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Design of a Transistor Amplifier

Electrical and Electronic Principles (GOEE4003)

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Introduction

Transistor Amplifiers play a big role in modern electronics, providing the ability to strengthen weak signals for processing, transmission and control. They are versatile and efficient which is why they are fundamental components in a wide range of things from communication devices to industrial equipment. This assignment covers the principles, operation, and practical design of transistor amplifier, beginning with the single stage design and will progress on to a two-stage amplifier and other possible designs. Throughout this report, this assignment aims to build a clear understanding on how transistor amplifiers function and how they can be optimized for real world applications.

Objectives

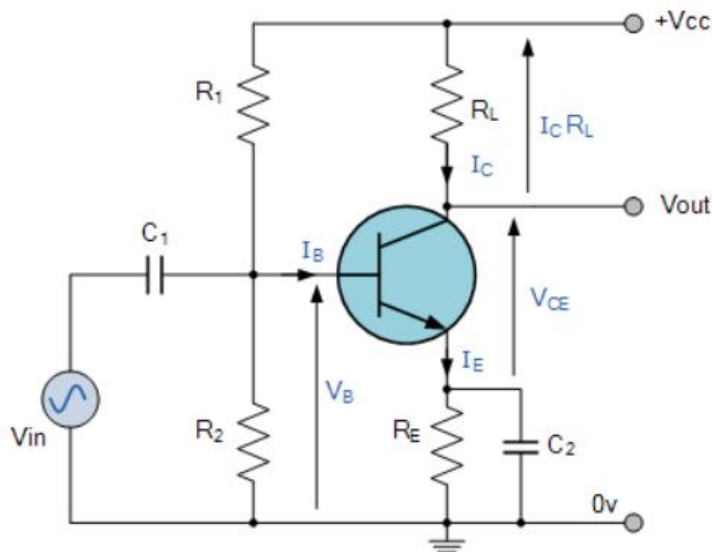
1. Create a design of a single stage transistor amplifier.
2. Simulate this single stage transistor amplifier.
3. Create a design of a two-stage transistor amplifier.
4. Simulate this design of a transistor amplifier.
5. Research why bypass capacitors are important and used.
6. Research alternative designs and why they may be important
7. Physically test the two-stage amplifier and compare results to simulation.

Theory / Research

Bipolar Junction Transistor Amplifiers (BJT)

There are many types of BJT transistor amplifiers. There are three basic versions. Common Emitter, Common Collector, and Common Base transistor amplifiers.

Common Emitter Transistor Amplifiers

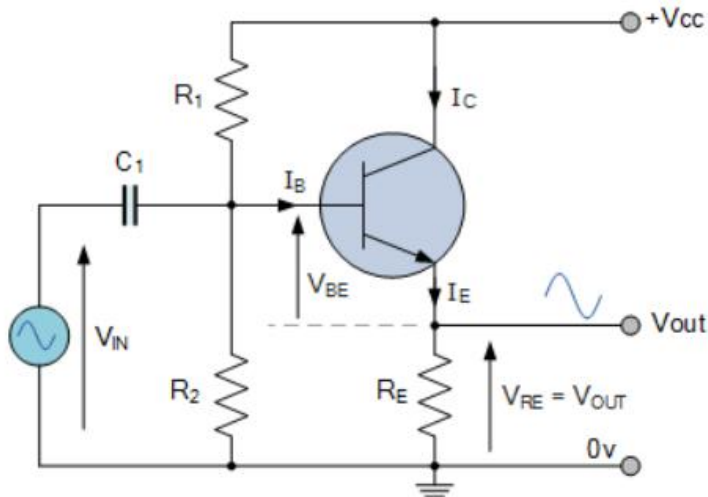


Common Emitter (BJT) Transistor Amplifier (Electronic Tutorials, N/A)

The common emitter amplifier is the most popular bipolar transistor configuration. This is because the input signal source and output load share the same emitter lead of the transistor. (Electronic Tutorials, N/A)

The common emitter amplifier uses two resistors in series as a voltage divider across the power supply which connects at the centre to supply the transistor with the required base bias voltage. (Electronic Tutorials, N/A)

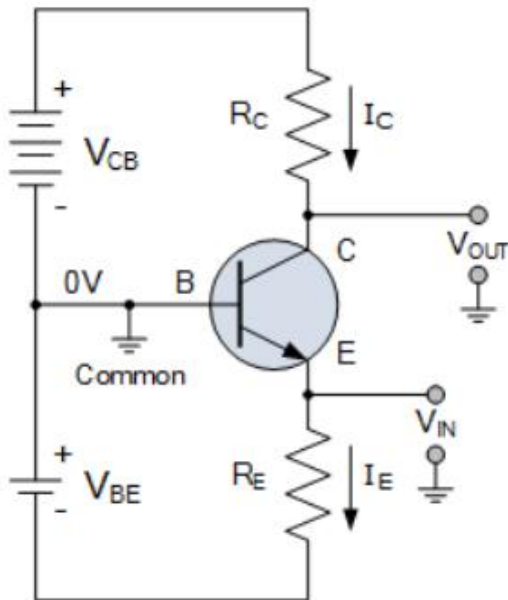
Common Collector Transistor Amplifier



Common Collector (BJT) Transistor Amplifier. (Electronic Tutorials, n.d.)

The common collector transistor amplifier is like the common emitter amplifier where the input is applied to the base of the transistor, but the output is taken from the emitter. And the collector acts as the common terminal as it is connected to the supply. This design does not produce voltage gain, so the output signal is close to the input signal but is less because of the drop between base and emitter. This Amplifier can be used for a buffer between stages as it has no voltage gain, very high input impedance, and very low output impedance. (Electronic Tutorials, n.d.)

Common Base Transistor amplifier



Common Base (BJT) Transistor Amplifier (Electronic Tutorials, n.d.)

Unlike the common emitter and collector. The common base amplifier has the transistor base at ground, with the input at the emitter, and output at the collector. This makes the current gain just smaller than 1. Therefore, this amplifier is suitable for applications such as RF stages and impedance matching. (Electronic Tutorials, n.d.)

Comparison

Amplifier	Voltage Gain	Current Gain	Power Gain	Input impedance	Output Impedance
Common Emitter	High	Medium	High	Medium	medium
Common Collector	None	High	None	Very High	Very Low
Common Base	High	None	Low	Low	High

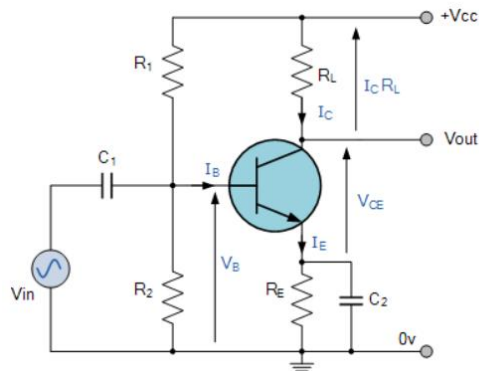
Experimental procedure / Methodology

Single Stage transistor amplifier

Design

The design that will be used is a common emitter amplifier. It is one of the three basic bipolar junction transistor (BJT) amplifiers. (Electronic Tutorials, N/A)

The image below is the schematic that will be followed.



(Electronic Tutorials, N/A)

Calculations

To begin with the calculations for this Common emitter amplifier design all known values are noted below as stated in the assignment brief.

$$V_{cc} = 10V, h_{fe} = \beta = 100, V_{be} = 0.7V, A_{gain} = 5, R_c = 600\Omega$$

To start the calculations V_{RC} needs to be found, we can do this by using $\frac{V_{cc}}{2} = \frac{10}{2} = 5V$

Then find I_{RC} which is found using the ohms law formula $I = V/R$ with inputted values

$$I_c = \frac{5}{600} = 0.0083A \text{ or } 8.3mA$$

Which is wrote as $8.3 \times 10^{-3}A$, in engineering format.

Now, R_E can be found by rearranging the formula $V_{gain} = \frac{R_c}{R_e}$ for R_E , which then turns into

$$R_e = \frac{R_c}{V_{gain}} \text{ and with known values inputted we can find } R_e, \frac{600}{5} = 120\Omega$$

Now to find I_E we know that $I_E = I_C$, so $I_E = 8.3 \times 10^{-3}A$ or $8.3mA$

Then to find V_E ohms law equation $V = I \times R$ can be used, $V_e = I_e \times R_e$

$$(8.3 \times 10^{-3}) \times 120 = 0.996V, V_E = 0.996V$$

$$I_B \text{ is found by using } \frac{I_c}{\beta} = \frac{(8.3 \times 10^{-3})}{100} = 8.3 \times 10^{-6} \text{ or } 8.3\mu A, I_B = 8.3\mu A$$

I_{R2} is found by using $10 \times I_B = 830 \times 10^{-6} \text{A}$

I_{R1} is found by using $11 \times I_B = 913 \times 10^{-6} \text{A}$

V_{R2} can be found by using V_{be} (which was stated in assignment brief) + $V_e = 1.696 \text{V}$

R_2 Can be found using $\frac{V_{R2}}{I_{R2}} = \frac{1.696}{830 \times 10^{-6}} = 2043.4 \Omega$

V_{R1} Can be found using $V_{cc} - V_{R2} = 10 - 1.696 = 8.304 \text{V}$

R_1 can be found using $\frac{V_{R1}}{I_{R1}} = \frac{8.304}{913 \times 10^{-6}} = 9095.29 \Omega$

Component Explanation and usage

R_1 and R_2 is a voltage divider circuit that provides a set voltage to the base of the transistor

C_1 is the input signal coupling capacitor. It blocks DC from the input and allows AC to pass through.

R_E is the Emitter resistor. It helps Stabilise DC by creating negative feedback. And steadies the operating point (Q) (Electronic Tutorials, N/A)

C_2 is the emitter bypass capacitor. It bypasses AC noise on DC signals. Which filters it and provides a clean DC signal. (Elprocus, n.d.)

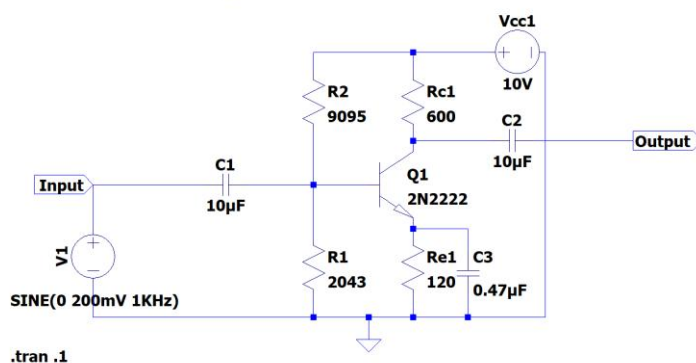
R_C is the load Resistor. It emulates the input impedance of the following stage. (Electronic Tutorials, N/A)

Transistor, it has high voltage and signal gain. And it inverts the signal. (Electronic Tutorials, N/A)

Simulation

Single stage amplifier simulation

First stage

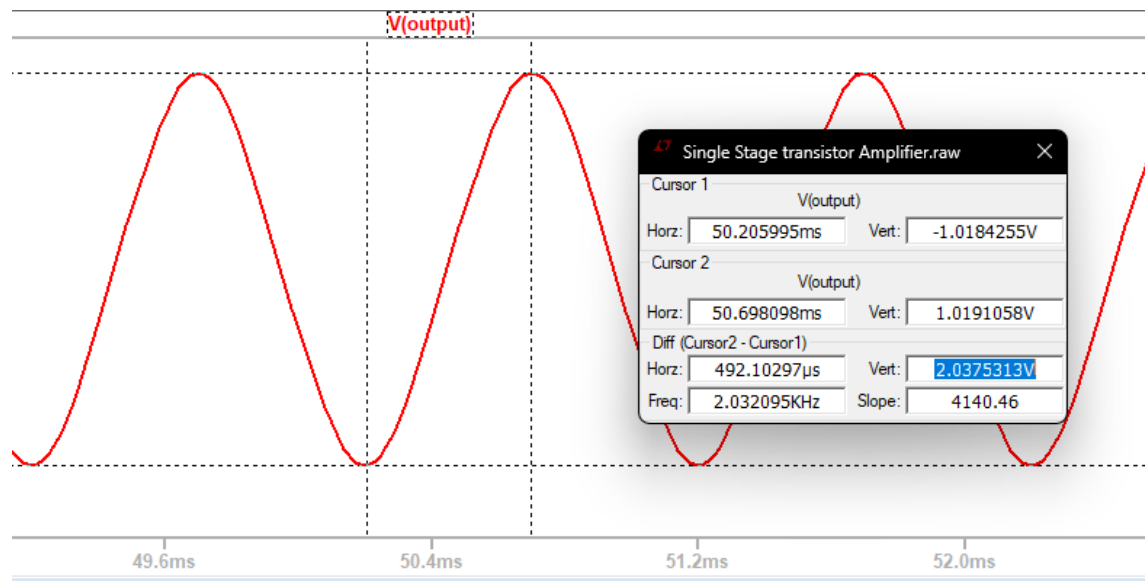


Transistor Amplifier First stage

As stated in the assignment brief a 2N2222 Transistor or a BC109 Transistor needs to be used as they are BJT transistors.

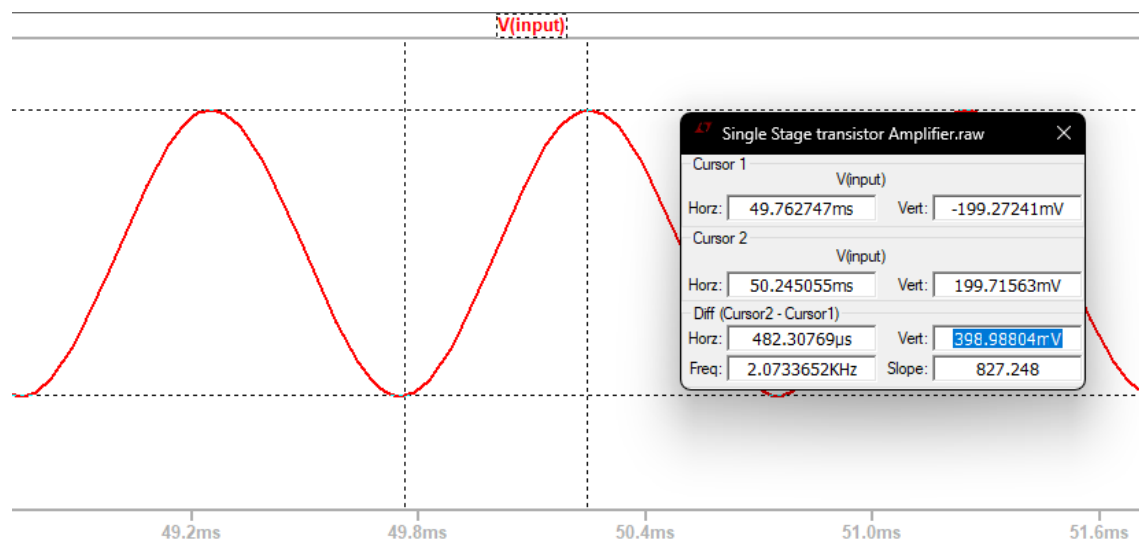
All component values are the ones calculated in the previous section.

By using a $0.47\mu\text{F}$ Bypass capacitor it will give a voltage of 2V at the output. This can be analysed using two cursors, cursor 1 on the trough of the wave and cursor 2 on the peak of the wave.



Output voltage of first stage amplifier

The same can also be done to find the input voltage, which reads 0.4V

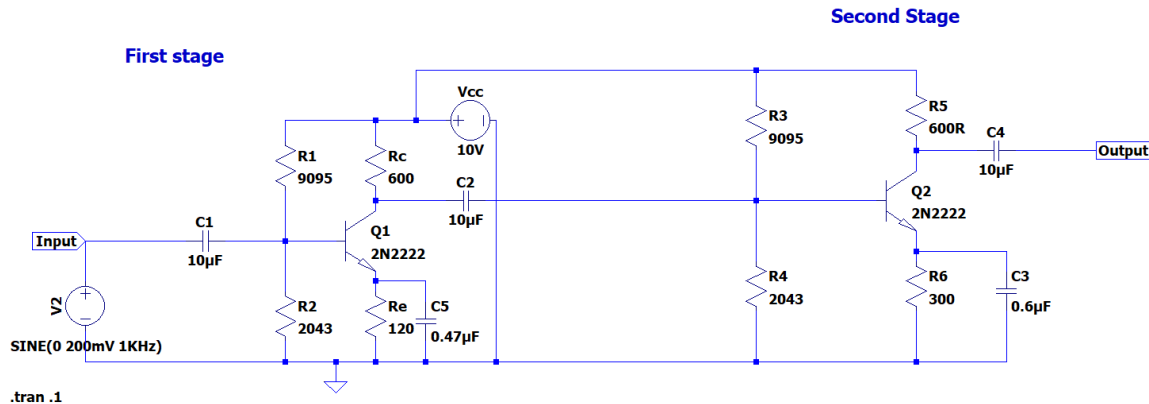


Input voltage of first stage amplifier

The gain of the first stage amplifier can be found using the equation $V_{gain} = \frac{V_{out}}{V_{in}}$

$$V_{gain} = \frac{2V}{0.4V} = 5V$$

Two Stage Amplifier Simulation



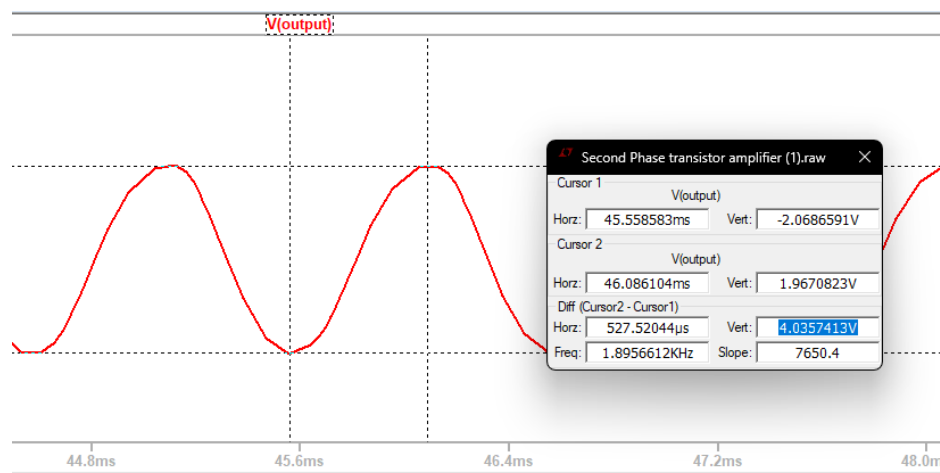
Two stage transistor amplifier.

For the second stage the same Common emitter amplifier will be used, with similar component values.

For the overall Voltage gain to be 10, we need the second stage to have a Voltage gain of 2, so some tweaks must be made.

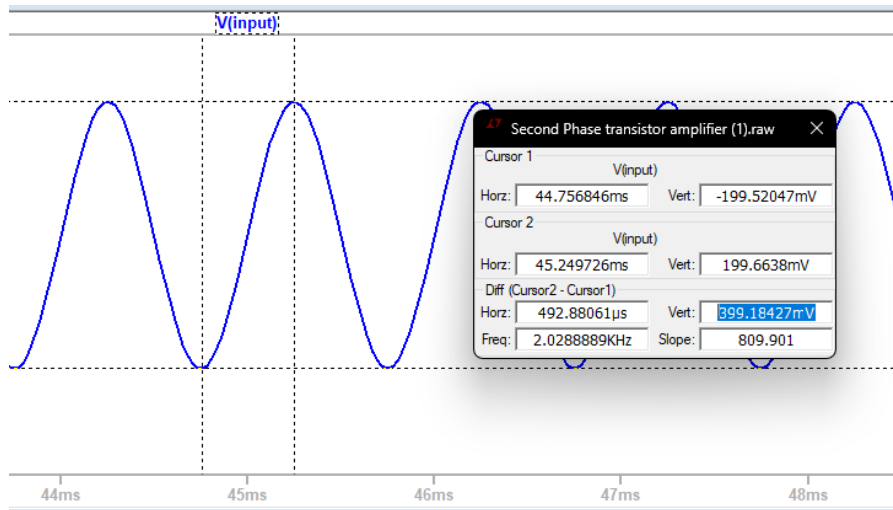
R_E needs to be changed from 120Ω to 300Ω , the second bypass capacitor needs to be changed to a higher Farad in need to get the gain of 2.

The output of the two-stage amplifier reads a voltage of 4



Output Voltage on the two-stage amplifier

The input voltage reads 0.4V



Input voltage of the two-stage amplifier

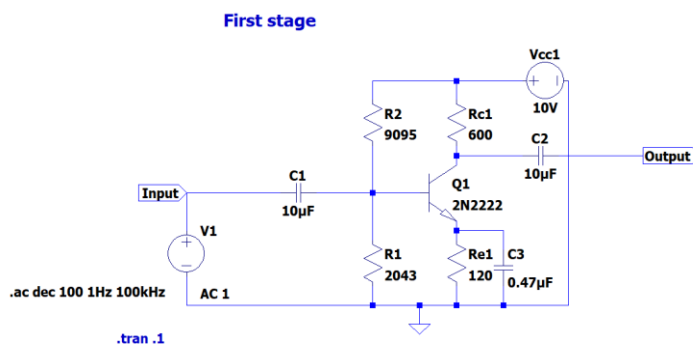
To find the overall voltage gain of the two-stage amplifier can be found with the equation

$$V_{gain} = \frac{V_{out}}{V_{in}} = \frac{4V}{0.4V} = 10V.$$

Impedance of Amplifier

Single stage Impedance

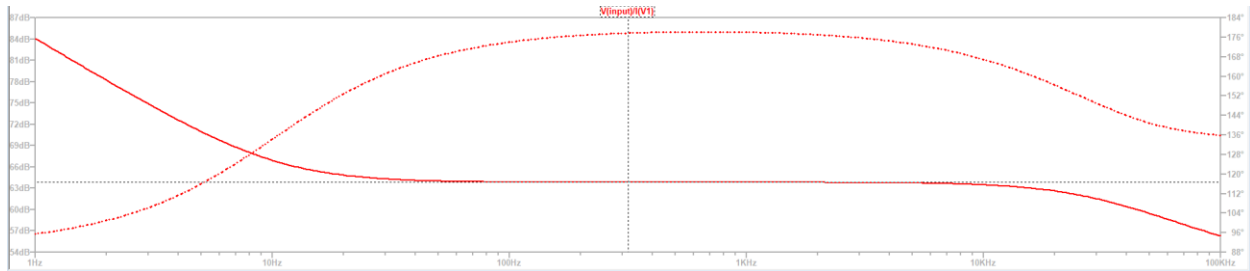
By replacing the signal source with an AC analysis source with an amplitude of 1, The impedance of the first stage can be measured



Amplifier with AC analysis source to measure impedance.

With the source placed the simulation can now be configured. The simulation will run a decade sweep, with 100 points per decade that starts at 1Hz and ends with 100kHz.

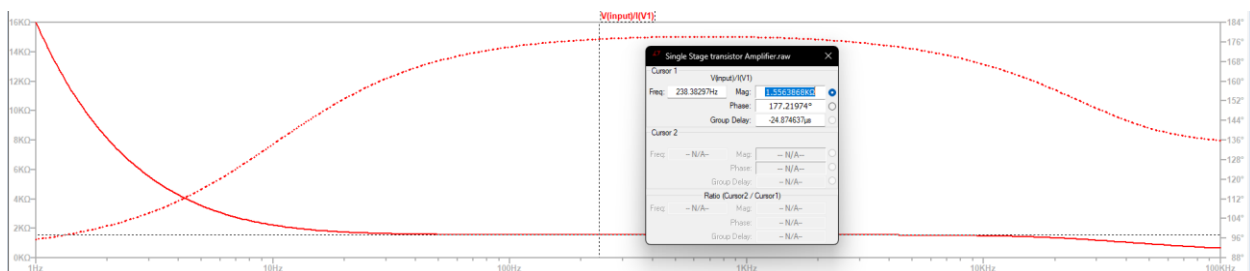
By changing the trace label with the expression 'V(input)/I(V1)' we can calculate the Input impedance of the single stage amplifier.



Input impedance of the single stage amplifier

On the Y axis it is still being measured in dB, so it needs to be changed into a linear representation.

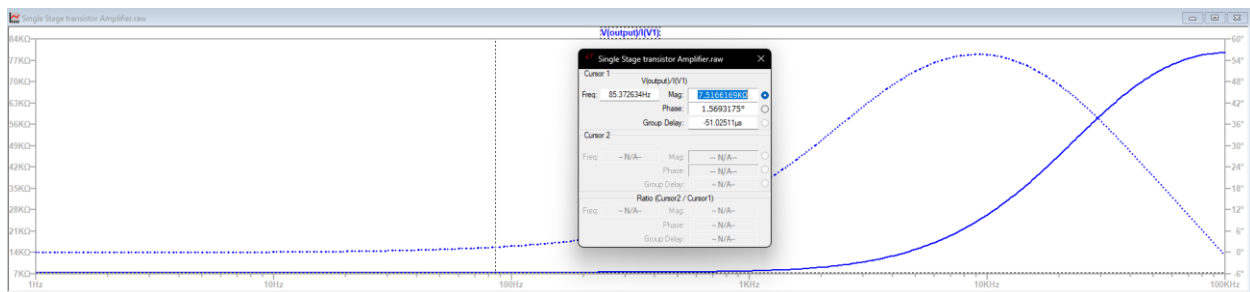
Now the impedance is shown in ohms, and at the steady point of the simulation it reads a value of 1.56KΩ



Input impedance in Ohms of the first stage amplifier.

To find the output impedance of the single stage amplifier the same process can be used.

The output impedance of the single stage reads 7.51KΩ

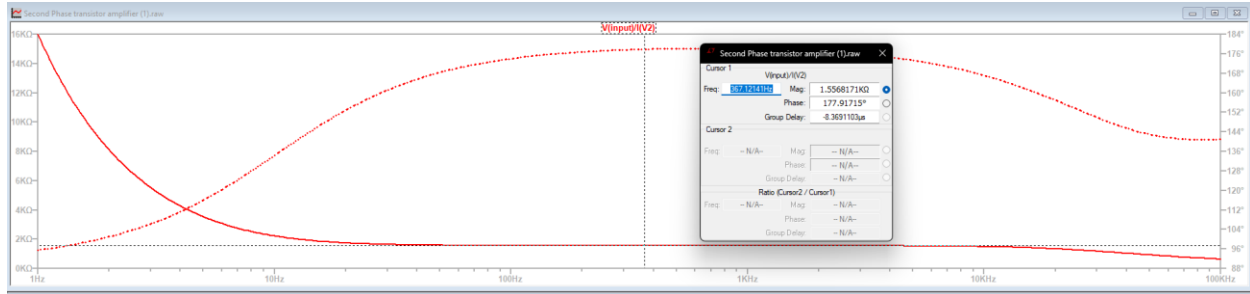


Output impedance of the single stage amplifier

Two-stage amplifier impedance

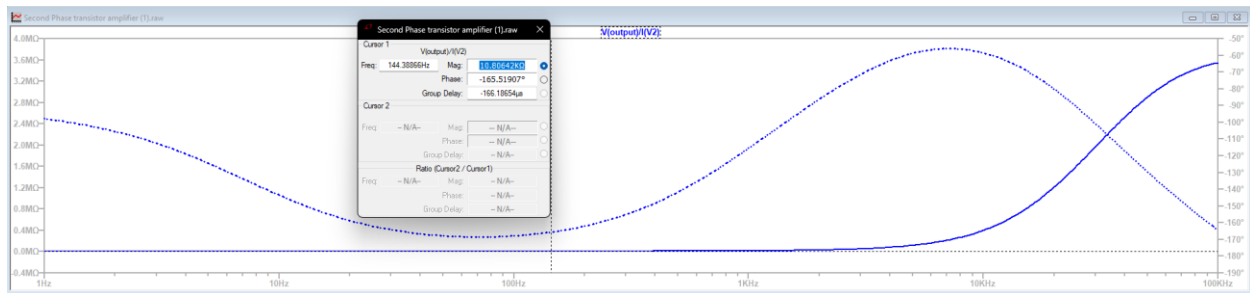
The exact same method will be used to measure the impedance of the two-stage amplifier.

The input Impedance still measures 1.56K Ω at a steady point.



Input Impedance of the two-stage amplifier

The output impedance of the two-stage amplifier measures 10.8K Ω at steady point.



Output impedance of the two-stage amplifier

Simulation Analysis

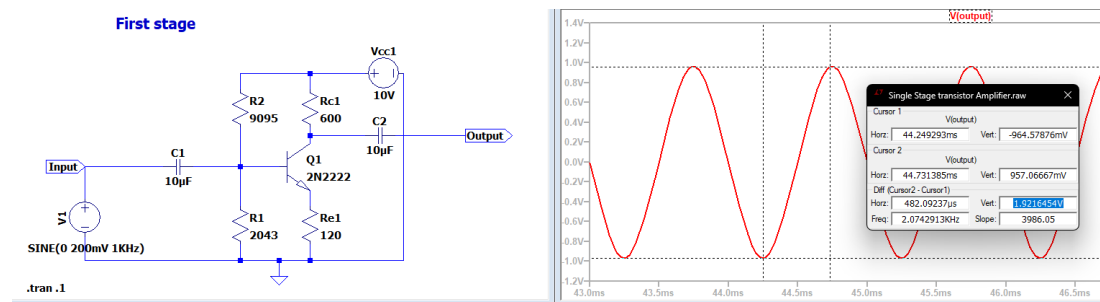
The first stage had an overall voltage gain of 5V, which is what was required in the assignment brief.

The Two-Stage amplifier had an overall voltage gain of 10V which was also required in the assignment brief.

Effect of Bypass capacitors on the single stage amplifier

When the bypass capacitor is removed in the first stage on its own, it does not make a big enough difference to cause any problems.

The input voltage will stay the same as it is not affected by the bypass capacitor. The output voltage with the bypass capacitor removed reads 1.92V



Output voltage on Single stage amplifier with Bypass capacitor removed

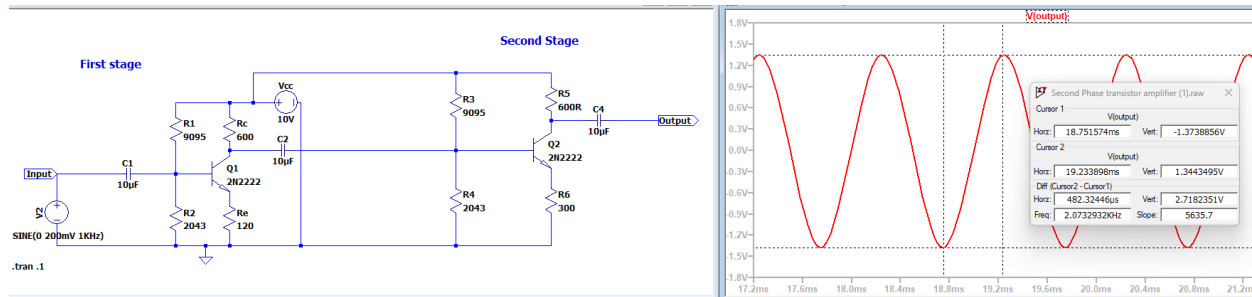
The overall voltage gain on the single stage amplifier without a bypass capacitor can be calculated with the same formula

$V_{gain} = \frac{V_{out}}{V_{in}} = \frac{1.98V}{0.4V} = 4.95V$. The change in overall voltage gain is not significant enough to make a big difference.

Effect of Bypass capacitors on the Two-Stage amplifier

On the other hand, With the bypass capacitors removed on the two-stage amplifier a big difference is made.

The input voltage will stay the same, But the output voltage of the two-stage amplifier reads 2.71V which is significantly less than when bypass capacitors are added.



Output voltage of two stage amplifier when bypass capacitors are removed

Which now using the V_{gain} equation we can find the gain of the two-stage amplifier when bypass capacitors are removed. $V_{gain} = \frac{V_{out}}{V_{in}} = \frac{2.71V}{0.4V} = 6.78V$

This is significantly less than the 10V gain required for the two-stage amplifier. Meaning the bypass capacitors are a useful part of the amplifier to get improved qualities and higher voltage gain.

Scenarios when this amplifier could be used

This two-stage amplifier would be used in scenarios when high voltage gain is needed.

Such as:

- Audio pre-amplifiers
- Radio and Communications circuits (With correctly tuned components)
- Electronic Measurement equipment

Improvements that could be made

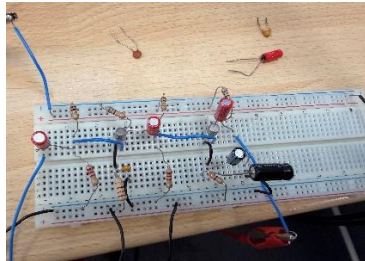
Some improvements that could be made are adding a buffer amplifier between the two stages, this could be a common collector amplifier that was discovered in the research beforehand.

Some component values could have been adjusted to remove the distortion on the second stage of the amplifier.

Conclusion

This simulation confirms that the calculations made were correct. The overall voltage gain of the stages meets the requirement of 10V. Some distortion was present in the simulation, but this is not a major fault and could potentially be fixed with some fine tuning to the calculations.

Breadboarding



Breadboarded Two-stage amplifier

First stage

To start, the first stage needed to be built. A lot of components values had to be changed as there were not any at hand. The resistors had to be rounded to the nearest standard value available, and the transistors were changed from 2N2222 to BC109 as there was no 2N2222 available. This is fine as the BC109 is still a BJT transistor and it is said that it is allowed.

The coupling capacitors stayed as $10\mu\text{F}$, but polarized capacitors were used. They still serve the same purpose as blocking DC so it's okay.

The value for R_1 was rounded from 9095Ω to $10\text{K}\Omega$, the value for R_2 was rounded from 2043Ω to $2.2\text{K}\Omega$.

R_E stayed the same as 120Ω is a standard value.

R_C was stated as 600Ω in the assignment brief, but 600Ω is not a standard value so it was rounded up to 820Ω .

The bypass capacitor stayed the same as the simulation at $0.47\mu\text{F}$.



$0.47\mu\text{F}$ bypass capacitor for first stage

Second stage

The second stage uses the same R_1 and R_2 values as they are the voltage divider circuit.

R_C also stays the same as it's the load resistor.

R_E value is rounded from 300Ω like the simulation to the nearest standard value to 330Ω .

The bypass capacitor had to be changed multiple times to get the desired overall voltage gain of 10. First a $1\mu\text{F}$ capacitor was used but the gain was too little, then a $2.2\mu\text{F}$ capacitor was used and the gain was still too little.

By adding two capacitors in parallel the total capacitance is increased. So, the $1\mu\text{F}$ and the $2.2\mu\text{F}$ capacitors were placed in parallel as the bypass capacitors and it should give the overall voltage gain of 10V



1 μF and 2.2 μF capacitors for second stage bypass capacitors

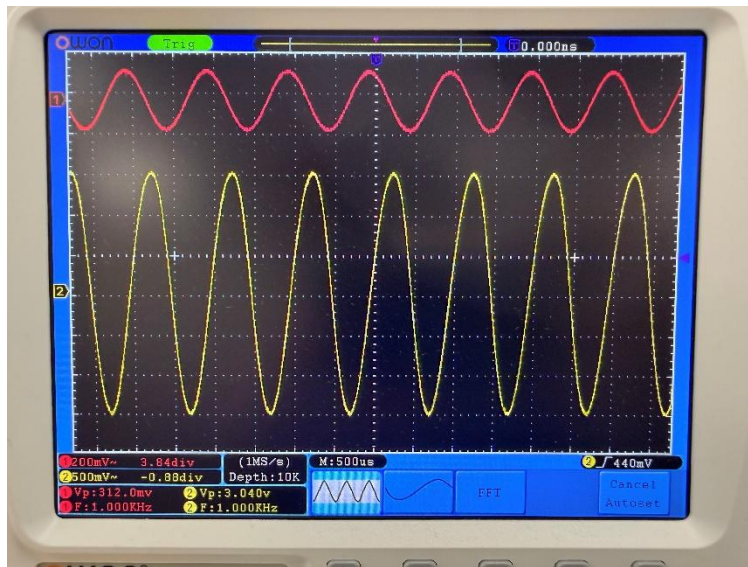
Results

By using the formula for $V_{gain} = \frac{V_{out}}{V_{in}}$ we can find the overall voltage gain.

The V_{in} of the two-stage amplifier measured 0.31V, and the V_{out} measured 3.04V

Therefore the overall Voltage gain for the Breadboard two-stage amplifier is:

$$\frac{3.04}{0.31} = 9.81V$$



Vin and Vout of the breadboarded Two-stage amplifier

Test Equipment

The test equipment in this practical that were used were:

- Function generator at 1kHz, 0.2V, Sine Wave
- DC power supply at 10V
- Oscilloscope, with two channels measuring AC.

Analysis

When simulated the results were theoretical as there was no real-world alterations such as tolerances and specific component values. Because of these issues the component values between the simulation and breadboard were quite different. But Afterall the breadboard had an overall voltage gain of 9.81V and the simulation had a voltage gain of 10V. These are very close to each other and are at or near the required overall voltage gain of 10V.

Overall Conclusion

In conclusion this two-stage BJT amplifier was successfully calculated, simulated, breadboarded, and tested. Showing how the common emitter amplifier can be used for circuits that require high voltage gain at small signals. By calculating, simulating, and testing this amplifier it has helped us to understand how it works, how to measure specific things such as impedance of the circuit and its voltage gain and over come minor issues when breadboard. Such as component tolerances, non-available specific component values.

In the future it would have been better to source and use a 2N2222 transistor to get more accurate results when comparing to the simulation. Also, in the future it would be good to measure the Input and output impedance of the circuit on breadboard to understand it better and see the difference when component tolerances are included and values are changed.

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