ECEN 204
Design Report 2 : Class A Preamp
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1. Introduction

This design outline the construction of a class A preamp using the BC547, NPN Bipolar junction transistor. It is required to operate from a 9V supply, and operate as an audio amplifier; ie over the 20Hz to 20kHz range at as close at a constant gain as possible. This design has two steps:

1. Without a bypass capacitor at least an absolute gain of 5
2. Addition of bypass cap that retains require frequency response

2. Design Description

This section will outline the process of determining the components required to meet the specifications defined in the previous section.

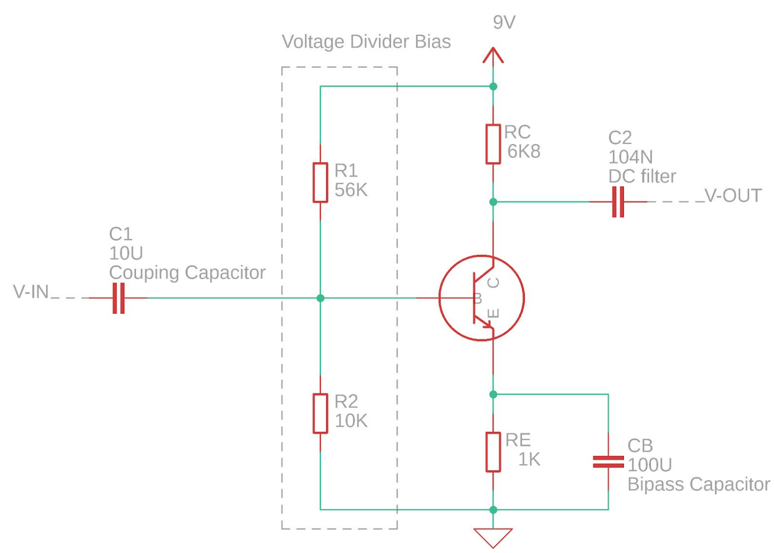


Figure 1: Circuit Diagram (with final values)

2.1 Q Point & Current

The first decision is the operating point/Q point/V_{cq}, as V_{CC} is 9V and design specifies the maximum possible swing the Q point is placed centrally between the rails:

$$V_{cq} = 4.5V$$

Next the current limiting resistor R_C, choose a reasonable value, $I_c = I_e = 0.66mA$ and calculate R_C

$$\begin{aligned} R_c &= \frac{V_{cc} - V_{cq}}{I_c} \\ &= \frac{9V - 4.5V}{0.66mA} \\ R_c &= 6K8 \end{aligned}$$

The gain, A, is to be a minimum of 5 and is represented as, $A = -\frac{R_c}{R_e}$

From available standard resistor values, the easiest way to achieve this was with an emitter feedback resistance, $R_e = 1K$. Yielding the absolute gain:

$$|A| = 6.8$$

2.2 Biasing

To have the transistor constantly operating in the linear current zone, the base must be supplied with sufficient bias, V_{bias}. This design uses a voltage divider from V_{cc}.
To determine the required bias voltage:

$$\begin{aligned} V_{bias} &= I_c * R_e + 0.7V \\ &= 0.66mA * 1K + 0.7 \\ V_{bias} &= 1.36V \end{aligned}$$

From this the value of the divider (R_1, R_2) can be determined. The choice of values for R_1 and R_2 is a trade-off between high input resistance and a too high base current. A good rule of thumb is to make R_2 approximately 10 times R_e. Therefore, $R_2 = 10R_e = 10K$ and from this and V_{bias}, R_1 can be calculated.

$$\begin{aligned} V_{bias} &= \frac{R_2}{R_1 + R_2} V_{cc} \\ 1.36V &= \frac{10K}{R_1 + 10K} 9V \\ 1.36V &= \frac{10K}{R_1 + 10K} 9V \\ R_1 &= 56K2 \end{aligned}$$

As this is not a standard value a trade off had to made, so **R_1 = 56K** is used. Note this alter assumed I_c/I_e value slightly, effecting the actual Q-point.

2.3 Input Coupling

The final requirements for this first version (no C_B) is a DC filtering capacitor, used a 104uF and a coupling input capacitor through which the small signal input is passed. The value of C_1 determines the low frequency cutoff. Specification requires min of 20Hz to have this constant, calculate for f_c is 10 times lower. $R_{in} = R_1 // R_2 = 8K5$

$$\begin{aligned} C_1 &= \frac{1}{2\pi \frac{f_c}{10} R_{in}} \\ &= \frac{1}{2\pi \frac{20Hz}{10} 8K5} \\ &= 9.3\mu F \\ C_1 &= 10\mu F \end{aligned}$$

This is the final component for the first version of the preamp with gain limit of 6.8

2.4 Bypass Capacitor

To remove the AC component of the feedback and increase gain a cap parallel with R_e is to be added. With it value also determined by the cutoff (20Hz) and r_e', the resistance into the emitter.

$$r'_e = \frac{1}{4} - \frac{1}{\ } - 38\Omega$$

$$\begin{aligned} C_B &= \frac{1}{2\pi f_c r'_e} \\ &= \frac{1}{2\pi 20Hz * 38R} \\ &= 219\mu F \\ C_B &= 100\mu F \end{aligned}$$

Due to availability restrictions a 100uF bypass had to be used, this restricts f_C to ~40Hz.

3. Prototyping, Construction and Testing

All circuits driven with the bench supply at 9V into V_{CC} and function generator as the small signal V-in.

3.1 No Bypass Breadboard Only

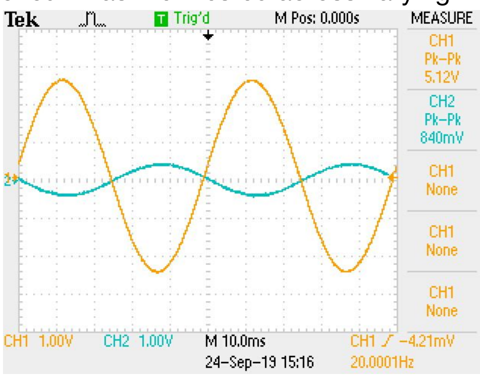
The first construction was to build the bypassless circuit on breadboard, ie circuit above without C_B.

3.1.1 Q-Point and Input Limits

This measure Q-point or V_{cq} of this circuit is **4.3V**, this is probably due to sacrifices made in the resistor picking stage, altering the true values fo I_C / I_E.
Measure input ranges: Nominal across bandwidth at Vin = 800mV_{PP}, Begins clipping from bottom at **1.4V_{PP}** input, giving a maximum output swing of ~**8.6V.**

3.1.2 Bandwidth Analysis

The circuit was then tested across varying input frequency at nominal V_{PP} ⇒ 800mV



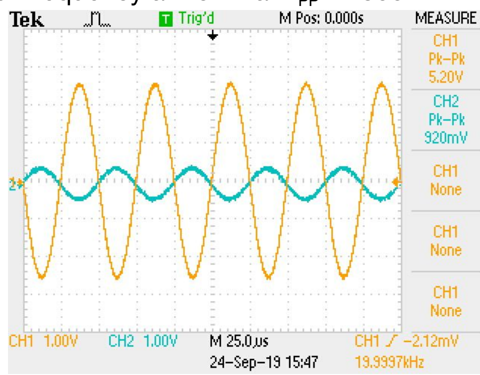


Figure 2a

Figure 2

Figures 2 shows V-in vs V-out at 20Hz and 20kHz, showing a near identical gain and a constant phase difference of 108°

A more rigorous analysis shows slight growth from 20-100Hz, constant gain of **6.5** to 20kHz and the beginning of upper cutoff at 100kHz.

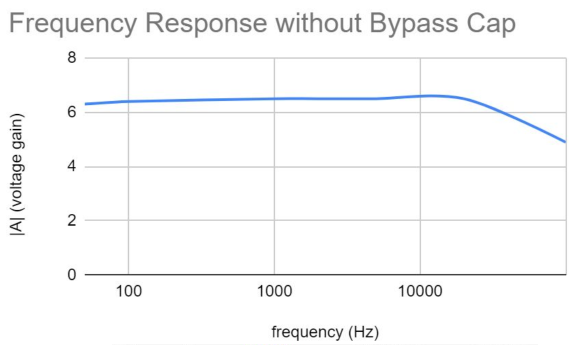
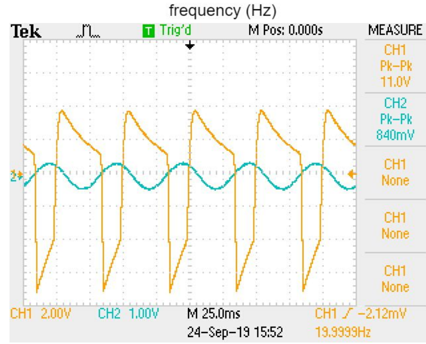


Figure right shows the result of adding the bypass capacitor (as calculated above) without altering V-in. It displays major overdriving.



3.2 Bypass Breadboard and Perfboard

To the breadboard circuit C_B is added and circuit is reanalyzed, then the components were transferred to a perfboard and soldered.

3.2.1 Input Limits

As shown the V-in must e be reduced to accommodate the much greater gain. Nominally the circuit functions well at **30mV (V_{PP} - in).** With a maximum input of **< 40mV** in without clipping.

3.2.2 Bandwidth Analysis

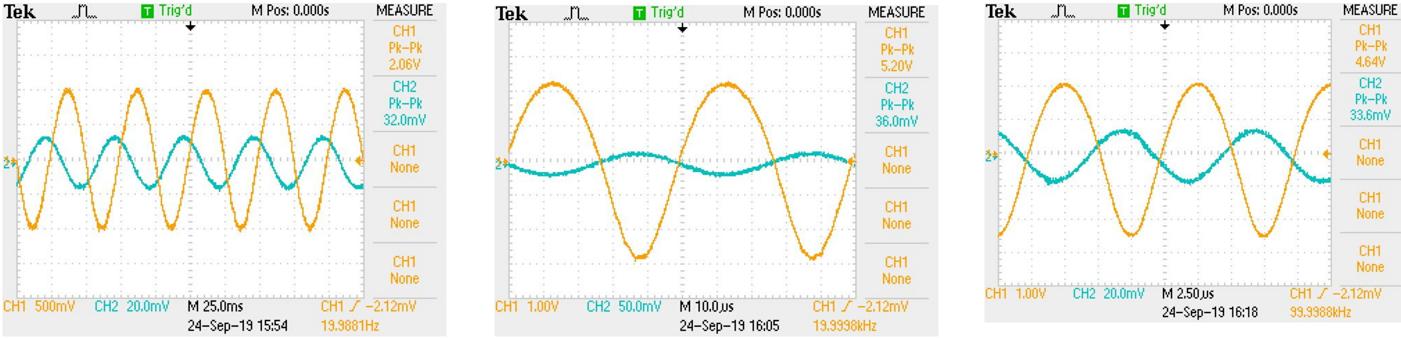
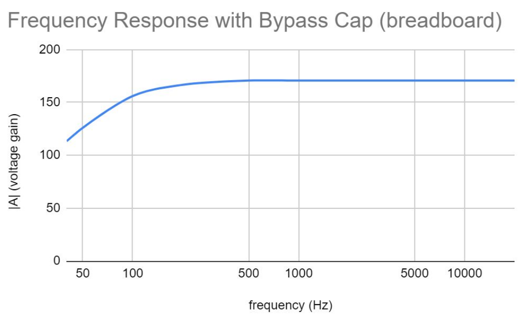
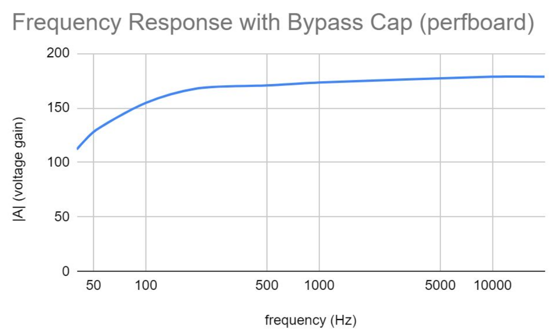


Figure 4

Figure 4 shows: Left, IN v OUT at 20Hz, shows gain in cutoff, a phase of only 90°
Center, response at 20kHz, with expected 180° phase and nominal gain,
Right shows the beginning of upper cutoff at 100kHz (still retains 180° phase)

In depth analysis of both the breadboard and perfboard constructions is below show the actual cutoff frequency of 40Hz and constant high gain of ~170 onwards.





3.2.3 Power Efficiency

Power from supply	
9V	0.845mA
power	7.605
Power at output	
113mV	245uA
	0.027685

Measured power consumption of the circuit against the actual output power to a load shows pretty bad efficiency.

As this is specified as an audio amplifier, the steady gain across the 20Hz-20kHz bandwidth is acceptable and the 30mV input while low, it useful in something like a microphone pre-amp.

4. Discussion and Conclusions

In the construction process it is reasonably trivial to calculate the need R values etc, but if there is a mistake in construction, ie wrong R value/short etc the output does not yield much info information toward the cause.

This design, while providing adequate gain (A ~= 170) and a good constant bandwidth (40Hz-20kHz+) it has an abysmal power output and non constant phase across its bandwidth, this will greatly affect the sound, especially as the phase issues are mostly at the lower frequencies - where human hearing is particularly receptive to phase difference.

This exercise was felt amazing when it works at yielding quite a lot of understanding of transistor operation. It was, however, very frustrating that due to my lab slot, I had not had the lecture about the topic before doing it, so brute forcing it was not fun.

5. Additional Questions

a) C_1 is the input coupling capacitor, determining the lower cutoff frequency and preventing DC signal offset. With

$$f_c = \frac{1}{2\pi C_1 R_{in}}$$

C_2 is just a DC filtering cap on the output to remove the offset from V-out, this does not affect the frequency response of the preamp.

C_B, the bypass cap, remove the AC from the feedback into the emitter and increases the gain. At lower frequencies due to it being a capacitor this effect is less and thus the gain increase lowers. Another factor in determining the lower cutoff. It follows:

$$f_c = \frac{1}{2\pi C_B r'_e}$$

b) My actual measured Q-point was ~4.3 vs ideal 4.5. This could be due to multiple factors; temperate, component variance and inaccuracy or trade offs/deviations from the calculated design. In particular I used a lower R_1 value than ideal, thus slightly changing the I_c value and changing the Q point slightly. This could be improved by back adjusting assumptions to meet restrictions in component availability.

6. Appendix

No BCap Input @ 10uF	Vin PP	Vout PP	A
20	0.8	4.8	6
50	0.8	5.04	6.3
100	0.8	5.12	6.4
1000	0.8	5.2	6.5
2000	0.8	5.2	6.5
5000	0.8	5.2	6.5
20000	0.8	5.2	6.5
100000	0.96	4.7	4.895833333

BCAP @ 100uF (bread)	Vin PP	Vout PP	A
20	0.03	2.08	69.33333333
40	0.03	3.4	113.3333333
50	0.03	3.78	126
100	0.03	4.68	156
200	0.03	5	166.6666667
500	0.03	5.12	170.6666667
1000	0.03	5.12	170.6666667
10000	0.03	5.12	170.6666667
20000	0.03	5.12	170.6666667

BCAP @ 100uF (perf)	Vin PP	Vout PP	A
20	0.03	2	66.66666667
40	0.03	3.36	112
50	0.03	3.84	128
100	0.03	4.64	154.6666667
200	0.03	5.04	168
500	0.03	5.12	170.6666667
1000	0.03	5.2	173.3333333
10000	0.03	5.36	178.6666667
20000	0.03	5.36	178.6666667