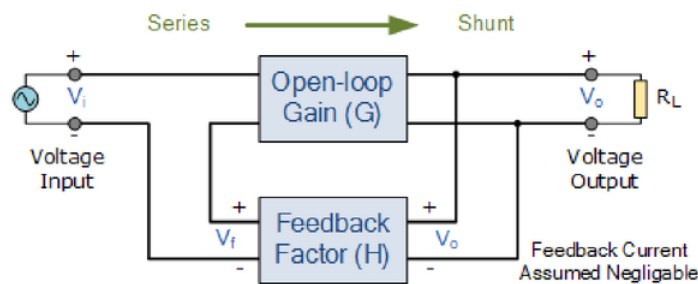
Feedback

Feedback involves, taking a sample of the output and fed back to the input, creating an error signal, which is then used to drive the system (Tutorial, 2017). There are four basic feedback systems, these are:

- Series Voltage Feedback
- Shunt Current Feedback
- Series Current Feedback
- Shunt Voltage Feedback

Series Voltage Feedback

This is a voltage controlled feedback system and feedback signal here comes from the output voltage and is connected with the input voltage in series. The feedback voltage is proportional to the output voltage. This then increases the input resistance but lowers the output resistance. (Yang, 2017) (Tutorial, 2017)



Shunt Current Feedback

This is a current controlled feedback system, as the feedback signal is proportional to the output current. The current is then fed back to the input in parallel. (Yang, 2017) (Tutorial, 2017)

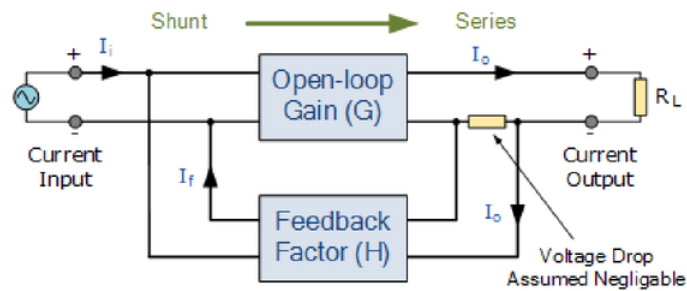


Figure 5 - Shunt Current Feedback (Tutorial, 2017)

Series Current Feedback

This is a voltage-current feedback system, the technique involves taking a sample of the output current and then returning as a voltage, in series with the input, and is taken away from the input. The voltage returned is proportional to the output current. This feedback system also stabilizes the amplifier gain and increases the input resistances (Syllabus, 2017), (Tutorial, 2017).

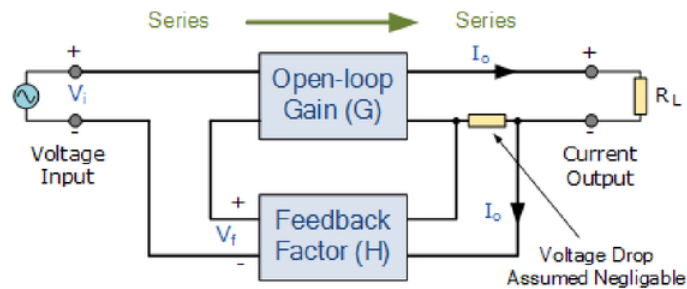


Figure 6- Series Current-Feedback (Tutorial, 2017)

Shunt Voltage Feedback

A shunt voltage feedback system works as a current-voltage feedback system. In this configuration the voltage from the output is then feedback in parallel with the input signal. The current is then taken away from the input current. This system reduces both the input and output impedance. (Yang, 2017) (Tutorial, 2017)

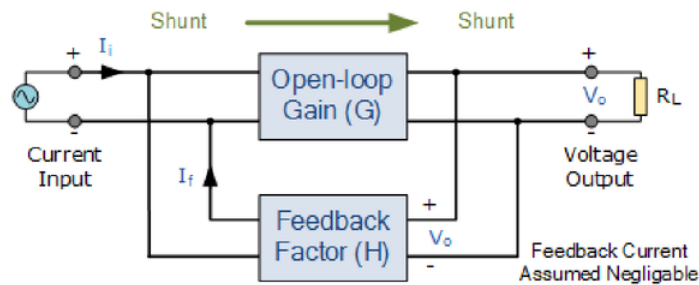


Figure 7 – Shunt Voltage Feedback (Tutorial, 2017)

Design Method, Choices and Calculations

Oscillator

This sine-wave oscillator was designed to the following specifications:

- Function at 150KHz
- Output of $1V_{rms}$.

The output of the oscillator was a guideline, as this can be amplified later on in the circuit. The frequency however cannot be altered.

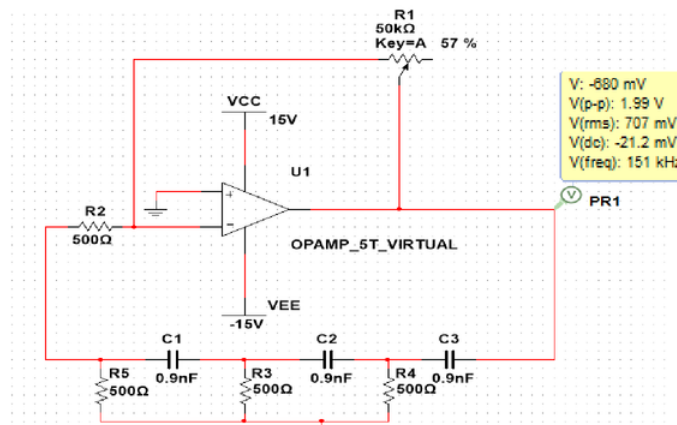


Figure 8 - Oscillator Circuit

The Oscilloscope was then connected onto the Oscillator to monitor an output from the oscillator, which can be seen below.

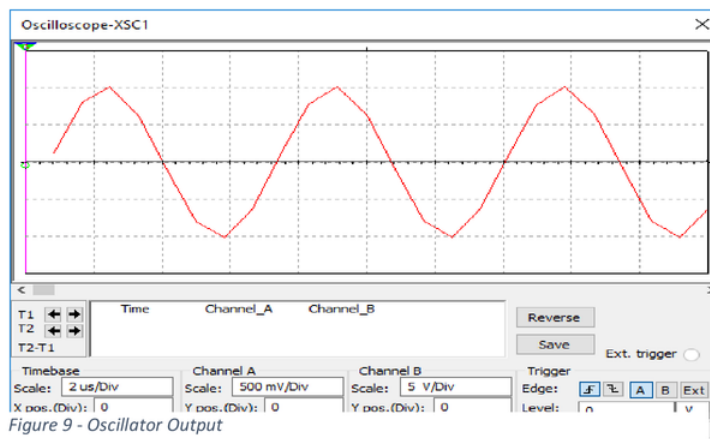


Figure 9 - Oscillator Output

Amplifier

The next stage was to design an amplifier circuit. This were to be designed to the following specifications:

- Centre Frequency: 150KHz
- Gain: 20
- Bandwidth: 80KHz
- Input Signal: 50mV_{pk}

The next step was to decide on the DC supply voltage (V_{CC}), this has to be lower than the maximum voltage of the transistor used. 14V was the chosen V_{CC} .

The next stage was to choose a small NPN transistor to use in the circuit. The MMBTH10-4LT1G was the transistor chosen. The data sheet for the transistor can be seen below.

MMBTH10L, MMBTH10-4L, SMMBTH10-4L, NSVMMBTH10L

VHF/UHF Transistor

NPN Silicon

Features

- S and NSV Prefixes for Automotive and Other Applications Requiring Unique Site and Control Change Requirements; AEC-Q101 Qualified and PPAP Capable
- These Devices are Pb-Free, Halogen Free/BFR Free and are RoHS Compliant

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	25	Vdc
Collector-Base Voltage	V_{CBO}	30	Vdc
Emitter-Base Voltage	V_{EB0}	3.0	Vdc

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Total Device Dissipation FR-5 Board (Note 1) $T_A = 25^\circ\text{C}$ Derate above 25°C	P_D	225 1.8	mW mW/°C
Thermal Resistance, Junction to Ambient (Note 1)	$R_{\theta JA}$	556	°C/W
Total Device Dissipation Alumina Substrate (Note 2) $T_A = 25^\circ\text{C}$ Derate above 25°C	P_D	300 2.4	mW mW/°C
Thermal Resistance, Junction to Ambient (Note 2)	$R_{\theta JA}$	417	°C/W
Junction and Storage Temperature Range	T_J, T_{stg}	-55 to +150	°C

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

1. FR-5 = 1.0 x 0.75 x 0.062 in.

2. Alumina = 0.4 x 0.3 x 0.024 in. 99.5% alumina

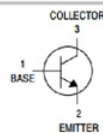


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SOT-23 (TO-236)
CASE 318
STYLE 6



MARKING DIAGRAMS



MMBTH10LT1G,
NSVMMBTH10LT1G



MMBTH10-4LT1G

3EM, 3E4 = Specific Device Code
M = Date Code†
• = Pb-Free Package

(Note: Microdot may be in either location)
†Date Code orientation and/or overbar may vary depending upon manufacturing location.

ORDERING INFORMATION

Device	Package	Shipping†
MMBTH10LT1G	SOT-23 (Pb-Free)	3,000 / Tape & Reel
NSVMMBTH10LT1G	SOT-23 (Pb-Free)	3,000 / Tape & Reel
MMBTH10-4LT1G	SOT-23 (Pb-Free)	3,000 / Tape & Reel
MMBTH10LT3G, SMMBTH10-4LT3G	SOT-23 (Pb-Free)	10,000 / Tape & Reel

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

Figure 10 – Transistor Datasheet (Semiconductor, 2016)

ELECTRICAL CHARACTERISTICS ($T_A = 25^\circ\text{C}$ unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS					
Collector-Emitter Breakdown Voltage ($I_C = 1.0\text{ mA}$, $I_B = 0$)	$V_{(BR)CEO}$	25	–	–	Vdc
Collector-Base Breakdown Voltage ($I_C = 100\text{ }\mu\text{A}$, $I_E = 0$)	$V_{(BR)CBO}$	30	–	–	Vdc
Emitter-Base Breakdown Voltage ($I_E = 10\text{ }\mu\text{A}$, $I_C = 0$)	$V_{(BR)EBO}$	3.0	–	–	Vdc
Collector Cutoff Current ($V_{CB} = 25\text{ Vdc}$, $I_E = 0$)	I_{CBO}	–	–	100	nAdc
Emitter Cutoff Current ($V_{EB} = 2.0\text{ Vdc}$, $I_C = 0$)	I_{EBO}	–	–	100	nAdc
ON CHARACTERISTICS					
DC Current Gain ($I_C = 4.0\text{ mA}$, $V_{CE} = 10\text{ Vdc}$) MMBTH10LT1G, NSVMMBTH10LT1G MMBTH10-4LT1G, SMMBTH10-4LT3G	h_{FE}	60 120	– –	– 240	–
Collector-Emitter Saturation Voltage ($I_C = 4.0\text{ mA}$, $I_B = 0.4\text{ mA}$)	$V_{CE(sat)}$	–	–	0.5	Vdc
Base-Emitter On Voltage ($I_C = 4.0\text{ mA}$, $V_{CE} = 10\text{ Vdc}$)	V_{BE}	–	–	0.95	Vdc
SMALL-SIGNAL CHARACTERISTICS					
Current-Gain – Bandwidth Product ($I_C = 4.0\text{ mA}$, $V_{CE} = 10\text{ Vdc}$, $f = 100\text{ MHz}$) MMBTH10LT1G, NSVMMBTH10LT1G MMBTH10-4LT1G, SMMBTH10-4LT3G	f_T	650 800	– –	– –	MHz
Collector-Base Capacitance ($V_{CB} = 10\text{ Vdc}$, $I_E = 0$, $f = 1.0\text{ MHz}$)	C_{cb}	–	–	0.7	pF
Common-Base Feedback Capacitance ($V_{CB} = 10\text{ Vdc}$, $I_E = 0$, $f = 1.0\text{ MHz}$)	C_{fb}	–	–	0.65	pF
Collector Base Time Constant ($I_C = 4.0\text{ mA}$, $V_{CB} = 10\text{ Vdc}$, $f = 31.8\text{ MHz}$)	τ_b/C_C	–	–	9.0	ps

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

Figure 11 – Transistor Datasheet (Semiconductor, 2016)

Then a Collector Current (I_Q) was decided. I_Q should be roughly 10-20% of the transistors $I_{C_{MAX}}$ figure. The value of I_Q was chosen to be 4 mA .

After the Supply Voltage and Collector Current was decided, the next stage was to calculate the value for the load resistor R_L . The transistor collector voltage was also calculated, and this was 7 V , half the V_{CC} , this then allows equal amounts of swing on the output signal and prevents the driving the transistor into saturation. R_L can then be calculated by dividing half of V_{CC} by I_Q , as seen below:

$$R_L = \frac{V_{CC} - V_C}{I_Q} = \frac{14 - 7}{4\text{ mA}} = \frac{7}{4\text{ mA}} = 1.75\text{ k}\Omega$$

The emitter voltage V_E should be 10% of V_{CC} , so my V_E is 1.4 V . The next stage was to divide V_E by I_Q to get the value for R_E . Calculations can be seen below:

$$R_E = \frac{V_E}{I_Q} = \frac{1.4}{4\text{ mA}} = 350\Omega$$

The next stage was to calculate a value for the base current, I_B . To be able to calculate this, take the middle value of the HFE of the transistor which is found from the transistors datasheet, which is 180. Then you have to divide the collector current, I_Q , which is 4ma. This is calculated below.

$$HFE = \frac{I_Q}{I_B} \quad 180 = \frac{4mA}{I_B} = I_B = \frac{4mA}{180} = 22\mu A$$

You can then calculate the base voltage, V_B , of the transistor. This should be about 0.7V higher than your V_E to ensure than the input signal, is biased with the transistors input characteristics.

$$V_B = V_E + 0.7V$$

$$V_B = 2.1V$$

Then you calculate your DC bias network current, this is to ensure that you have sufficient bias stability. Your DC bias network current should be 10 time greater than the current flowing through R1 and R2, I_B .

$$I(R1 + R2) = I_B \times 10$$

$$I(R1 + R2) = 22\mu A \times 10$$

$$I(R1 + R2) = 0.22mA$$

To complete your DC conditions, you must then calculate our resistor values for R1 and R2. There are both calculated separately, R1 is calculated by calculating the difference between V_{CC} and V_B , and then dividing this value by the DC bias network current.

$$R1 = \frac{V_{CC} - V_E}{I_{R1}} = \frac{14 - 2.1}{0.22mA} = \frac{11.9}{0.22mA} = 54.1K\Omega$$

R2 is calculated by dividing the base voltage V_E , by the DC bias network current.

$$R2 = \frac{V_E}{I_{R1}} = \frac{2.1}{0.22mA} = 9.5K\Omega$$

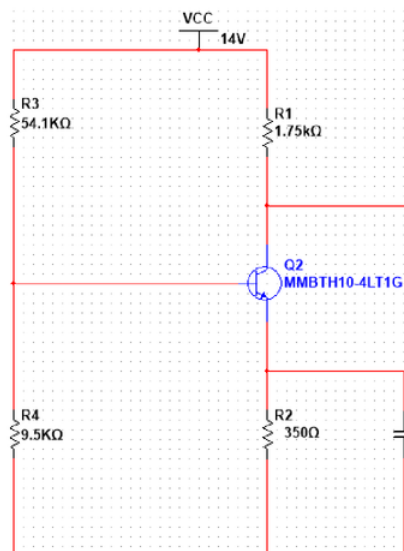


Figure 12 - Amplifier DC Conditions

Probes were then added to test the voltages at different points of the circuit.

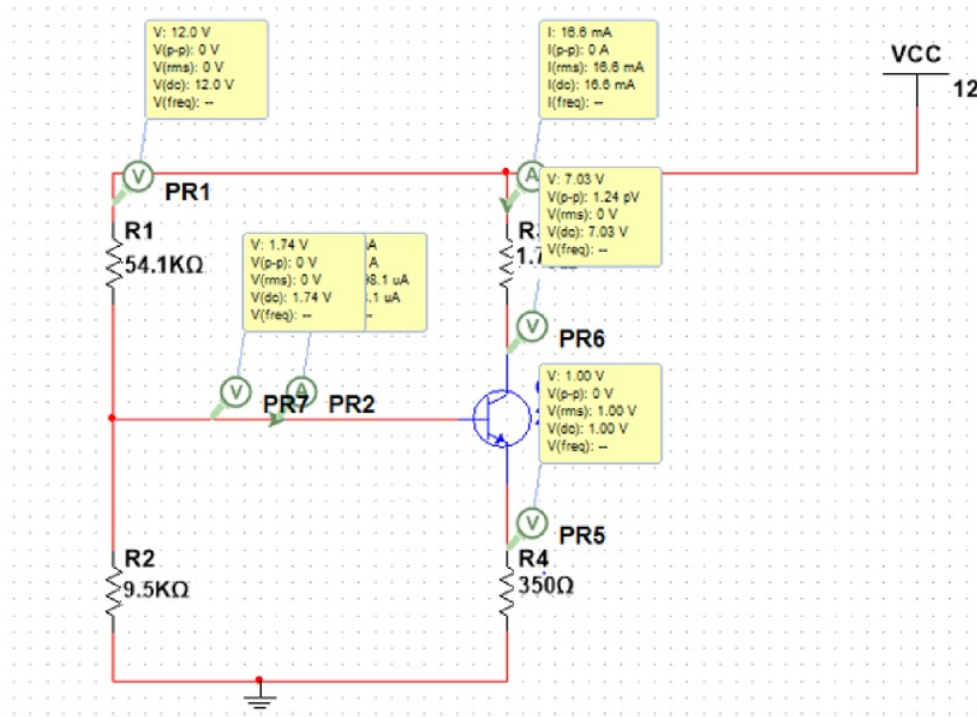


Figure 13- Testing Amplifier

AC Conditions

The next step was to calculate and add in the AC components, capacitors. It is important that the capacitors have a high reactance under DC conditions, as they are essentially blocking the input and output voltages from connecting circuits by essentially creating an open circuit, this is to ensure the bias condition of the amplifier is not disrupted.

While under AC conditions, they allow signals to pass, so therefore has low reactance under AC conditions. To achieve this, C is made the subject of the formula and a low value for X_c is selected, for example 0.9 ohm. Use a centre frequency of 150 kHz, which is gathered from the task description.

$$C = \frac{1}{2\pi F X_c}$$

$$C = \frac{1}{2\pi 150kHz 0.9\Omega}$$

$$C = 1.18\mu F$$

1.18 μ F was then used as the values for C1, C2 and C3.

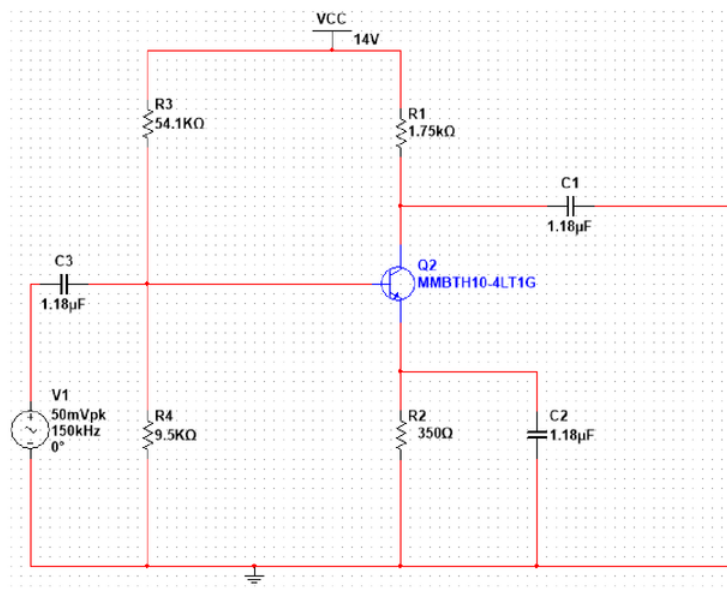


Figure 14 - Added AC conditions

The oscilloscope was then added in to the circuit, which would then allow the output to be read.

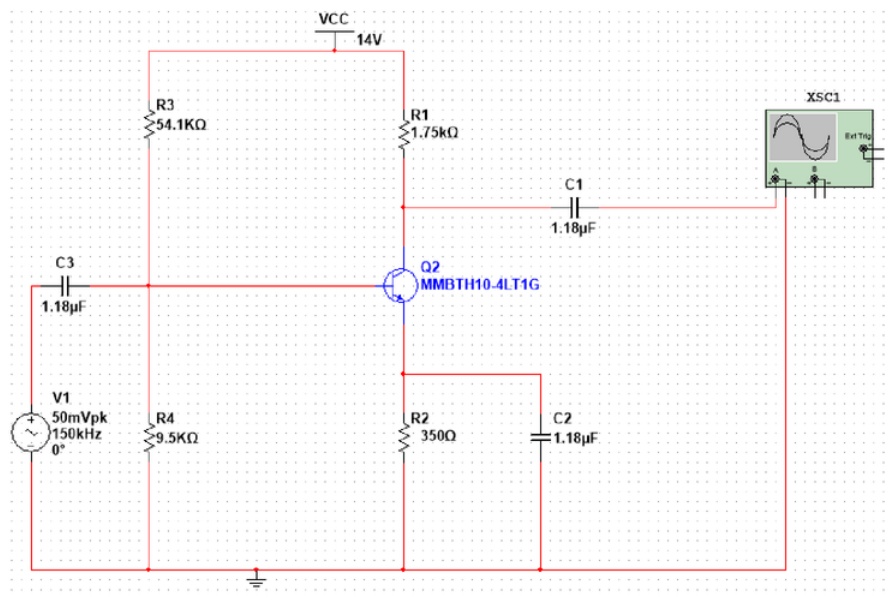


Figure 15 - Oscilloscope connected to Amplifier

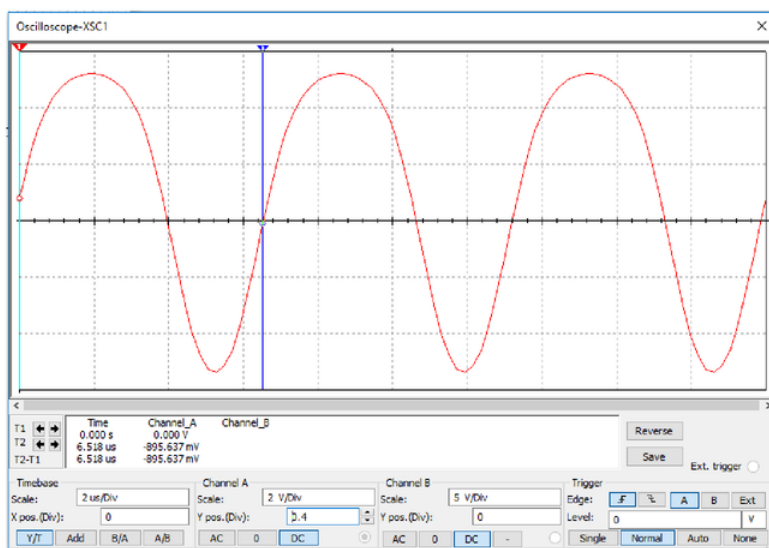


Figure 16 - Oscilloscope Results

The oscilloscope reading shows the time period which is 6.518μs.

Impedance

To calculate impedance, the variable resistor must be inserted between the supply and C1. Then the value of the resistor needs to be adjusted until the output peak to peak voltage is exactly half its original voltage, which was 10.5V. The value of the resistor at this point is the input impedance of the circuit.

At 0% of 2k Ω resistor the output voltage is 10.6V

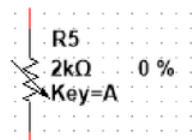


Figure 17 - Variable Resistor

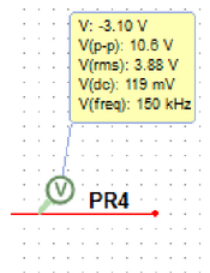


Figure 18 - Output Voltage

At 56% of the 2k Ω resistor, the out voltage is 5.25V which is half the original voltage. This the means that the input impedance is 56% of 2k Ω , which calculates to be 1.12k Ω .

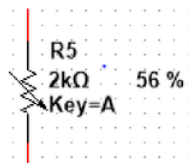


Figure 19 - Variable Resistor

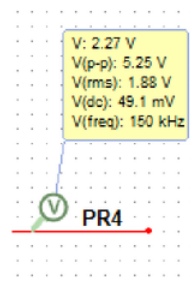


Figure 20 - Output Voltage

The next step was to split R2 into two resistors but ensuring the equal the same resistance of R2. This was done because under AC conditions the capacitor essentially becomes a 0.9Ω resistor. This was used as the value for X_c when calculating our capacitive values. Therefore, with just R_E in the circuit, this allows 100% feedback, which gives a maximum gain. Then with R_E and C_2 in the circuit, the resistance is roughly 0.9Ω , and so the emitter voltage will act as ground (0V) and therefore there will be no negative feedback. By adding R_3 into circuit, this allows a feedback of between 0-100% as R_2 allows some voltage in the circuit. The two new resistors were altered until the gain reached 20.

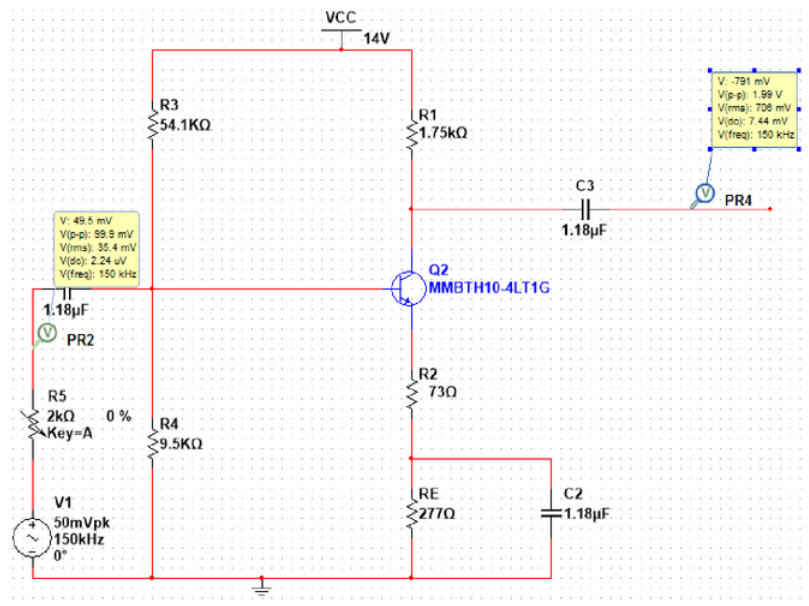


Figure 21 - Splitting R2 into 2 Resistors

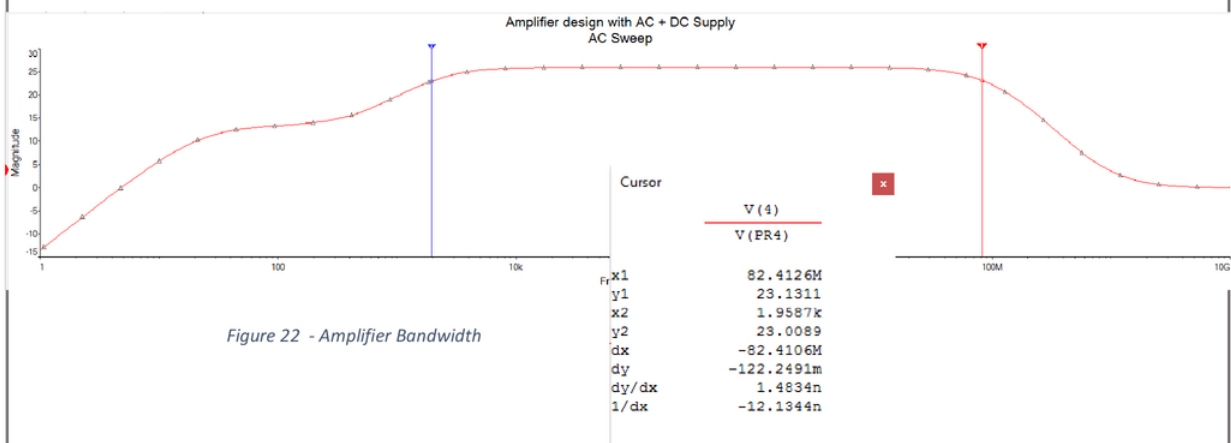


Figure 22 - Amplifier Bandwidth

Calculating values for Capacitor

$$C1 = \frac{1}{2\pi \times FL \times Z_{in}}$$

$$C1 = \frac{1}{2\pi \times 110K \times 1.12K}$$

$$C1 = 1.29nF$$

$$C4 = \frac{1}{2\pi \times FL \times Z_{out}}$$

$$C4 = \frac{1}{2\pi \times 190K \times 1.75K}$$

$$C4 = 0.48nF$$

These capacitor values were added into the circuit to reduce the bandwidth to what was optimal. The high and low frequency boundaries were found by taking 3dB from the maximum frequency, which was 24.5, so the high and low boundaries were set to 21.5.

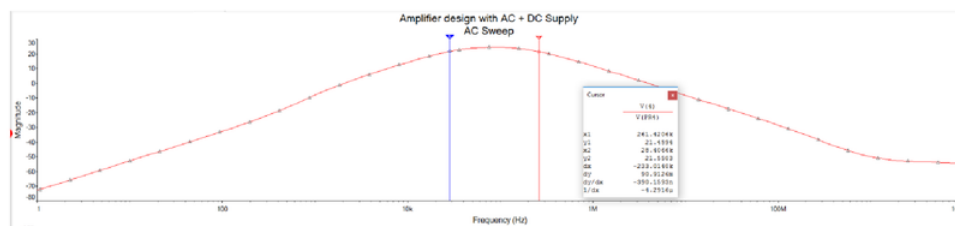
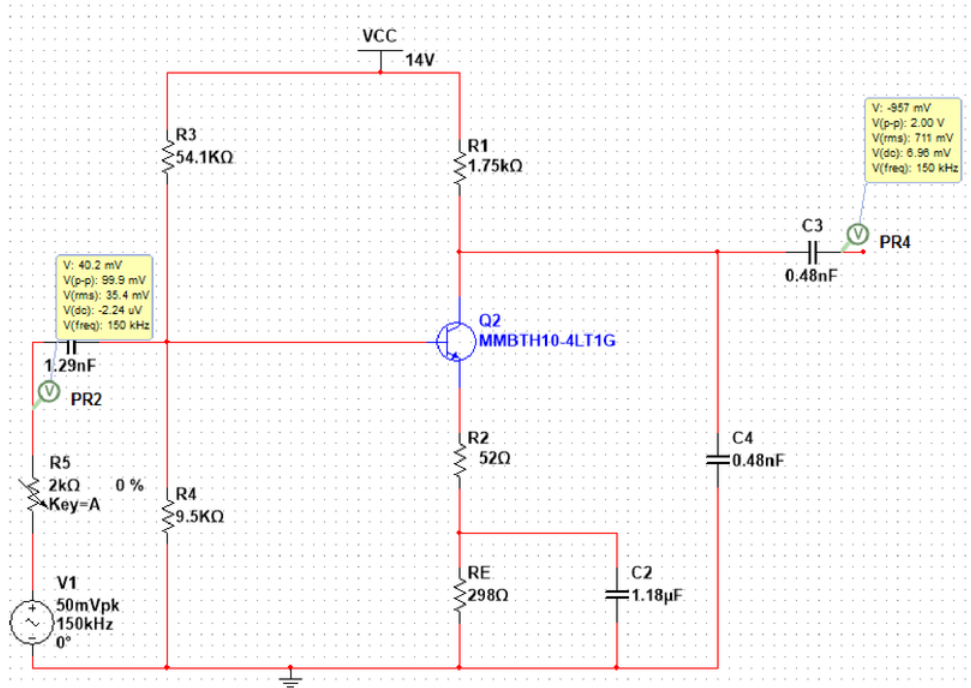


Figure 23 - Amplifier Bandwidth

Cursor	
	V(4)
	V(PK4)
x1	261.4206k
y1	21.4594
x2	28.4066k
y2	21.5503
dx	-233.0140k
dy	90.9126m
dy/dx	-390.1593n
1/dx	-4.2916u

After the capacitors were adjusted to reduce the bandwidth, the R2 and RE resistors were adjusted to ensure a gain of 20 was maintained.

Figure 24 - Amplifier



Gain

To calculate gain, the following equation was used:

$$Gain = \frac{V_{out}}{V_{in}}$$

$$Gain = \frac{2}{99.9 \times 10^{-3}}$$

$$Gain = 20.02$$

Below shows the bandwidth of 163k HZ, this was found by taking 3db away from the Y-Max, which was 29.738. The centre frequency was Y-max on the graph below, which is 157kHz

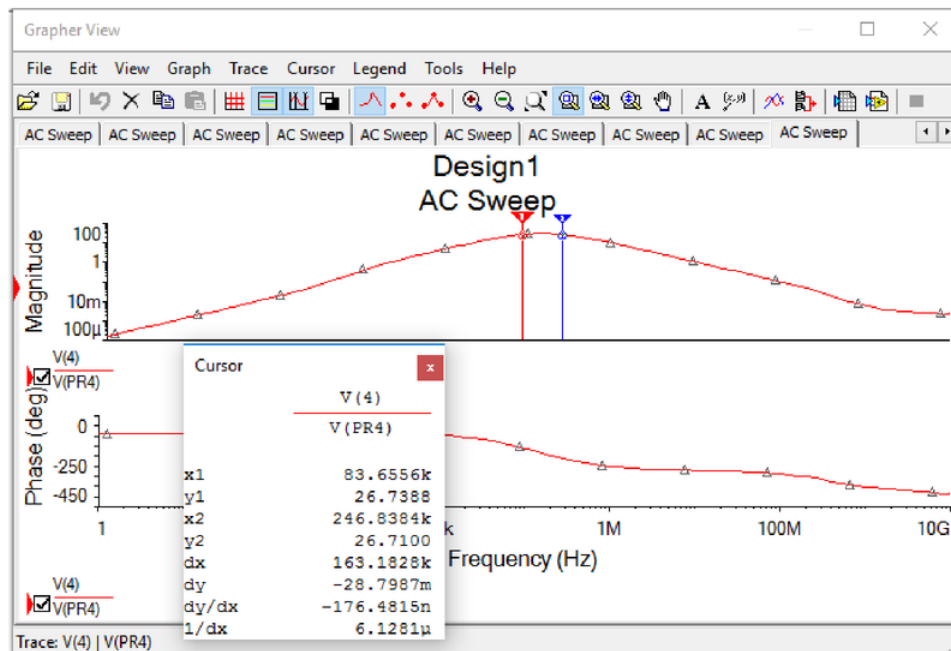


Figure 25 - Bandwidth

Combining the Circuits

The next stage was to combine the circuits, and to be able to do this, a buffer circuit needed to be designed. This allows both circuits to be isolated and it also reduces the output voltage of the oscillator to the required input voltage of the amplifier.

Firstly, the gain had to be calculated to be able to calculate the value for R_f in the buffer circuit

$$A_v = \frac{R_f}{R_s}$$

$$A_v = \frac{50mV}{680mV}$$

$$A_v = 0.0735$$

To calculate the value for R_f it is assumed that R_s is $1k\Omega$, and then rearrange the equation to make R_f the subject.

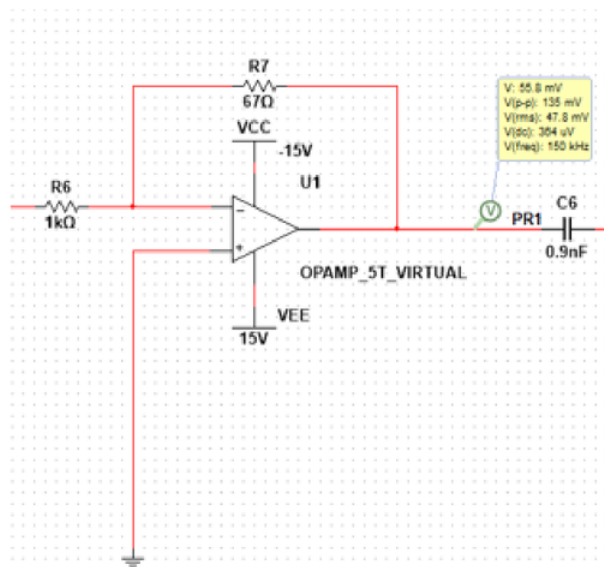
$$R_f = A_v \times R_s$$

$$R_f = 1k\Omega \times 0.0735$$

$$R_f = 73.5\Omega$$

The actual R_f value was slightly lower, as it was altered to ensure the voltage was sufficient to the amplifier circuit.

Figure 176 - Buffer Circuit



Below show the values of the output of the Amplifier circuit.

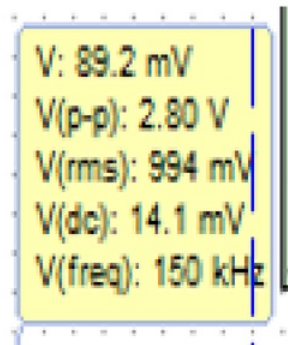


Figure 29 - Output of Amplifier

An oscilloscope was connected on the output of the amplifier to show the waveform of the output signal. See Figure below.

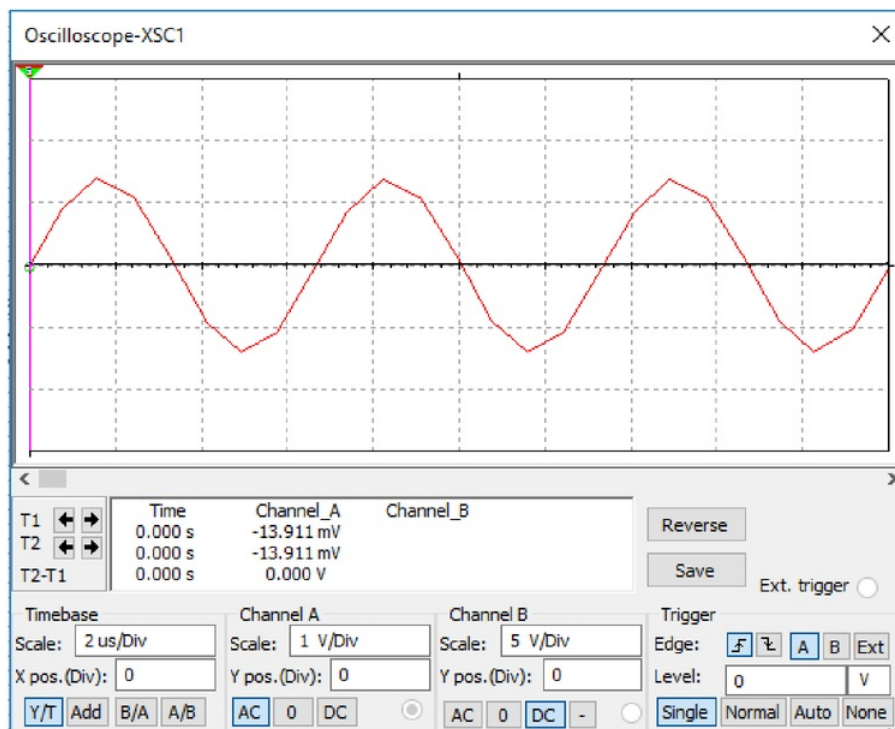


Figure 30 - Output Waveform

Evaluation

To conclude, the circuit designed was very similar to the specification that was provided. The oscillator was also developed to the required specification, which was to operate at 150kHz and an output of $1V_{rms}$. A gain of 20 was specified and this was achieved as 50 mv was the input and 994 mv was the output from the amplifier. The assignment specified a bandwidth of 80kHz, however the final bandwidth was 163kHz and this is because it contained an RL circuit. To achieve a bandwidth of 80kHz, a tuned circuit is required. The centre frequency achieved was 157kHz, which was just above the specification of 150kHz.

The circuit could be improved by using a tuned circuit instead of a RL circuit to allow the optimal bandwidth to be achieved. A more suitable transistor could also be used as this would allow a higher current to be used, as the transistor used was suited for low currents.

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PSDE 4004, Assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

89/100

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GRADING FORM: CSG-RUBIC

ETHAN HOWELLS**89****RESEARCH-INFORMED LITERATURE**



There was evidence of extensive further reading and research from highly credible and reliable sources. Your interpretation and understanding of the additional research was excellent and demonstrated a deep underlying appreciation of the subject. Your references were appropriate to the task and your reference list was of an appropriate length for this assignment.

9**KNOWLEDGE AND UNDERSTANDING**



The knowledge and understanding of the subject demonstrated by this assignment was generally excellent. There were very few gaps in your knowledge of the basic principles and the higher level concepts were very well explained. Your explanation of the design process and calculations

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was also excellent and it did extend your knowledge well beyond that contained in the course notes.

ANALYSIS



Your explanation of the experiment was good, however the conclusions lacked some detail. You could have evaluated the results in more detail and specified whether they concurred with theory suggesting reasons for any discrepancies. You have however demonstrated good analytical skills and your approach to the task was logical. Further work – in your conclusion, you should relate the results to the original specification and to accepted theory.

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PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally excellent. You used the resources available in MultiSim appropriately when designing the circuit and you used appropriate options for testing and evaluating the circuit performance. You managed to design a very efficient circuit that functioned well within the specification and achieved with very little assistance. Your results were very detailed, well presented and allowed for an excellent conclusion to be attempted.

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SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was very well structured and written in a coherent and logical way. The report was presented in a professional manner using appropriate language and formatting, good

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diagrams in appropriate places, good
sentence/paragraph structure and clear calculations