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by Ryan Radcliffe

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HNC Electrical and Electronic Engineering

SGEE4003 - Electronics I

Analogue Circuit Design

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01/02/2021

2525 Words

70-75

- ① RESEARCH OK, BUT YOU MUST USE IN TEXT CITATIONS AND YOUR REFERENCE LIST WOULD BE LONGER AND USE HARVARD CONVENTIONS.
- ② DESIGN METHOD WAS EXPLAINED WELL
- ③ REFINING THE SPECIFICATION WAS BRIEFLY EXPLAINED, COULD HAVE BEEN MORE DETAILED
- ④ TEXTING WAS GOOD AND RELATED MORE TO SPECIFICATION.
- ⑤ ANALYSIS WAS GOOD WITH SOME VALID CONCLUSIONS.

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EXECUTIVE Summary

This assignment involved researching about different classes of amplifiers as well as oscillators. An amplifier circuit was designed from the beginning, first by selecting a transistor and then looking at the data sheet for relative information such as I_C and h_{FE} . Calculations were then done based off this information to get correct DC biasing for the circuit, finding values for resistors and then later, capacitors. There were specified values that should be measured from the circuit like centre frequency, bandwidth, gain, and input signal. All but one of these were met, bandwidth was higher than specified but due to the lack of calculations that could be done to achieve correct values the only way it can be gotten is with trial and error. Another complication when trying to get the right value was changing some of the components values to try and correct bandwidth would unintentionally impact the output of gain. Trying to then adjust for gain would then alter bandwidth, causing a back and forth of trying to find the perfect balance.

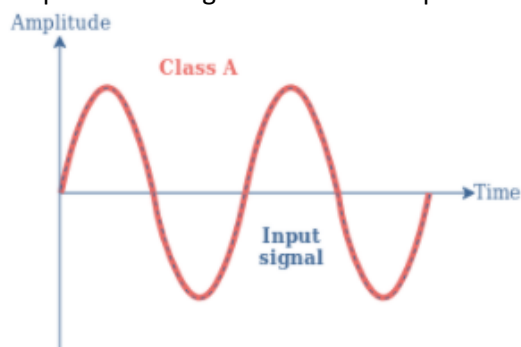
Oscillator circuit was also built along with a buffer amplifier, these also had specified outputs, frequency and output voltage. These were much easier to achieve and got both to meet the specification by changing the values of a couple of components. The fact of changing two capacitors and an inductor for frequency was unaffected to voltage output made it much easier to meet the criteria. Likewise, changing resistor values to obtain voltage output made no difference to frequency of the circuit. The buffer amplifier made sure nothing negative from the oscillator circuit could impact the amplifier circuit, acting as a sort of isolator but still allowing frequency and voltage to go through.

Qus

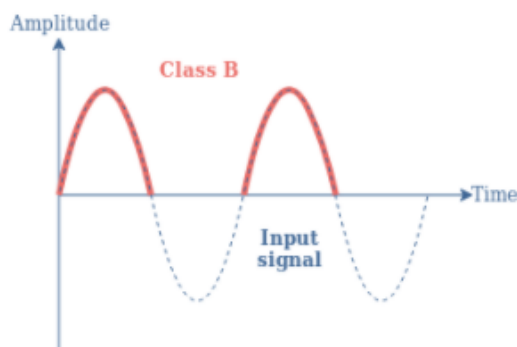
Research

Amplifier

There are various types of amplifiers with similar purposes of increasing the gain of a circuit, making sure the output waveform of a circuit is larger than input. However, transistors used in amplifier circuits can vary to create different types of amplifiers based on the purpose. Different classes of amplifiers exist and are distinguished by classes, class A, AB, B and push and pull. These are separated by their characteristics on duty cycle. Duty cycle is the time when something is conducting for, class A amplifiers for example have a 100% duty cycle which means it is trying to conduct even when in the negative zone of the sine wave. This is one of the most popular used class of amplifier however it also is the least efficient as it wastes power conducting when there is nothing there, when in the negative zone. As its always in an on state it means current is being drawn, heating up the amplifier creating further losses of power in form of heat.

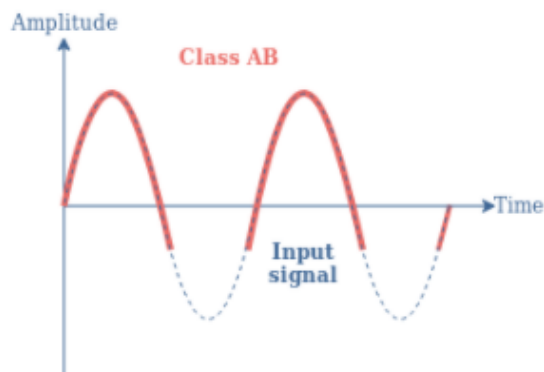


After class A comes class B, this is an improved version of the previous class as it tries to increase the efficiency and remove some of the losses class A provides. Unlike class A this class uses two transistors in the amplifier design, one to conduct during the negative half of the cycle and the other for positive. Since this means it will amplify twice each transistor will only amplify half of its cycle in order to get the full positive wave. Because only the positive wave is being used now the duty cycle decreases to 50% and efficiency also increases to 50%. One of the downsides to this class is that since there are two transistors used in the circuit there can be a small amount of downtime where neither transistor is active, leaving a small section of the waveform where nothing is conducting, and voltage is 0. This is known as cross over distortion and is a non-issue with the previous amplifier since there is only one transistor used in the circuit.

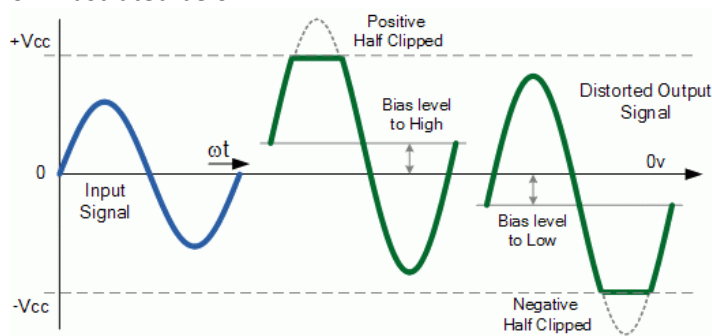


CITATIONS?

A combination of these two classes will result in an AB class, where one of its main selling points is that it is more like class B. This is because it does not include the full 360° cycle but just slightly more than what was used in class B, roughly 50% of one of the cycles. This removes the issue of cross over distortion as slightly more of the duty cycle is used than what is needed so there is a smooth transition between each positive cycle.



One problem to be aware of that all classes can be impacted by is the q point, this is the centre line of the sine wave that determine whether a full waveform will be used or if there will be some cut off on either side. Amplifiers must operate at the q point otherwise it would be inefficient due to the cut off illustrated below.

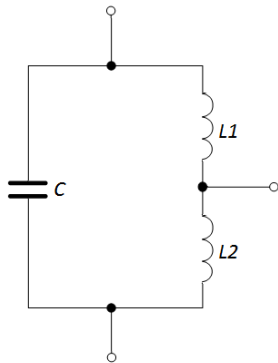


The first sine wave is shown to be at q point, the second however is distorted in the positive cycles. In order to fix this distortion, the biasing must be changed to lower the wave to get closer to the q point. Final waveform shows the opposite issue, this time distortion is happening in the negative cycle so biasing will have to be increased to bring it back up so full waveform can be produced.

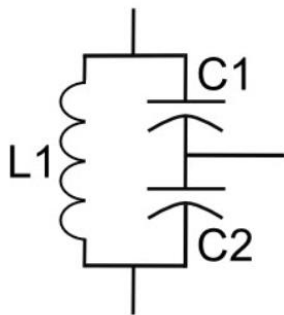
Oscillator

Oscillators main purpose is to produce an oscillating output which can create a waveform that alternates similarly to AC however with DC inputs. This can be helpful when trying to come up with a specific frequency when connected to an amplifier, frequency can be decided by changing values of components in the oscillator circuit.

Two main different oscillators can be constructed, the Hartley and Colpitts oscillator. With Hartley's design the components used to create the feedback involve two inductors and a single capacitor. The inductors used here act as a transformer, working in a ratio from one another to get the desired amount of feedback back to the amplifier.

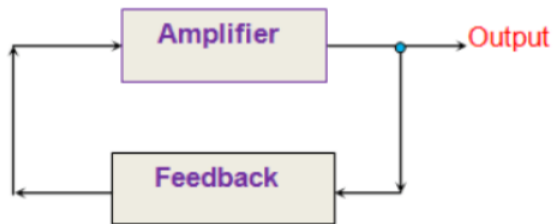


Alternatively, Colpitts oscillator could be used which was the one built later in this assignment. Unlike Hartley's this circuit is the complete opposite where two capacitors are used, and a single inductor is included to control the alternating current. Current is able to alternate by the interaction of capacitors and inductor, as one discharges the other charges and the other way around, causing alternation of current between components.



Negative Feedback

A feedback loop is needed for an oscillator to work, this is essentially taking the output of the amplifier used in the oscillator and feeding it back into its own input.



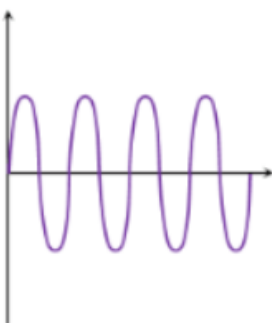
Feedback from the amplifier can sometimes be higher than the initial input, when this happens it creates an increasing oscillation. This would not be ideal as it means the waveform will increase as time goes on instead of being stable.



When the amplifier is fed back with slightly less gain it does the opposite and here the loop creates decaying oscillations. Here waveforms will slowly decrease after time until eventually there is little to nothing left to output.



Best case scenario occurs when gain for both feedback and initial input to the amplifier are the same. This creates a stable sine wave with a constant amplitude as its output. This can then be applied to other amplifier circuits as an alternating power source.



RESEARCH IS OK, BUT YOU
MUST USE INTER CITATIONS.

Designing an Amplifier

Before calculations can be done for some of the components in the circuit a transistor will have to be chosen first. For this circuit, a BCW32 was chosen and so by looking at the datasheet more components can be added with their correct values.

h_{FE}	DC current gain		$I_C = 10 \mu A; V_{CE} = 5 V$			
	BCW31		–	190	–	
	BCW32		–	330	–	
	BCW33		–	600	–	
	DC current gain		$I_C = 2 mA; V_{CE} = 5 V$			
	BCW31		110	–	220	
	BCW32		200	–	450	
	BCW33		420	–	800	

Transistors have h_{FE} values which is the forward current gain of a given transistor, these come in ranges as can be seen in the table above from the datasheet. Alongside BCW32 it ranges from 200-450 so an average between both values will be used to determine final h_{FE} which ends up being 325.

I_C	collector current (DC)	–	100	mA
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Value for I_Q is found by taking 10-20% off I_C , for this transistor it leaves I_Q being 10mA.

Data sheet:

<https://datasheet.octopart.com/BCW32%2C235-Nexperia-datasheet-87580940.pdf>

With these values taken from the datasheet of the transistor it is now possible to create the class A voltage amplifier circuit. Specifications for this circuit are as follows:

- Centre Frequency – 200KHz
- Bandwidth – 60KHz
- Gain – 50
- Input Signal – 50mV_{pk}

Firstly, the collector voltage can be calculated as it is supposed to be half of V_{CC} , which in this case is 16V. This means value of V_C should be around 8V, this leads to finding what R_L should be:

$$R_L = \frac{V_C}{I_Q}$$

$$R_L = \frac{8}{10 * 10^{-3}}$$

$$R_L = 800\Omega$$

R_L , shown as R3 in the circuit, has a value of 800 Ω .

R_E is a resistor on the emitter path and in order to find this V_E needs to be found, V_E is shown below:

$$V_E = \frac{V_{CC}}{10}$$

$$V_E = \frac{16}{10}$$

$$V_E = 1.6V$$

I_Q is also used in this equation:

$$R_E = \frac{V_E}{I_Q}$$

$$R_E = \frac{1.6}{10 * 10^{-3}}$$

$$R_E = 160\Omega$$

R_E is the resistor labelled as R4 in the circuit. Base current or I_B can be found by again using I_Q but this time with h_{FE} .

$$I_B = \frac{I_Q}{h_{FE}}$$

$$I_B = \frac{10 * 10^{-3}}{325}$$

$$I_B = 30.77\mu A$$

Finding base voltage is slightly easier as it is the same as the emitter however since the measurement is before going through the transistor 0.7V will have to be added. This is because transistors drop 0.7V from base to emitter.

$$V_B = V_E + 0.7$$

$$V_B = 1.6 + 0.7$$

$$V_B = 2.3V$$

Before R1 can be calculated the current on this path must be found first.

$$IR1 = I_B * 10$$

$$IR1 = (30.77 * 10^{-6}) * 10$$

$$IR1 = 307.7\mu A$$

Now R1 can be calculated.

$$R1 = \frac{V_{CC} - V_B}{IR1}$$

$$R1 = \frac{16 - 2.3}{307.7 * 10^{-6}}$$

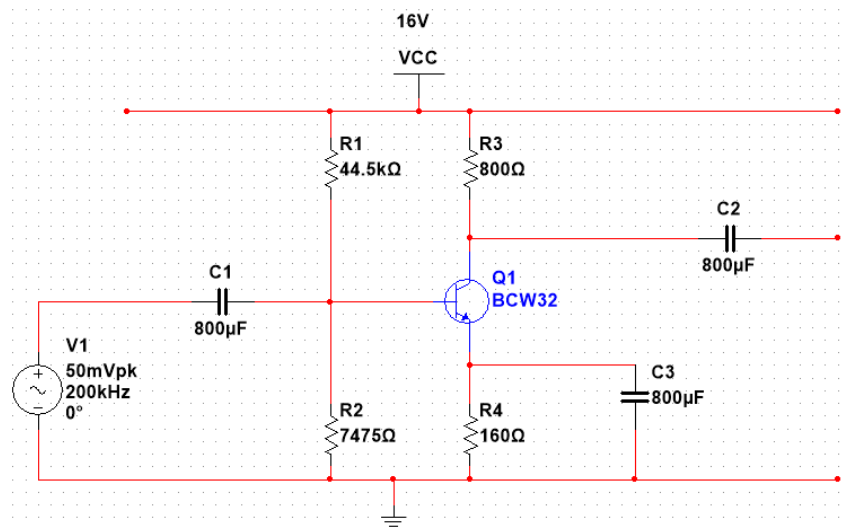
$$R1 = 44523\Omega$$

Finally, R2 is worked out in a similar way however this time Vcc is not applied and the current works out to be the same as R1s current.

$$R2 = \frac{V_B}{I_{R2}}$$

$$R2 = \frac{2.3}{307.7 * 10^{-6}}$$

$$R2 = 7475\Omega$$



For the sake of basic construction for this circuit the capacitors were kept at 800μF until more measurements could be made for future additions.

Modifications made now will be to AC components, C1 as well as adding an extra capacitor, C4. A 5kΩ variable resistor, VR1, is temporarily added just before C1 and is set to 0Ω so Vout can be measured which is 13.6V. VR1 is gradually increased until Vout reaches half of its original value, 6.8V. This is met when 32% of VR1 is applied, meaning 32% of 5KΩ will be needed to work out C1 as VR1 = Zin.

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

In this case f_L is lower frequency which would be 170KHz.

$$C1 = \frac{1}{2\pi(170 * 10^3)(1600)}$$

$$C1 = 0.585nF$$

C4 has a similar calculation where f_H , higher frequency and Zout is used where:

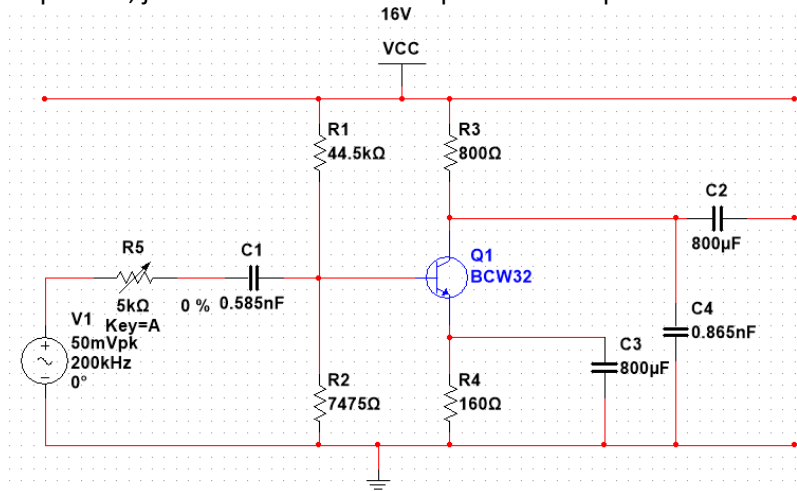
$f_H = 230KHz$

Zout = 800

$$C4 = \frac{1}{2\pi(230 * 10^3)(800)}$$

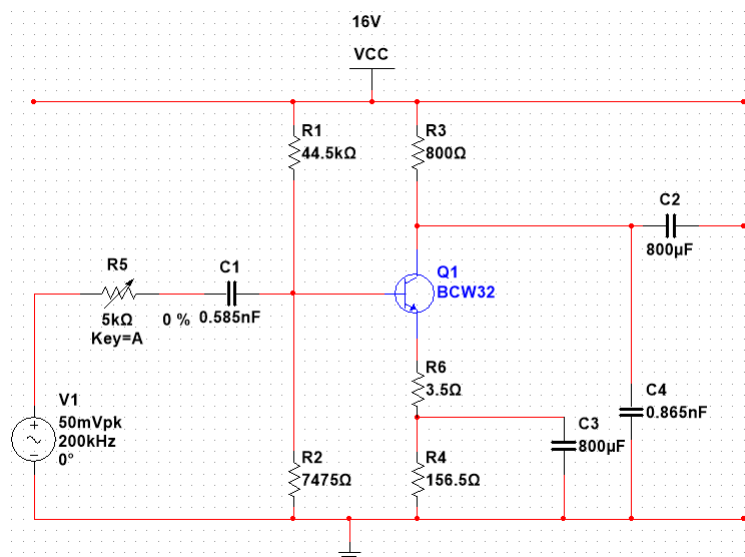
$$C4 = 0.865nF$$

C4 is connected in parallel, just before C2 on the output of the amplifier.



C3 is responsible for blocking AC and decoupling the circuit, in order to change gain an extra resistor will have to be added to the emitter path, in between R4 and C3. Gain can be altered by changing the value of R4 and the new resistor, R6. Initially these resistors can be split in half, each being 80Ω and then by measuring Vout.

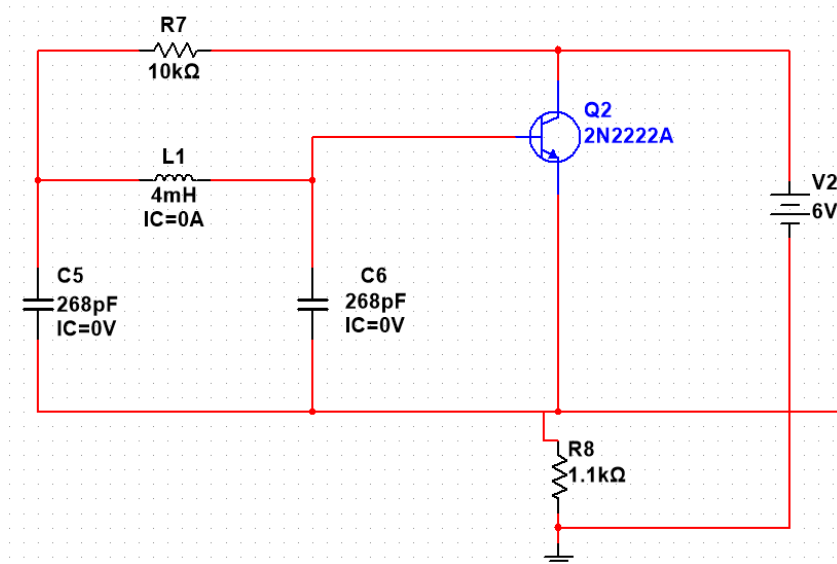
After changing values of both resistors for some time the final values ended up being 3.5Ω for R6 and 156.5Ω for R4.



BRIEF EXPLANATION OF REFINISH
THE SPECIFICATION.

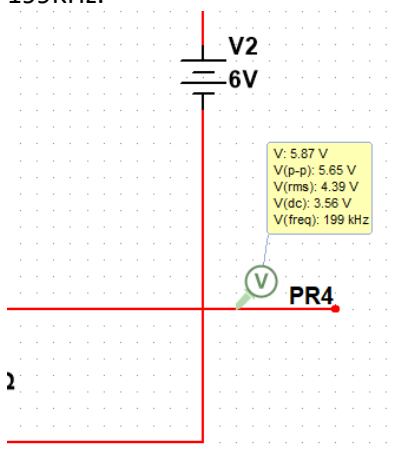
Designing an Oscillator

Instead of using an AC signal source for the final circuit an oscillator is built to replace it. As frequency was initially gotten from the AC input in order to get 200KHz again C5 and C6 will have to be altered and must be done so with the same values using trial and error. As well as capacitors the inductor will have to be changed until frequency has reached 200KHz. Testing for this will be done in the next section.

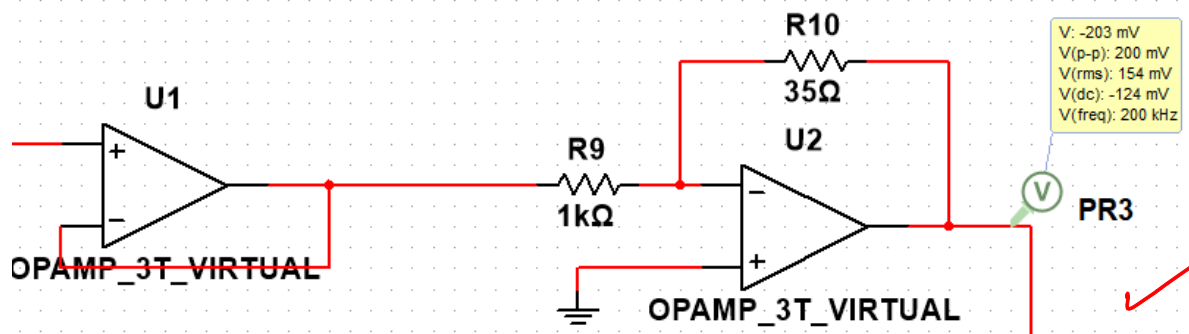


Simulating the Circuits

Before connecting the oscillator to the amplifier circuit, a small test will be done to ensure it is outputting the correct frequency. Using the voltage probe given on Multisim to put on the output it measures frequency to be close enough to the target 200KHz, with the current frequency being 199KHz.

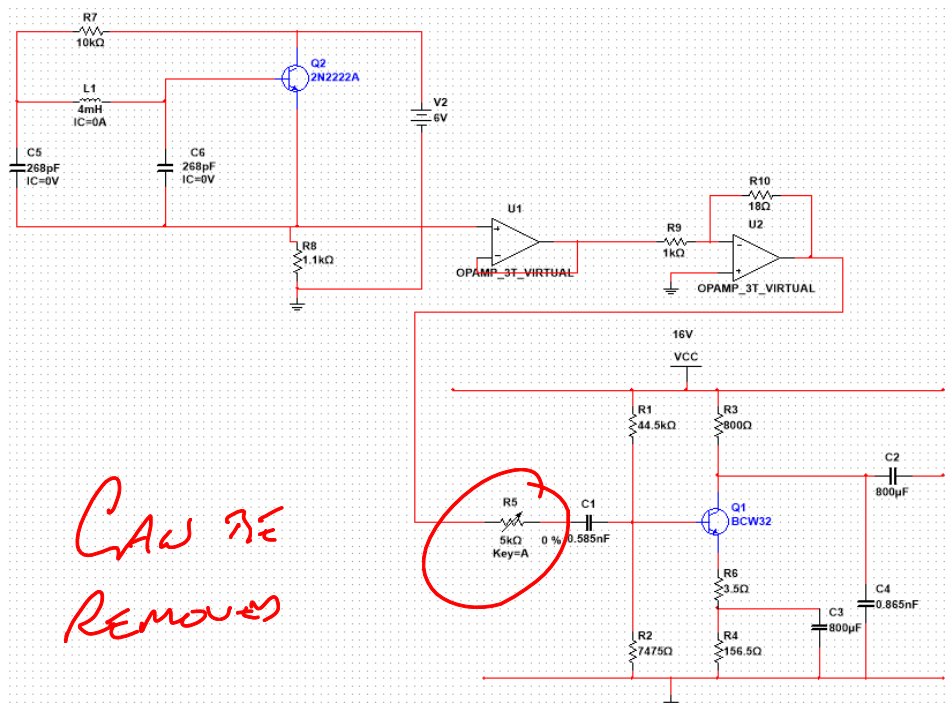


One final addition needs to be made in order to connect the oscillator to the amplifier, that is creating a buffer amplifier. The buffer amplifier will be connected to the output of the oscillator and will drop the voltage down so that it can meet the requirement of 100mV.



As shown on the right probe frequency reaches 200KHz and voltage is dropped down to desired 100mV_{pk} , since its measured in peak to peak dividing it in half will give peak value. U1 is an Op-amp and is the actual buffer amplifier which is basically used as a way of stopping interference from other circuits, keeping the original unaffected. U2 is another op-amp and changing resistor values will allow the output voltage to change to 100mV.

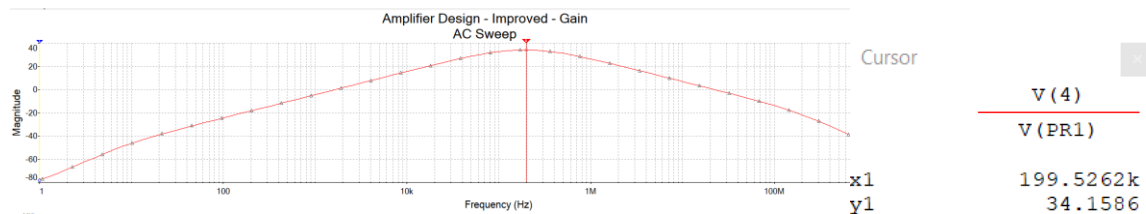
When specification here is met it can all be connected into a single circuit as shown below.



Test and Evaluation

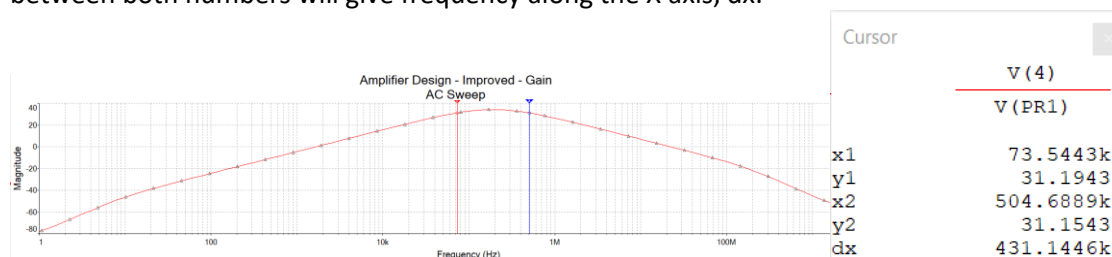
To test circuits there needs to be an expected value in order to compare it to what was measured, a comparison table is made to easily see what met the criteria and what failed.

First on the list to check is the centre frequency, this is measured by doing an AC sweep on the circuit and placing a cursor at maximum level on Y axis. Whatever number is read off X1 is the centre frequency.

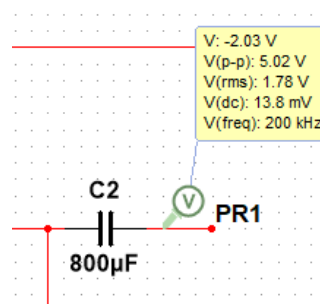
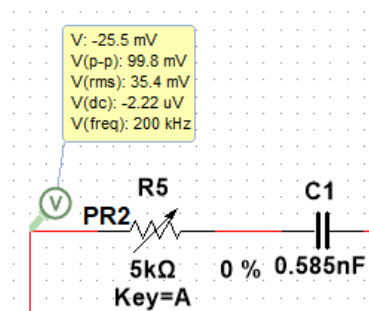


Centre frequency on this circuit is 199.53KHz, close enough to what was specified for, small deviations like this are going to happen since these are more of guidelines as for what is to be expected.

Bandwidth also needs the AC sweep to get measured, this time however two probes are used where one is placed at the lower frequency cut off and second at higher frequency cut off. Both probes can be set at maximum Y value and from there taking three away from that Y value on either side will give both cut off frequencies. This is due to -3dB point and after doing this the difference between both numbers will give frequency along the X axis, dx.



Gain is the next requirement at 50, this is measured by dividing output voltage by input voltage. Measurements will be done using voltage probes. Input voltage on the probe reads to be 99.8mV, for the sake of doing the calculations this will be rounded up to 1mV. Output Voltage is shown on the right, 5V.

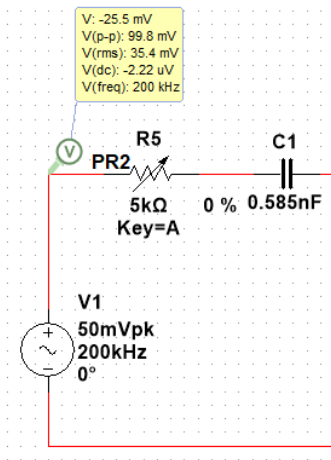


$$\text{Gain} = \frac{V_{out}}{V_{in}}$$

$$\text{Gain} = \frac{5}{0.1}$$

$$\text{Gain} = 50$$

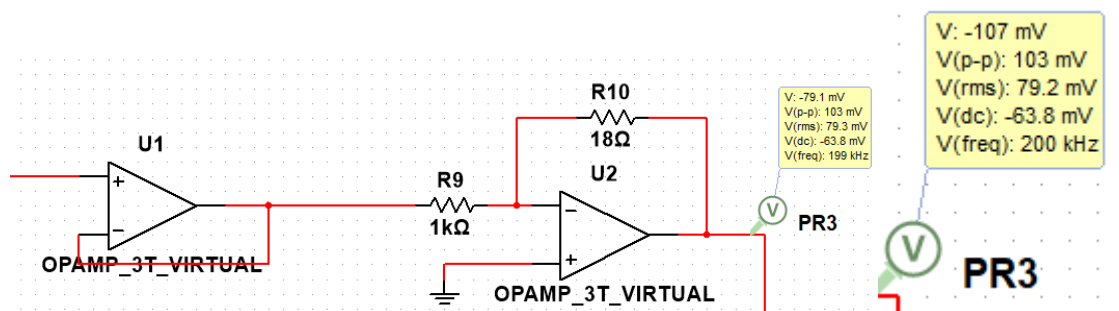
Input signal on the circuit was rated at 50mV_{pk} , this can also be seen from measuring the circuits voltage which was done for working out gain. Since the input signal is 50mV to its peak and measurements done to the circuit are done through peak to peak it would be expected to be double this value, $100\text{mV}_{\text{p-p}}$.



Amplifier	Specified	Measured
Centre Frequency	200KHz	199.53KHz
Bandwidth	60KHz	431KHz
Gain	50	50
Input Signal	50mV_{pk}	50mV_{pk}

A brief look at the comparison table for the amplifier will show most of the specification had been met. The only issue is with the bandwidth being 431KHz when it should be around 60KHz . Other aspects of the tests however were successful and managed to meet the requirements.

Similarly, the amplifier circuit, the oscillator circuit has specified values to achieve but in this case its only two. Frequency must again reach 200KHz and output also needs to be at $100\text{mV}_{\text{pk-pk}}$ or more.



The probe reads at 200KHz as well as $100\text{mV}_{\text{pk-pk}}$.

Oscillator	Specified	Measured
Frequency	200KHz	200KHz
Output	$100\text{mV}_{\text{pk-pk}}$	$100\text{mV}_{\text{pk-pk}}$

For the oscillator circuit all measured values meet the requirements listed in the brief.

Conclusion

Looking at the results for the oscillator there is not much to comment on, both measurements managed to meet the specified values of 200KHz and 100mV_{pk-pk}. This is mainly due to this circuit having less variables in it to affect the output, for example, when trying to get the correct voltage only two resistor values need to be changed in order to get 100mV. Likewise, only capacitors and inductor need changing when trying to get frequency right and neither of these two requirements impact the other from being achieved.

As for the amplifier there are four different criteria to meet, centre frequency, bandwidth, gain, and input signal. Input signal was fine to reach since this just involved getting the input value right from the oscillators output. Centre frequency is another one that was most likely going to be correct since it is taken from the signal source and only being affected by C4 and C1. When it came to working out gain and bandwidth that's where issues would arise because when gain increases, so would bandwidth. Altering R6 and R4 is known to change the gain but an undesired consequence of this is it also impacts bandwidth, but when trying to alter bandwidth by adjusting C4 and C1 it would then alter the gain. This back and forth would continue until eventually after lots of trials and errors bandwidth will be low enough to reach the specification as well as gain.

Some recommendations to be made would be to search further for correct values for C4, C1 and R4, R6 in order to meet the specification for bandwidth and gain. Because adjustments being made here can only really be done using trial and error it can make it much more time consuming to find the right values, unlike other resistors for example which are found by doing calculations.

SOME VALID CONCLUSIONS!

References

Amplifier classes:

<https://www.electronics-tutorials.ws/amplifier/amplifier-classes.html>

Hartley Oscillator:

<https://learnabout-electronics.org/Oscillators/osc21.php>

Colpitts Oscillator:

<https://www.elprocus.com/colpitts-oscillator-circuit-working-and-applications/>

Feedback Loop:

<https://www.electrical4u.com/what-is-an-oscillator/#:~:text=An%20oscillator%20is%20a%20circuit,decided%20by%20its%20circuit%20components.>

Could be lower

FINAL GRADE

GENERAL COMMENTS

Instructor

70/100

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RESEARCH-INFORMED LITERATURE



There was some evidence of further reading and research and your interpretation and understanding of the additional research was satisfactory and demonstrated an underlying appreciation of the subject. Your references still rely on a small selection of mostly credible sources and you need to be more consistent with your referencing conventions e.g. citing diagrams as well as text.

5/10

KNOWLEDGE AND UNDERSTANDING



The knowledge and understanding of the subject demonstrated by this assignment was generally very good. There were few gaps in your knowledge of the basic principles and your understanding of the higher level concepts was demonstrated to a high degree. You have demonstrated a competent critical understanding of the main concepts and expanded your knowledge beyond that contained in the course notes.

21/30

ANALYSIS



Your analysis of the task was generally very good, both in class and as shown in this assignment. You have demonstrated sound critical analysis skills and your approach to the task was logical. You carried out a detailed evaluation of the results and included a good conclusion relating the practical results to researched theory. The conclusions demonstrated very good cognitive skills and the ability to interpret quantitative and qualitative data without error.

21/30

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally excellent. You used both the basic and advanced features of the resources appropriately when designing the circuit and you used appropriate advanced options for testing and evaluating the circuit performance. You managed to design an effective circuit that functioned well within the specification and achieved this by rarely asking for assistance thus demonstrating some advanced problem solving skills. Your results were comprehensive and allowed for a detailed conclusion to be written.

16/20

SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was written in a professional and confident style, however you still need to be more efficient with your word count. The report was very well presented, with excellent diagrams in

7/10

appropriate places, good sentence/paragraph structure and clear calculations.