ELECTRONIC DESIGN EXERCISE 2 – Audio Preamplifier.
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Section 1: Introduction

This report focuses on the design, construction and testing of a class A amplifier (Figure 8). The class A amplifier can be used as a preamplifier, in the case of this report a microphone preamplifier. The aim was to use capacitors, resistors and the BC547[1] transistor to construct the amplifier on stripboard using the ideas learned in 204 and revolving around the general design of the common emitter amplifier (Figure 8). The pre-amp must have met certain design specifications: it must use the components supplied and be able to amplify signals over a wider part of the audio range as possible, without a bypass capacitor have a gain of 5x to amplifier small signals (20mv Typical value for the output of a cell phone.) and run from a 9-volt power supply. Following this to add an emitter capacitor and examine the change in gain values.
The BC547 Transistor is the main component of the circuit being constructed. The BC547 is an NPN type transistor that has three terminals. The base terminal (Thin (a few micron) semiconductor region with very low doping), the collector terminal (Relatively thick with a medium high doping (10^16)), and the emitter terminal (Thick with the highest semiconductor doping of all three terminals (10^18)). The NPN transistor has a configuration like that in figure 9 which shows how current from the collector to the emitter terminal is controlled by the base terminal. The BC547 is a current operated device which allows large IC to flow freely only if the base terminals current is flowing into the base terminal. The current gain in the transistor is a ratio of IC to IB which is directly linked to value beta. Ic = βIB. But we can generally ignore beta in the common emitter amplifier set up. As the resistors selected generally are what limits the current. Generally, it is useful to find a way to rid the dependency on beta as it is known to change in different conditions and various components.

Section 2: Design Description

Prototyping the circuit involved constructing a circuit schematic with the general components and then calculating the values required. The schematic attached includes the actual values of the circuit components. To find component values we look at the design specifications given. We have a 9v power supply, the operating point V_CQ of this amplifier can be assumed to be about half of this. This case 5.5v was subtracted from the 9v to make sure the circuit is well below the thresholds. Assuming Ic = 1mA we could find the value of RC:

$$Rc = \frac{9v-3.5v}{1mA} = 5.5K\Omega \rightarrow\ 5.6\text{K}\Omega\ (\text{E12})$$

As the circuit was to have a gain of 5:

$$Av = -\frac{Rc}{RE} \rightarrow (Av * RE) = RC = 1.1K\Omega \rightarrow\ 1.2\text{K}\Omega$$

These values give a gain:

$$Av = \frac{5.6k}{1.2k} = 4.667x$$

which is low, so adding a 470-ohm resistor in series with Rc allowed the gain to be just over 5:

$$Av = \frac{6070}{1200} = 5.06x$$

To find R1 and R2 used a simple voltage divider. The transistor at its heart is no more than 2 diodes back to back, the transistor itself has a constant voltage drop of 0.7V. We can in this case assume the emitter current will be the same as the collector current as the differences between the actual values are negligible:

$$I_E \approx\ I_C \approx 1mA$$

We can then calculate VEQ:
1mA*1.2KΩ =1.2v
Adding this to our constant voltage drop gives a Vb minimum so 1.9v is the minimum voltage required for the amplifier to work. So:

$$R2 = 10RE = 12K\Omega$$

$$R1 = R2\left(\frac{Vcc-1.9v}{1.9v}\right)=$$

$12K\Omega(\frac{9v-1.9v}{1.9v})$ = 44.8KΩ →39K + 5.6K (E12)

With resistors selected the capacitors we selected with design simplicity in mind and so, all capacitors in the amplifier were selected to be 10uF.
All components were calculated first to find the vest values to fit. One of the main trade-offs is the use of E12 series. These are ideal values of resistors but are still not exact to what was calculated as that would require far more components. And more complicated design, the use of values not perfect meant the gain was not an exact value. Not that it could have been as components in real-world application are not perfect. A trade-off I knowingly made was the use of same value capacitors. Using 10uF allows for a simpler design, however does not limit the bandwidth as much calculated capacitors could have.
The bypass capacitor was added with a switch to allow the circuit to be tested with and without the capacitor interference. This capacitor like the others was 10uF and allowed for a massive increase in gain overall, peaking at 200x.
Circuit Schematic:

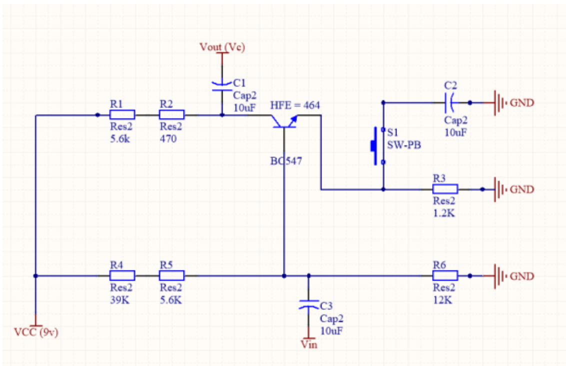

Figure 1 (Circuit schematic for the common emitter amplifier, shows the general layout and makeup of the circuit with each individual component value.)

From the prototyped circuit and the schematic, I was able to design the circuit as a PCB that could be used to make for a cleaner and smaller design:

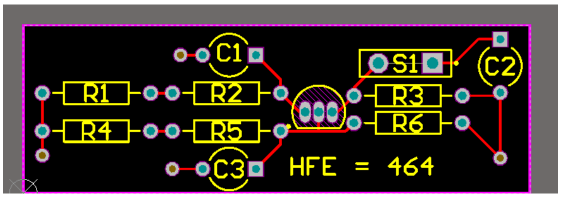

Figure 2 (PCB Design for the common emitter amplifier based on the above circuit schematic (Figure 1))

As seen in the PCB the design has been streamlined and uses the extra holes for wire attachments, the schematic has a switch added to make for ease of testing. The circuit layout follows the logic of the circuit the best the components allow.
Note the lack of right angles to prevent heat and therefore heat induced resistance allows for longer life of the circuit.

Section 3: Prototyping, Construction and testing.

Testing confirmed the circuit would work well as a microphone pre-amp. Preliminary results showed that as the input was increased dramatically, the gain decreases. When the input reached 1.2vpp noticeable clipping of the negative cycle occurred. Preliminary results for the circuit with the bypass capacitor shows clipping at signals over 12-15 mV, to allow for testing a 10kΩ potentiometer was added (Figure 6), this effectively acted like a volume switch and allowed me to examine smaller input voltages, where clipping did not occur. Originally the gain was 4.667 the prototyping on the breadboard showed the resistance in RL needed to be increased to get the appropriate gain.
Construction of the circuit followed a simple method, using the components from the prototype, they were inserted into the board before soldering, a circuit diagram was drawn to follow the logic of the circuit. Once confident the design was correct. The components were soldered and clipped, to create a clean and effective circuit.
When testing the final constructed circuit several issues were encountered. The use of polar capacitors meant that the polarity and position of these capacitors were of importance. Initially, the 2 out of the 3 capacitors were incorrectly placed and had to be removed and replaced. This would not have affected the operation of the amplifier in the short term. Over extended periods of time the circuit would have stopped functioning.
To help with the logic of the circuit, the wires were colour coded: Red → Vcc, Black → Ground, Yellow → Input, Brown → output. This allowed for functional connections to be made for the circuit to be tested.
The circuit did work as expected with the expected frequency and phase response like shown in the data, the main issue is the operating point used to find the resistor values were far too small, 1.9 instead of 3.5 this resulted in the negative cycles clipping. The circuit did have the operating point of 1.9 which was the value used in calculations and so this shows the circuit was operating as designed. And human error caused this clipping.
The final circuit can be seen in figure 5, which shows the logical layout of the circuit board and shows the error made with the wire colours.
Data
All voltage inputs recorded in the data were measured from the signal generator in HI Z output mode so are taken as exact.
Prototype data:
Frequency: 1kHz

Vout (Vp-p)	Vin (mV p-p)	Gain
1	200	4.8x
2.32	500	4.6x
3.16	700	4.514x
3.52	800	4.4x

N.B: Gain decreased as the input was increased. The larger the input the more clipping occurred on the bottom rail. Clipping began at 1.2vp-p input without a bypass.
These results promoted the increase in resistance for RC from 5.6kΩ to 6070Ω for the final design.
With the emitter bypass, there was no signal small enough to test the circuit successfully. (without clipping) Hence the addition of the 10KΩ Potentiometer in the final design (Figure 6).

With the circuit constructed:
Frequency 1kHz
Without Bypass emitter capacitor.

Vin (mV p-p)	Vout (V p-p)	Gain
20	102mV	5.1
50	250mV	5
100	500mV	5
250	1.25V	5
500	2.44V	4.88
1v	4.36V (Clipped)	4.36
2v	7.52V (Clipped)	3.76
3v	7.44V (Clipped)	2.48
5v	7.52V (Clipped)	1.504

With the circuit constructed:
Frequency 1kHz
With the Bypass emitter capacitor.

Vin (mV p-p)	Vout (V p-p)	Gain
1	280mV	280
5	780mV	156
10	2.04	205
15	2.56	170.67
20	3.08 (Clipped)	154

N.B At 1mV the input signal was almost more noise than signal. What we can see with this data is the gain is highest when the circuit has a smaller input. As the input increases in size the value of gain decreases. This data shows how the common emitter amplifier behaves at a single frequency as the input signal is increased. The relationship between the input voltage and the gain can be shown in figure 3 for the common emitter amplifier without the bypass and figure 4 with the bypass capacitor. (Figure 11 shows the output for a 15mv input.)

Frequency response data:
Constant Vin:
Without Bypass: 20mV
With Bypass: Shifted with the frequency and so was also recorded.

Frequency	Vout (Vp-p)	Gain	Vin (Vp-p) With Bypass	Vout (Vp-p) With Bypass	Gain with bypass
1MHz	30.8mV	1.54	NaN	NaN	NaN
750KHz	40.4mV	2.02	NaN	NaN	NaN
500KHz	54.4mV	2.72	NaN	NaN	NaN
250KHz	80mV	4	NaN	NaN	NaN
150KHz	90.4mV	4.52	NaN	NaN	NaN
75KHz	98.4mV	4.92	NaN	NaN	NaN
22KHz	100mV	5	800mV	3.95mV	202
2KHz	100mV	5	1.5V	8mV	188
200HZ	100mV	5	1V	5.2mV	192

25Hz	96mV	4.8	NaN	NaN	NaN
5HZ	60mV	3	NaN	NaN	NaN
2HZ	22.4mV	1.12	NaN	NaN	NaN

N.B: From the results above we see that without the bypass capacitor the bandwidth is massive with gain from 1MHz right down to 3Hz this was surprising, as it was unexpected to see gain with such a high frequency as well as such a low frequency. But what the results show is the perfect calculated gain occurs between the audible range of 22kHz down to 200Hz. This shows the circuit does function best at the audible range and so is working as it should. With bypass capacitor, the results show that the emitter amplifier only functions within the audible range. Anything above 22kHz was massively noisy and distorted to the point it was unrecognizable, and lower frequencies the amplifier stopped functioning. I can only assume looking at the data that high frequencies have a smaller input and lower frequencies do as well. So, the higher/lower the frequency the smaller the input to the point it is negligible, and the amplifier cannot amplifier it as it will be amplifying the noise more than the signal. But it does show that with the capacitor it works within the audible range and so functions as it was designed to except cutting off a little too high. Ideally, we would like to see frequency's right down to 20Hz
From the frequency response results, it can be concluded the circuit is functioning properly/ Most ideally within the audible bandwidth. This gain→frequency relationship can bee seen in figure 12

Phase response: To gather the phase response a rather simple method was used. Counting the divisions between the peaks of the input and output dividing the divisions counted by 2 divisions (Which is 180 degrees) then multiplying the answer by 180 to see the amount of phase shift. Dealing with capacitors in an AC environment we know the current will lead the voltage in the circuit. So, the phases shift was then added to 180 to see what angle it was at in comparison to the voltage peak that was following:

The Input for the circuit was 200mV Pk-Pk without the bypass capacitor.

Frequency	Phase Shift	Total Phase	Vin (Vp-p) With Bypass	Phase Shift	Total Phase
1MHz	50	230	NaN	NaN	NaN
500KHz	63	243	NaN	NaN	NaN
250KHz	72	252	NaN	NaN	NaN
100KHz	36	216	NaN	NaN	NaN
22KHz	45	225	800mV	0	180
2KHz	0	180	1.5V	0	180
200HZ	0	180	1V	0	180
25Hz	0	180	NaN	NaN	NaN
5HZ	18	162	NaN	NaN	NaN

N.B: The results assuming the calculations correct shows that as frequency increases, the phase shift increases. Then decreases following the pattern of the gain. What is also noticed is within the audible range with and without the bypass capacitor the phase is stable at 180, which is expected as the current leads the voltage. (Figure 10 Shows the effect of a 1MHZ frequency on a 200mv signal input)

The common emitter is quite inefficient. Calculating the power consumption proves this.

$$DC_{power\ consumption} = V_{cc} * I_{cc} \rightarrow 8.94v * 1.12mA = 10.8mW$$

$$Active_{power\ consumption} = V_{cc} * I_{cc} \rightarrow 8.94v * 1.12mA = 10.8mW$$

N.B There is absolutely no change in the power consumption for active and DC, which is a slightly surprising result considering it was expected for there to be a small change.

$$AC_{power\ consumption} = V_{CE_{RMS}} * I_{C_{RMS}}$$

$$V_{CE_{RMS}} = \frac{V_{cc} - I_{EQ}(R_c + R_E)}{2\sqrt{2}}$$

$$= \frac{9v - 1mA(6070 + 1200)}{2\sqrt{2}}$$

$$= 1.035V$$

$$AC_{power\ consumption} = 1.035V * 2.86E^{-5}A = 3E^{-5}$$

Efficiency of the circuit can be then calculated with:

$$\mu = \frac{AC_{power\ consumption}}{DC_{power\ consumption}} \rightarrow$$

$$\mu = \frac{3E^{-5}W}{10.8mW} = 0.002777 \rightarrow * 100 = 27.7\%$$

This shows the amplifier works at about 30% efficiency which is as expected for a common emitter class A amplifier.

What this concludes is all the tests taken show the circuit functions as a typical class A amplifier.

Power calculations:

$$I_{C_{RMS}} = \frac{V_{C_{RMS}}}{R_{C_{RMS}}} \rightarrow \frac{34.4\ mV}{5970} = 2.86E^{-5}A$$

$$A_i = \frac{I_{out}}{I_{in}} \rightarrow \frac{2.86E^{-5}A}{3.8\mu A} = 7.53x$$

$$A_v = \frac{V_{out}}{V_{in}} \rightarrow \frac{176mV}{33.2\ mV} = 5.3x$$

$$A_p = A_v * A_i = 5.3 * 7.53 = 39.9x$$

Section 4: Discussion and conclusions

When constructing the circuit, it was found that 2 of the polar capacitors where soldered into the circuit in the wrong polarity. These capacitors had to be removed and replaced, this issue would only have impacted the circuit with extended use. While after soldering the wires in place, testing for the circuit was begun. The issue was the circuit did not work at all. Recalculating values and using a DVM to point test each of the transistor pins as well as input and output could not find the issue. Continuity testing showed that there was not short. It was concluded the logic of the circuit may be wrong. Following the input through the circuit, a circuit diagram was drawn, and the issue was found to be the wires for the input and output where inverted. The input was brown (Compared to

the planed yellow) and the output was yellow (Compared to the planed brown). Once the circuit was connected properly the circuit was fully operational and worked the way it should.
While testing it was noted the negative cycle of the output was clipped when the input was increased to 430mV or if the Bypass capacitor was connected. The reason for this was:
The circuit itself was of best design possible for the components supplied. If this circuit was to be used in applications, it would not perform to the standards it should. The circuit itself was far too large and could have been reduced. With some recalculations and calculations of capacitor values could create a far better circuit, capable to do what it designed to do. The common emitter amplifier did amplify small signal voltage correctly but without the bypass capacitor had a bandwidth from 5HZ to 250KHZ which is massive and impractical. If this alignment was to be repeated the values for components in the amplifier would be recalculated and instead of shipboard, the PCB design above would be utilized. This would create a smaller more concise more logical circuit which has a better more restricted bandwidth and a larger gain.

The problem with the Q-point of this circuit. If you look a section 1, we see the equations use Vb as the operating point. This is incorrect and is the reason the circuit when with higher inputs being passed in the negative cycle of the input hits the ground rail. The Circuits operating point (Vc in respect to ground) is measured as 2.71v in both DC and active mode. This is different from the calculated 3.5 which it should be. This could be due to the difference in ideal to real components used in the design vs the construction of the circuit. This is built on further in the extension section.

However, the main issue with the construction of the amplifier was the error in calculations. Because of this error, the resistor values calculated were incorrect. This meant that R2 was too large reducing the operating point which is theoretically at its best when half of Vcc about 3.5-4.5 volts. Hence when a 56k ohm resistor was placed in parallel with R2 allowing the value to be dropped and the operating point to be raised to a value more suitable. Allowing for a larger Vin and increasing the input current too.

Personal Comments:
Well like the last design exercise it was enjoyable albeit stressful. When I first started this exercise, I decided being so busy to take some shortcuts, however after the first lab taking 3 hours to shortcut my way through I was no further ahead when I left than when I walked in. in other words, it didn't help me at all and only wasted my time. The next day I came in at 8 in the morning and calculated all the values I used in less than an hour I had calculated and prototyped a perfectly functional amplifier with a gain of 5. Goes to show shortcuts never help in the end. I enjoy exercises like this because it really feels like we are learning about what our degree is. For most, it is a small taste of the future for us. It's educational. I can't say that I really had anything I didn't enjoy. I would have really enjoyed printing a circuit board as stripboard was complicated to understand for me at first. But overall the project was again one of the most enjoyable things I've done at university so far.

Conclusion
To conclude, it would seem the circuit prototyped constructed and tested in this report works functionally as a microphone preamplifier, able to take small signals in and out put larger signals, without the bypass capacitor there is a gain of 5x which is was required, the circuit operates most ideally when the frequency is within the audible range of humans, in the case of the circuit with the bypass capacitor, it will only operate in this range except towards the lower end of the spectrum in which the circuit dies out around 100HZ. Operating from a 9v Vcc, within the audible range, with gain, it would seem the investigation was successful. Like mentioned in section 3,4 perhaps the circuit could have been constructed to work more as intended with specific cut off frequencies if the capacitor values where calculated. But in future it would not only be the capacitors but the resistors as well, and the use f a PCB would mean a clean functional circuit. Something for next time.

References

[1] FAIRCHILD, "BC546/547/548/549/550," FAIRCHILD, [Online]. Available: https://www.sparkfun.com/datasheets/Components/BC546.pdf. [Accessed 7 6 18].

[2] ASPENCORE, "NPN Transistor," ASPENCORE, [Online]. Available: https://www.electronics-tutorials.ws/transistor/tran_2.html. [Accessed 08 06 18].

Section 5: Extension Questions

- Explain the purpose of each capacitor you used in your circuit, how do you expect the frequency response of your amplifier to change with a change in the values of each of these capacitors? Explain:
  - C1 and C3 in figure 1 are coupling capacitors. These capacitors separate AC signals from DC biasing voltage. This ensures that only AC signals can be passed into the preamplifier. In application coupling capacitors are used to prevent any DC component from other amplifier stages. C2 or the emitter bypass capacitor acts as effectively an open circuit for DC biasing, the capacitor essentially becomes a short circuit at higher frequencies so at his point on RC and a very small re (not to be confused with RE) acts as the load for the transistor, hence the voltage gain increases drastically. In the circuit in figure 1, changing the value of C1 would change the output cut-off frequency, (Dictating the highest frequency that could exit the preamplifier) Changing C3 would change the lower cut-off frequency. (Dictating what the lowest frequency could enter) Changing C2 would change the gain output as it would alter its frequency response. And so, if its cut off frequency was higher, then the circuit would require high frequencies to make it behave like a short circuit, then it would require a higher frequency input, and so lower frequencies would still pass through the capacitor as if it was an open circuit.

Equations:

Input cut-off: $\frac{1}{2\pi(R_s||R_1||R_2||\beta(R_E)+r_e)+(C_{be}+C_{Miller})}$

Output cut-off: $f_c = \frac{1}{2\pi(R_c+R_L)+C1}$

- Discuss the designed Q point, and the actual Q point of the circuit, what is this due to? Can you improve on the design?

  I designed my circuit to have a Q-point of 3.5 volts at IC=mA however due to some errors in calculations this was not the case. The Q- point measured was 2.71. I can assume that it should be higher. And for a variety of issues including human error, this value has changed. If the collector current was lower the q-point would increase, as with a lower current the voltage drop of the collector resistor would decrease, and so VCE would be closer to what is ideal. One reason I can assume IC is too high is the beta value of the transistor. This value varies greatly between transistors and so with IC=βIB there is massive room for variation this equation can also show that if the current through the base is large IC will be larger. To prevent this, we can reduce R1 or R2 which during my testing I did, by placing a 56kohm resistor in parallel with 6070 which reduce it to 5476 Ohms, this reduction pushed my Q-point to 4.003 Volts. Allowing for larger inputs before clipping and a more stable amplifier.

Appendix

- Graphs

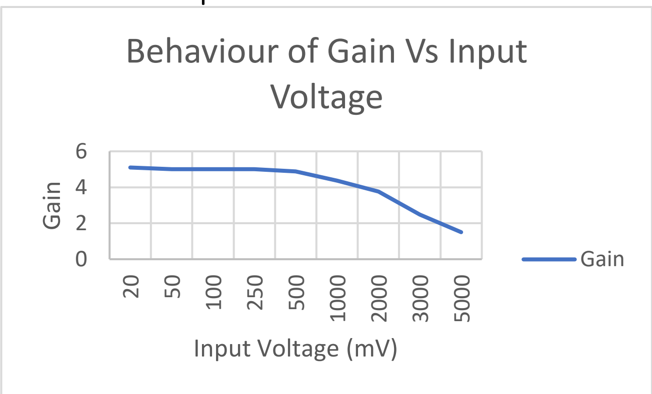

Figure 3 (Shows the relationship of gain and the input voltage.)

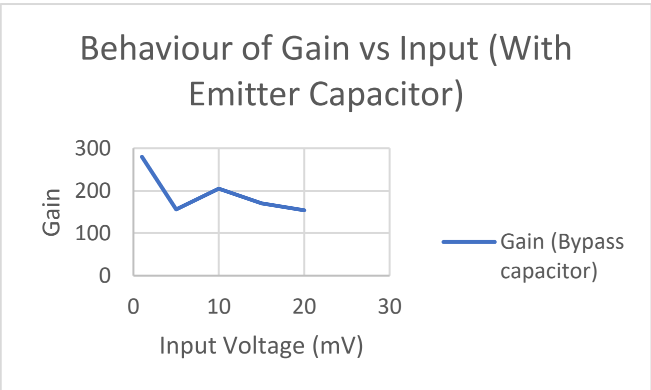

Figure 4 (Shows the difference of the relationship between input voltage and gain when an emitter capacitor is added)

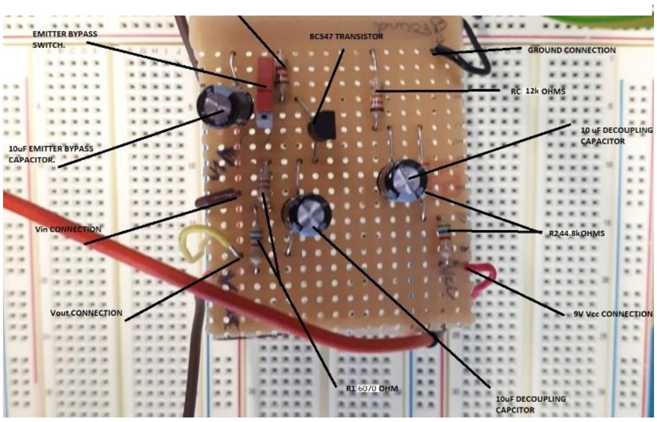

Figure 5 (Completed Circuit board used for testing)

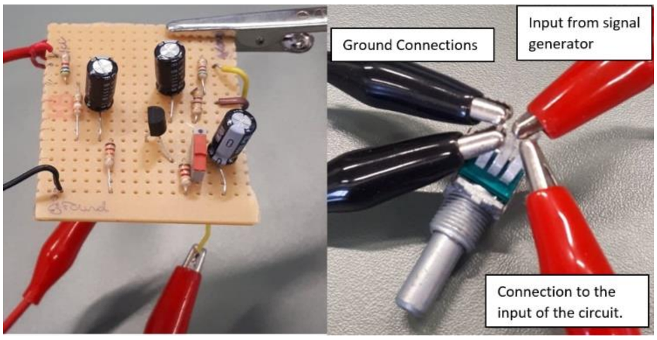

Figure 6 (Shows how the potentiometer is connected to the circuit when testing the emitter capacitor.)

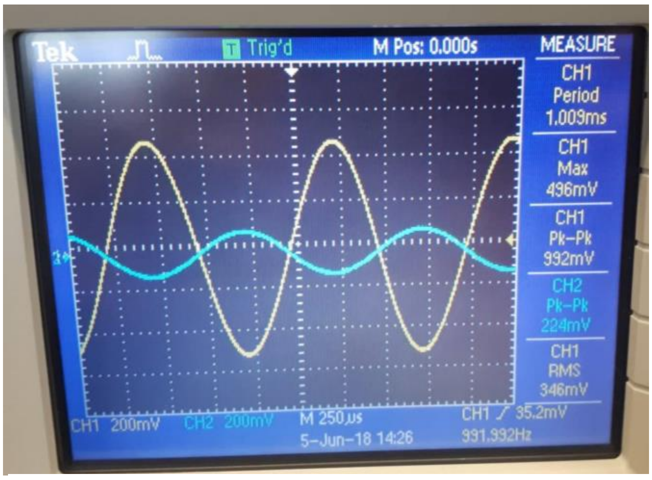

Figure 7 (Output waveform (Yellow) against the input waveform (Blue) of the circuit to show a gain of 5.)

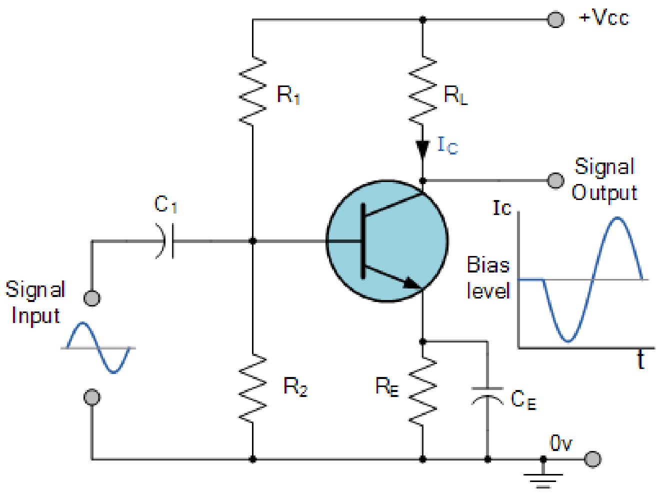

Figure 8 (Most basic form of class A amplifier includes an emitter bypass capacitor and an inward decoupling capacitor but does not included the third capacitor on the output, which provides stability.)

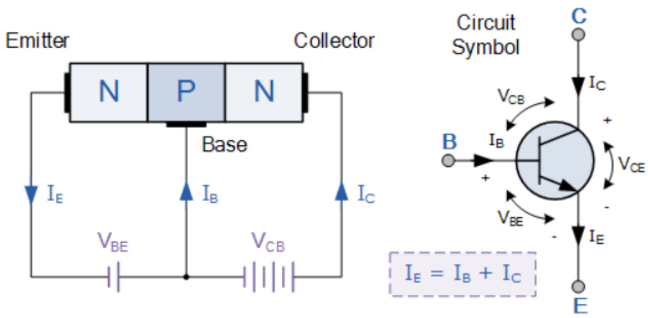

Figure 9 (Shows the most general form of an NPN transistor and how the currents through each terminal are linked to one another.)

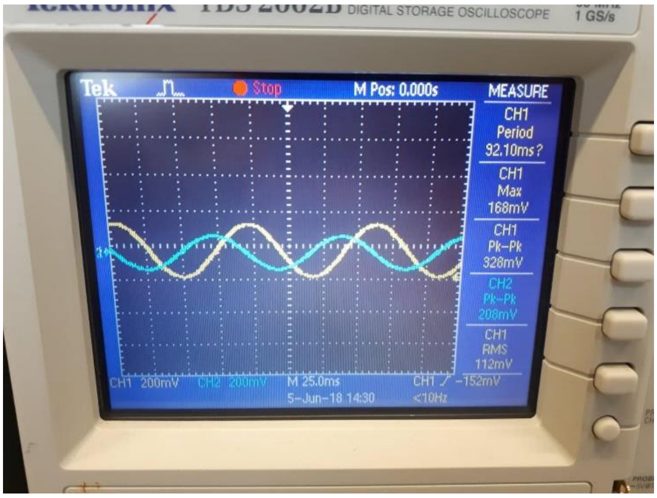

Figure 10 (The output (Yellow) as shifted in position compared to the input (Blue) when the input is at such a large frequency. notice the gain has also dropped to 1.57x showing that at higher frequencies the circuit does not function as well.)

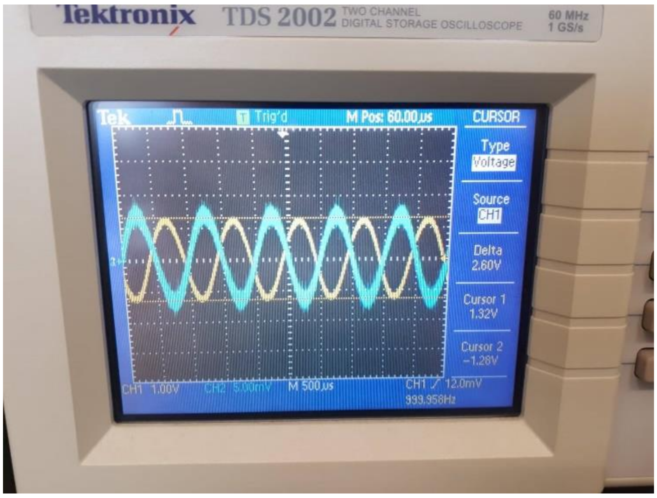

Figure 11 (This figure shows an extremely noisy input signal of approximately 15 mV (Blue) compared to the output (yellow) which at this point has a gain of 173X

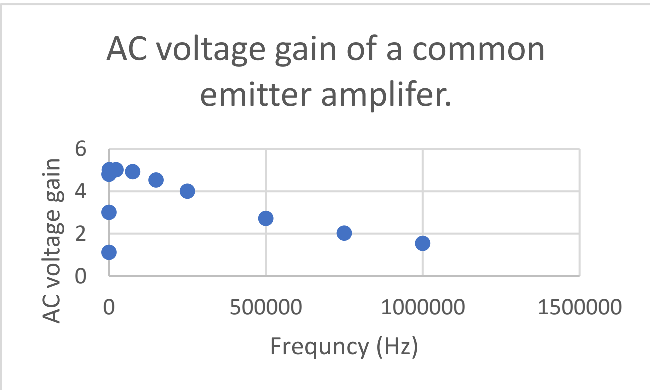

Figure 2(What you can see is the gain increase dramatically from 0 Hz to about 22kHz where it peaks. from here as the frequency is increase the gain decreases significantly.