POWER AMPLIFIERS

1. Explain what are classes A, B, AB and C amplifiers in terms of DC biasing using a MOSFET drain characteristic.

2. Refer to the graphs of page 2 and the table at the top of page 3 of the theory notes to answer the following questions:
   A) How does efficiency vary with signal level?
   B) In classes B and AB, does efficiency vary with the type of waveform used? Explain.
   C) What waveform produces the worst case power dissipation of the power transistors? Explain.
   D) For what signal level is the power supply stressed the most? Explain
   E) For what signal level are the power transistors stressed the most? Explain

3. Explain what crossover distortion is and what causes it in class B amplifiers?

4. How does class AB biasing reduce crossover distortion?

5. Explain what harmonic distortion is.

6. When feedback is used with an op amp, explain how crossover distortion is reduced and how the op amp frequency response will affect the amount of distortion.

7. Explain why diodes or a V_{BE} multiplier are better than a simple resistor to bias a (BJT) push-pull stage in class AB.

8. Refer to the circuit diagram on the next page and the MOSFET transfer curves shown below.

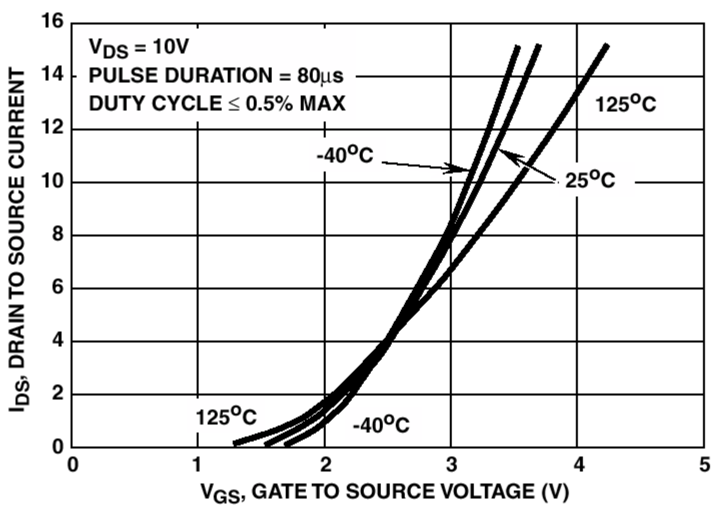
A) Assuming that the MOSFET's have a $|V_{GS(TH)}|$ that ranges from 1V to 2V, determine the values of R1, P1, R2 and P2 that are appropriate – allow for safety margin, say V_{GS} adjustment range of 0.5V to 2.5V. Assume 1W pots are used

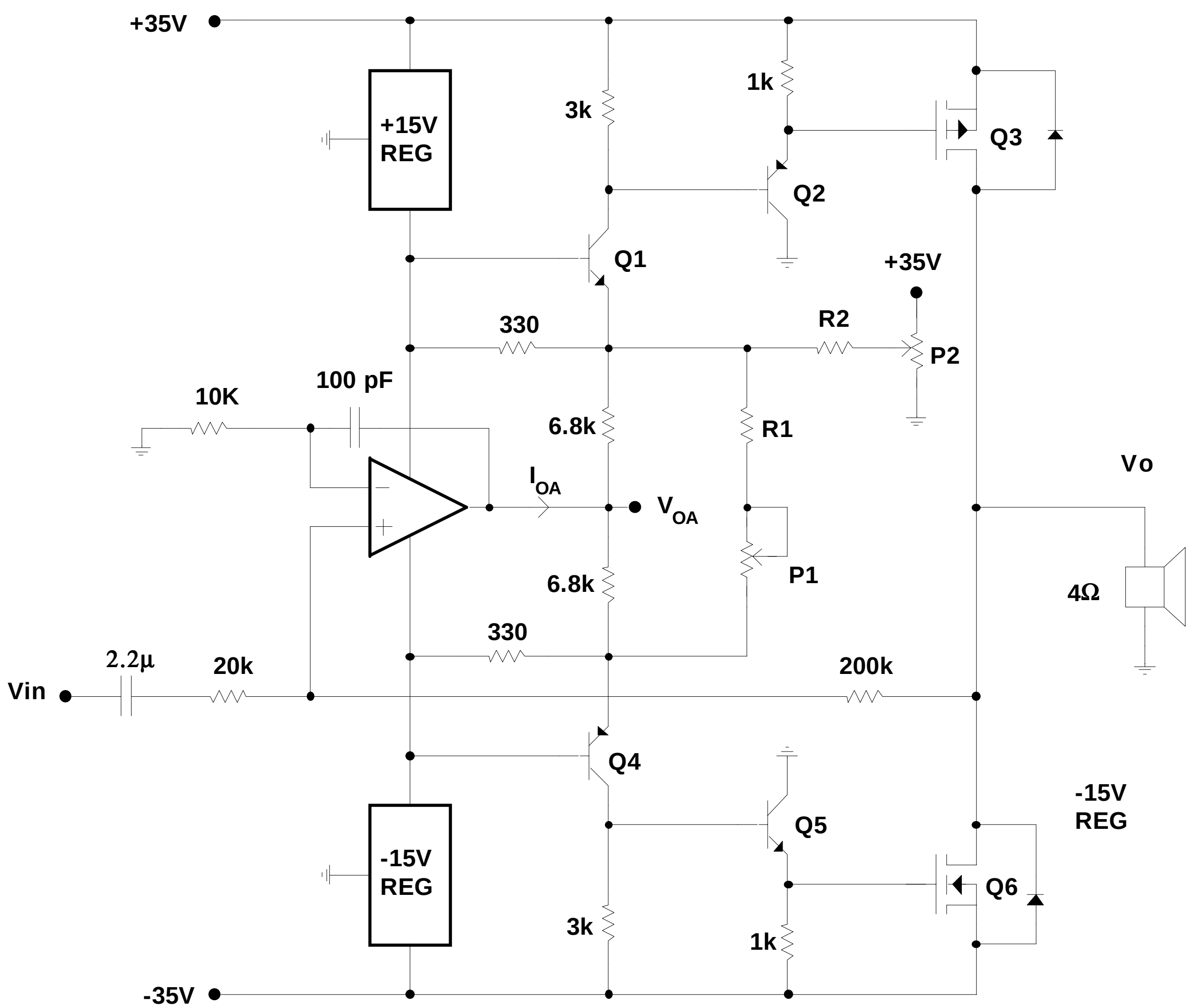
B) If $R_{DS\ (ON)}$ = 0,3Ω for the MOSFET's when V_o is maximum, determine the **peak AC values** of V_o, V_{OA}, v_{gs3} and v_{gs6} and I_{OA} . Assume MOSFET's heat up to 125°C – use 125°C MOSFET curve.

C) From values obtained in part B, calculate P_L max and the maximum efficiency of this amplifier and P_{max} of each MOSFET assuming a sinewave input. Specify at what input signal level the power transistors will dissipate maximum power.

D) Repeat question C for a square wave input.

E) What is the effect of the 2.2 μF capacitor on the gain response of the amplifier?

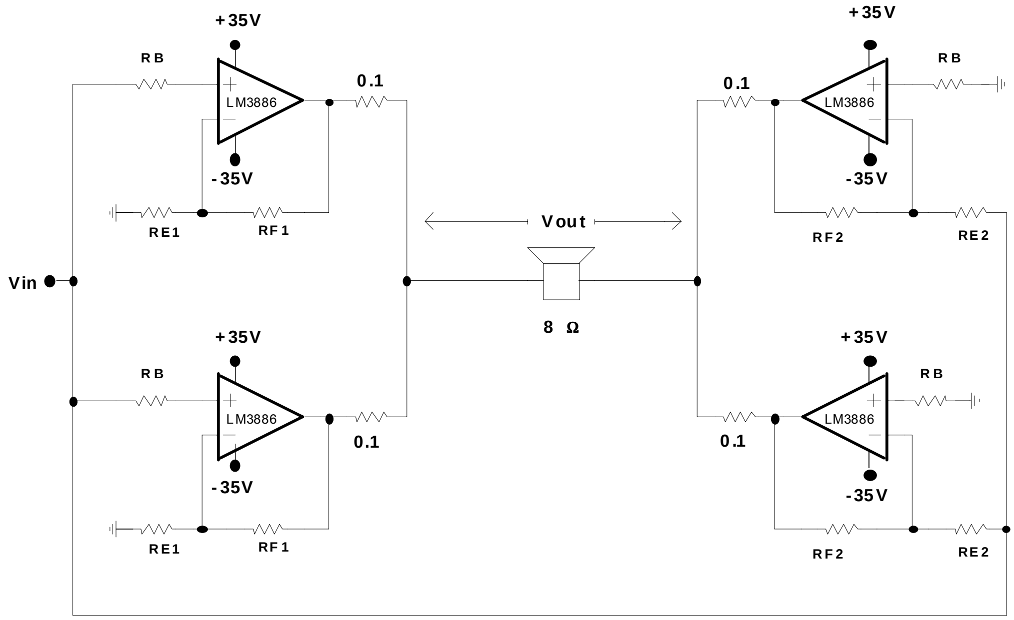




9. Sketch a bridge power amplifier, explain how it works and also explain why it quadruples the maximum O/P power.

10. Sketch a bridge-parallel power amplifier, explain how it works and explain what the advantage is over the simple bridge amplifier.

11.



A) From the clipping voltage graph in the data sheets, determine the maximum unclipped O/P voltage across the load and then compute the maximum O/P power (assume sinewave input) and compare it against the typical value specified in the data sheets.

B) What is the power consumption of the above amplifier at the maximum power level found above? Assume sinewave input. Determine the maximum heat sink resistance required at $T_A = 30^oC$ assuming that the four amplifiers are mounted on a single heat sink with $0.2^oC/W$ insulators.

C) If the input signal ranges from 0 to $1V_{rms,}$ determine all resistors required to provide maximum O/P power to the speaker. Assume sinewave input and allow for 10% more gain than required minimum to ensure maximum power is achieved.

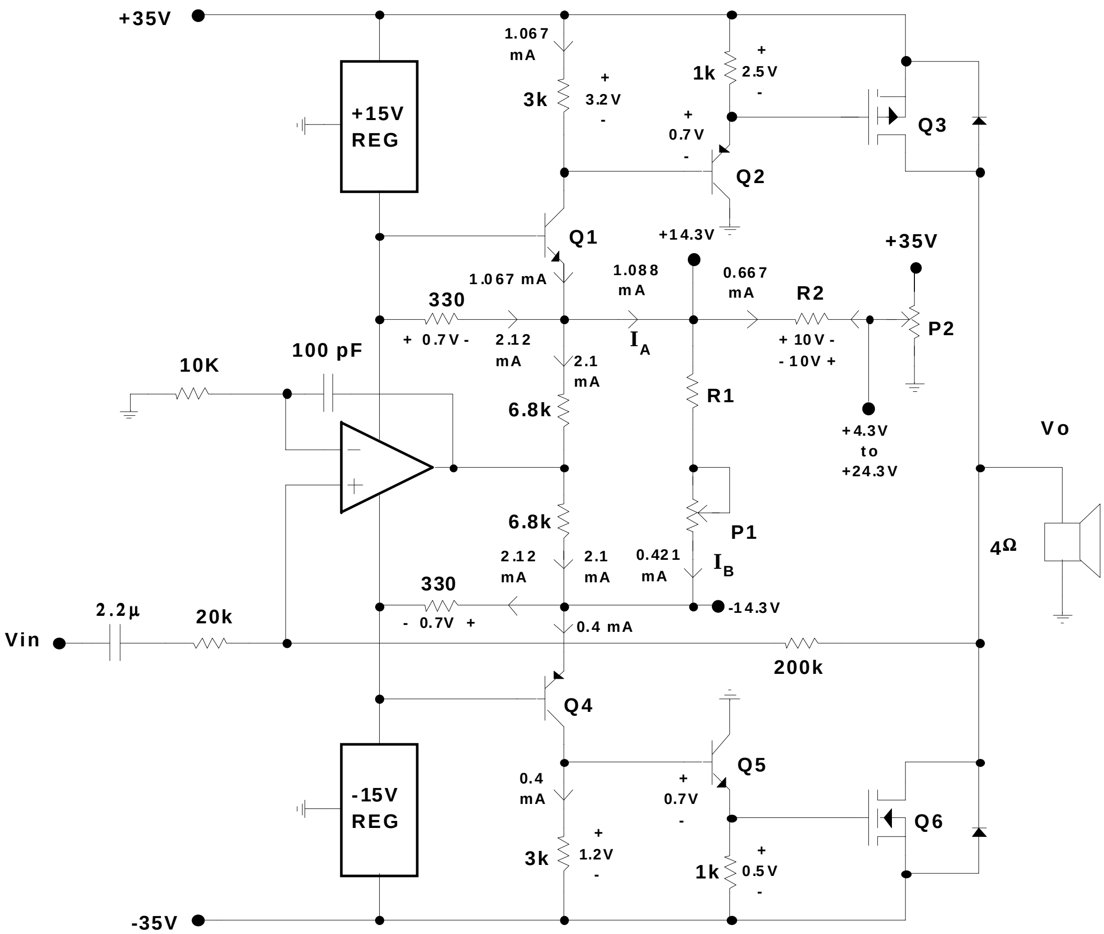
D) If all R_E's and R_F's have 0.1% tolerance, what is the maximum current imbalance between two parallel amplifiers?

E) What is the maximum current imbalance caused by DC offsets of the LM3886's between two parallel amplifiers?

F) To solve the current imbalance caused by DC offsets, add an AC coupling capacitor to the input and also insert a capacitor in series with all R_E's. Calculate proper values for an audio signal and explain how that reduces the DC current imbalance in parallel amplifiers.

G) Sketch the gain response of the inverting amplifiers and that of the non-inverting amplifier. Include the effect of the AC coupling capacitor used with the front-end buffer in both gain responses.

8. A)



To calculate P_1 and R_1 assume matched MOSFET's, equal V_{GS} values, this entails $I_A = I_B$ and $I_{R2} = 0$ and a range of current of 0.4212 mA to 1.088 mA through P_1 and R_1.

$$R_1 + P_1 = \frac{28.6V}{0.4212\ mA \rightarrow 1.088\ mA} = 26.29k \leftarrow 67.9k \qquad P_1 \rangle\ 67.9k - 26.29k = 41.61k \quad P_1 = 50k$$

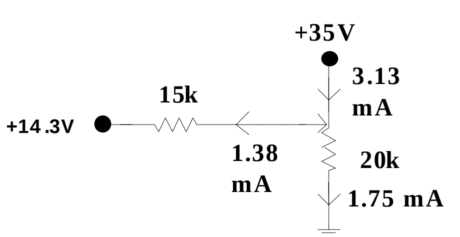
$$Let\ R_1 = 24k\ then\ P_1 + R_1 = 24k \rightarrow 74k$$

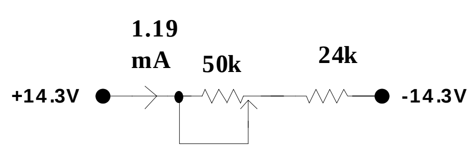
When MOSFET's are mismatched, V_{GS} values are different, R_2 has to absorb the difference between I_A and I_B that is $I_A - I_B = I_{R2}$. R_2 should be selected such as not to set P_2 too close to +35V and not too close to 0V, the worst case being 0V. Let V_{R2} max = 10V, therefore V_{TAP2} = 14.3 ±10 = 4.3V to 24.3V which is a safe range.

$$R_2 = \frac{10V}{0.666\ mA} = 15k$$

Let P_2 = 20k and verify that maximum current is not excessive.

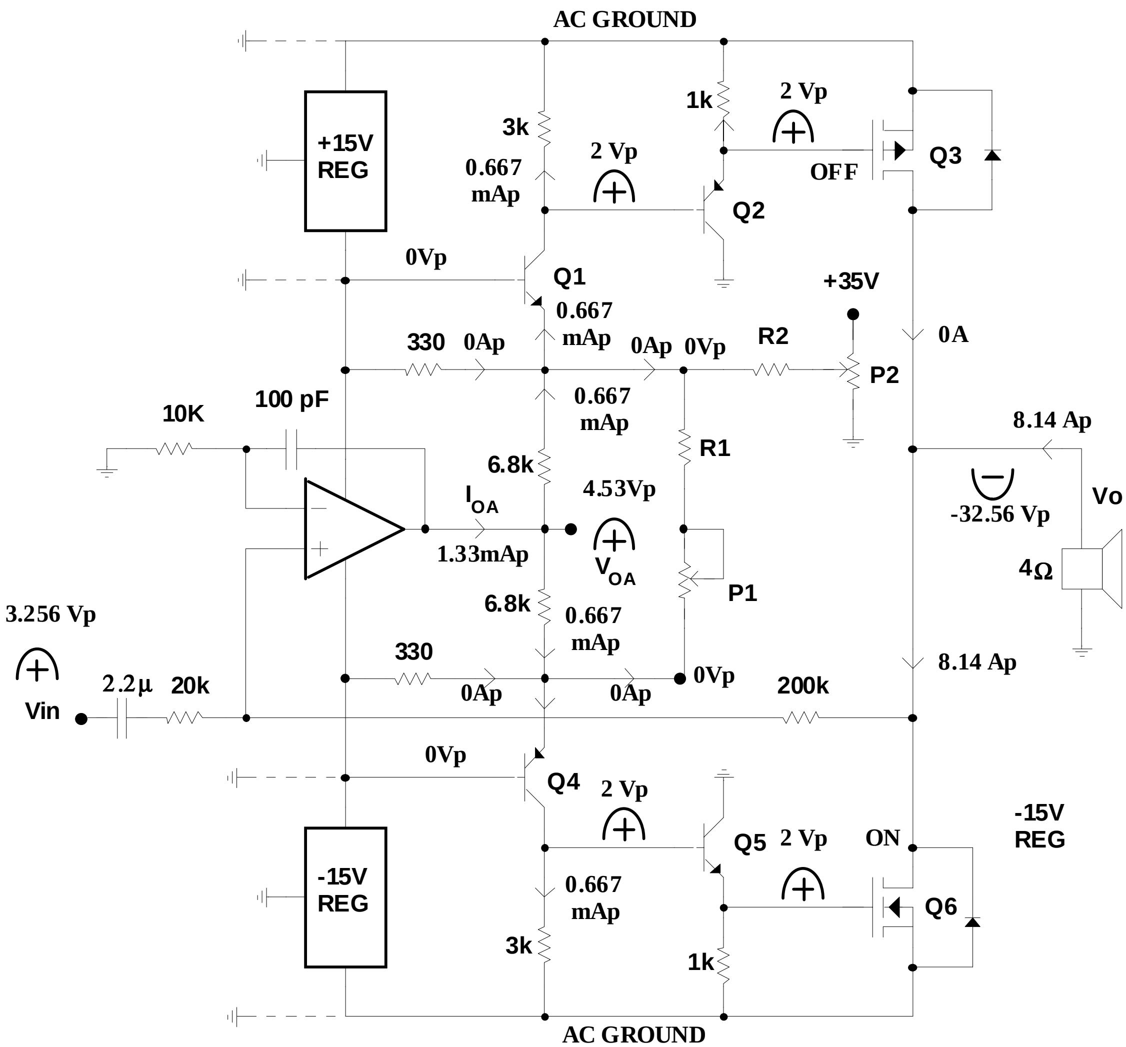
$$P_{max} = I^2_{max} R \rightarrow I_{max} = \sqrt{\frac{P_{max}}{R}} = \sqrt{\frac{1W}{20k}} = 7.07\ mA\ for\ P_2 \quad and \quad I_{max} = \sqrt{\frac{1W}{50k}} = 4.47\ mA\ for\ P_1$$

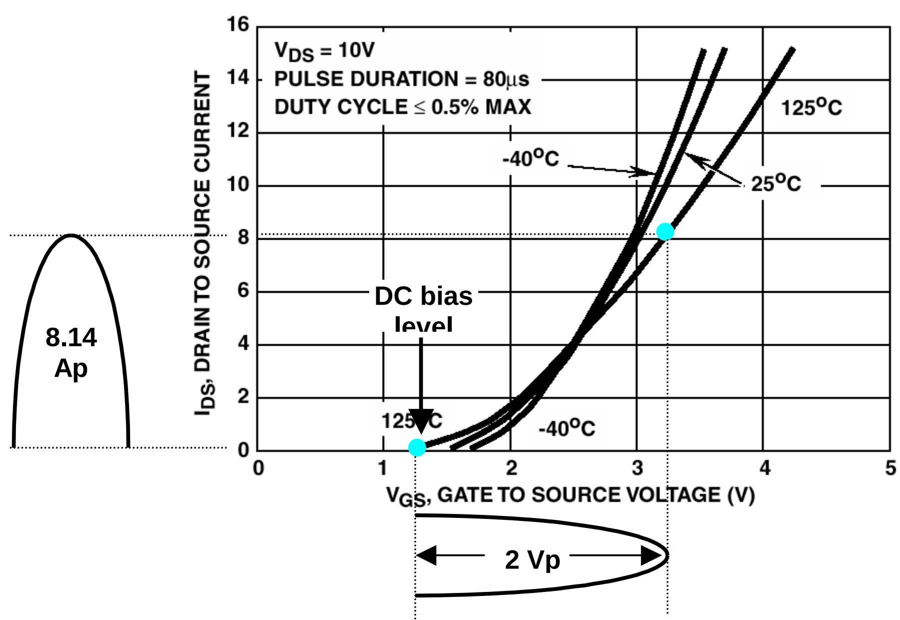




Worst case scenarios are shown beside. One must ensure I_{max} to be below maximum values calculated above. Any part of the pot that carries more than limit becomes a hot spot that may be damaged.

8 B) $V_o = 35 \times \frac{4}{4+0.3} = 32.56\, V_P \text{ max}$ $\quad I_L = \frac{23.56}{4} = 8.14\ A_P \text{ max}$





8 C) For sinewave input see equations and graph on page 2 of theory notes.

$$P_{\max} = \frac{2}{\pi} \times \frac{V_S^2}{R_L} = \frac{2}{\pi} \times \frac{35^2}{4} = 194.96W \qquad dri = \frac{V_{peak}}{V_S} = \frac{32.56}{35} = 0.9303$$

$$P_L \max = \overline{P}_L \times P_{\max} = \frac{\pi}{4} \times dri^2 \times P_{\max} = \frac{\pi}{4} \times 0.9303^2 \times 194.96 = 132.52W$$

$$P_Q \max = \overline{P}_Q \times P_{\max} = \frac{1}{\pi} \times 194.96 = 62.06W \rightarrow 31.03W \;\; per\ MOSFET$$

$$P_Q \max\ occurs\ at\ V_o = \frac{2}{\pi} \times 35 = 22.28\,V_P \quad and\ V_{in} = 2.228\,V_P$$

$$\eta \max = \frac{\pi}{4} \times dri = \frac{\pi}{4} \times 0.9303 = 0.7306 \rightarrow 73.06\%$$

8 D) For squarewave input see equations and graph on page 2 of theory notes.

$$P_{\max} = \frac{V_S^2}{R_L} = \frac{35^2}{4} = 306.25W \qquad dri = \frac{V_{peak}}{V_S} = \frac{32.56}{35} = 0.9303$$

$$P_L \max = \overline{P}_L \times P_{\max} = dri^2 \times P_{\max} = 0.9303^2 \times 306.25 = 265W$$

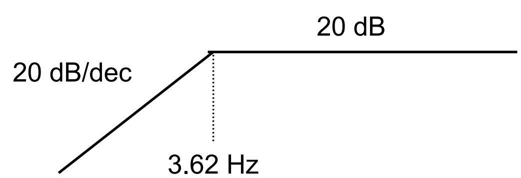
$$P_Q \max = \overline{P}_Q \times P_{\max} = 0.25 \times 306.25 = 76.56W \rightarrow 38.3W \;\; per\ MOSFET$$

$$P_Q \max\ occurs\ at\ V_o = 0.5 \times 35 = 17.5\,V_P \quad and\ V_{in} = 1.75\,V_P$$

$$\eta \max = dri = 0.9303 \rightarrow 93.03\%$$

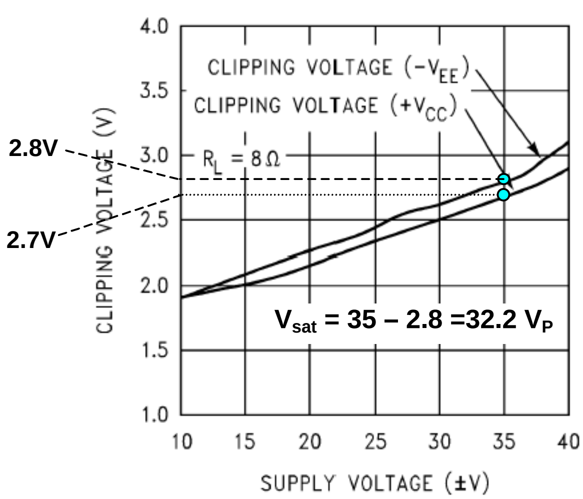
8 E)

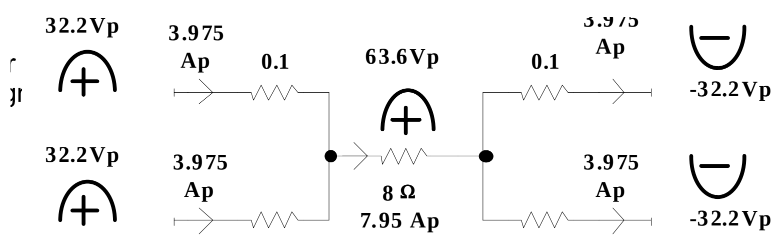
$$A_{VF} = -\frac{R_F}{Z_E} = -\frac{R_F}{R_E + \dfrac{1}{SC_E}} = \frac{SC_E R_F}{1 + SC_E R_E}$$



$$F_C = \frac{1}{2\pi C_E R_E} = 3.62\ Hz$$

9A) Use lower saturation voltage, that is $V_{SAT\ min} = V_{SUP} - V_{CLIP\ max}$

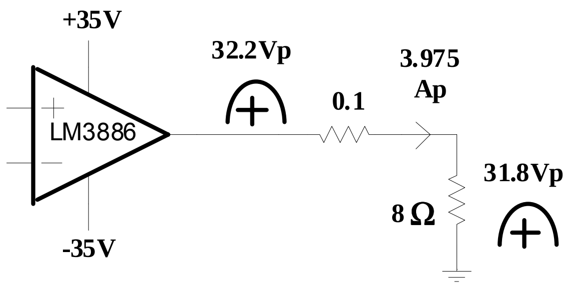




The load voltage is $V_{LOAD} = 64.4*8/(8+0.1) = 63.6\ V_P$. The load seen by each amplifier O/P is a grounded 8.1Ω load.

$$R_{EQ} = \frac{V_o}{I_o} = \frac{32.2}{3.975} = 8.1\Omega \qquad P_L = \frac{V_P^2}{2R_L} = \frac{63.6^2}{2 \times 8} = 252.8W$$

This corresponds to 63.2W per amplifier delivered to the load.



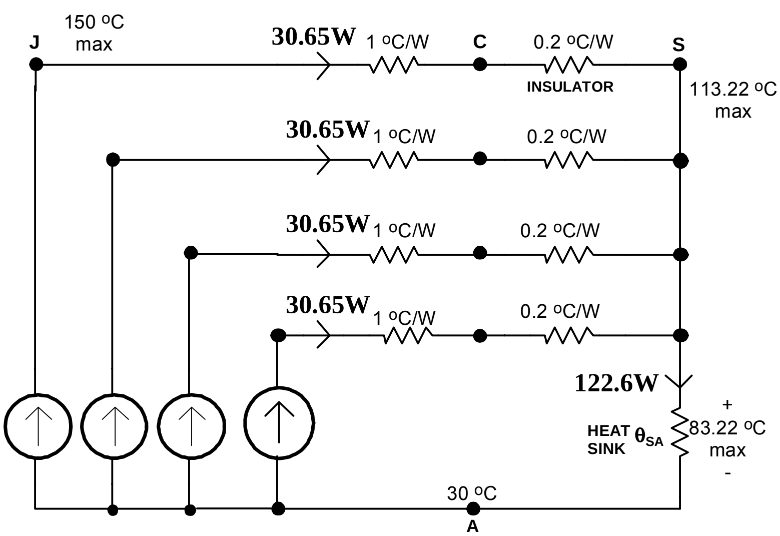
The data sheets state 50W typical O/P power for an 8Ω load with 35V supplies for THD < 0.1%. We calculated P_L max = 63.2W (for sinewave signal) per amplifier at the lowest clipping level which produces a THD higher than 0.1%.

$$P_{max} = \frac{2}{\pi} \times \frac{V_S^2}{R_L} = \frac{2}{\pi} \times \frac{35^2}{8.1} = 96.28W \qquad dri = \frac{V_{peak}}{V_S} = \frac{32.2}{35} = 0.92 \; at \max O/P \; or \; drive \; level$$

$$P_Q \max = P_{IC} \max = \overline{P}_Q \times P_{max} = \frac{1}{\pi} \times 96.28 = 30.65W \;\; per \; LM3886 \; occurs \; at \; V_o = \frac{2}{\pi} \times 35 = 22.28\,V_P$$

$$P_S \max = \overline{P}_S \times P_{max} = dri \times P_{max} = 0.92 \times 96.28 = 88.58W \;\; per \; LM3886 \; occurs \; at \max O/P \; or \; drive \; level$$

The total power consumption is therefore P_S max = 4 * 88.58 = 354.3W



The maximum heat sink resistance is

$$\theta_{SA} = \frac{83.22}{122.6} = 0.68 \; ^oC/W$$

The above value was obtained assuming a sinewave input, therefore in practice the power dissipation may exceed the value we have calculated. To be safe, we should use a heat that has less than half of the above calculated thermal resistance.

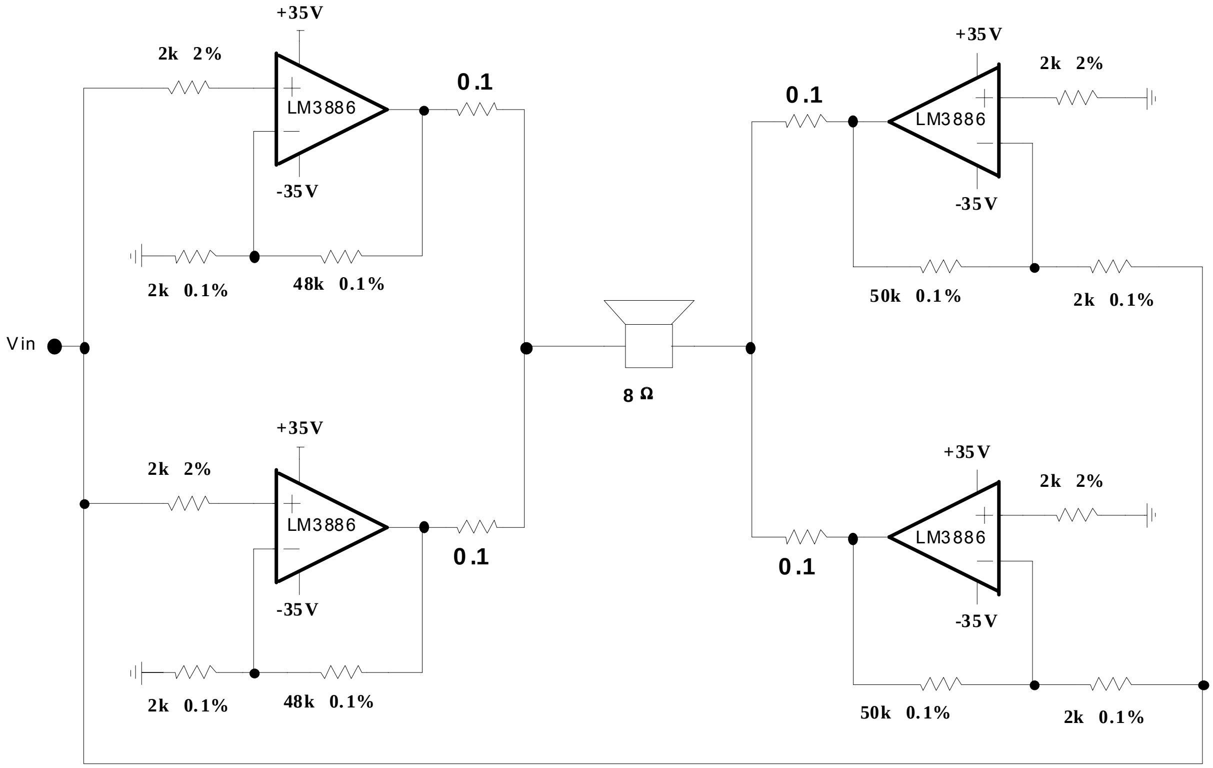
11 B)

$$A_{VF} = \frac{V_o}{V_{in}} = \frac{32.2V_P}{1V_{rms} \times \sqrt{2}} \times 1.1 = 25.05\,V/V$$

$$Non-inverting \; amp \; A_{VF} = 1 + \frac{R_F}{R_E} \Rightarrow \frac{R_F}{R_E} = 24.05$$

$$inverting \; amp \; A_{VF} = -\frac{R_F}{R_E} \Rightarrow \frac{R_F}{R_E} = 25.05$$

The gain value itself is not critical, but matching of the inverting and non-inverting gains is very critical, therefore let us use a gain of 25 V/V and 0.1% tolerance resistors for R_E and R_F. The balancing resistors are not critical, they are there just to minimize the O/P DC offset.



D) Using the formula from the notes, we have

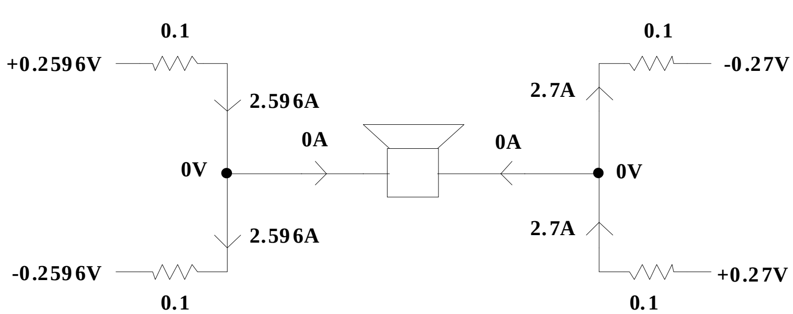
$$\Delta I = \frac{4 \times \frac{TOL}{100} \times V_0 \ nominal}{0.1} = \frac{4 \times 0.001 \times 32.2}{0.1} = 1.288 A_P = I_1 - I_2 \qquad I_1 + I_2 = \frac{64.4 V_P}{8.1} = 7.95 A_P$$

Solving for the above two equations we have I_1 = 4.62 A_P and I_1 = 3.33 A_P. Mismatch of the gain setting resistors - R_E and R_F - causes AC current imbalance between parallel amplifiers.

E) $V_{oo} \max = \pm V_{io}\left(1 + \frac{R_F}{R_E}\right) \pm I_{io} R_F$ for balanced inputs

Non-inverting amp $V_{oo} \max = \pm 10m\left(1 + \frac{48k}{2k}\right) \pm 0.2\mu \times 48k = \pm 0.2596V$

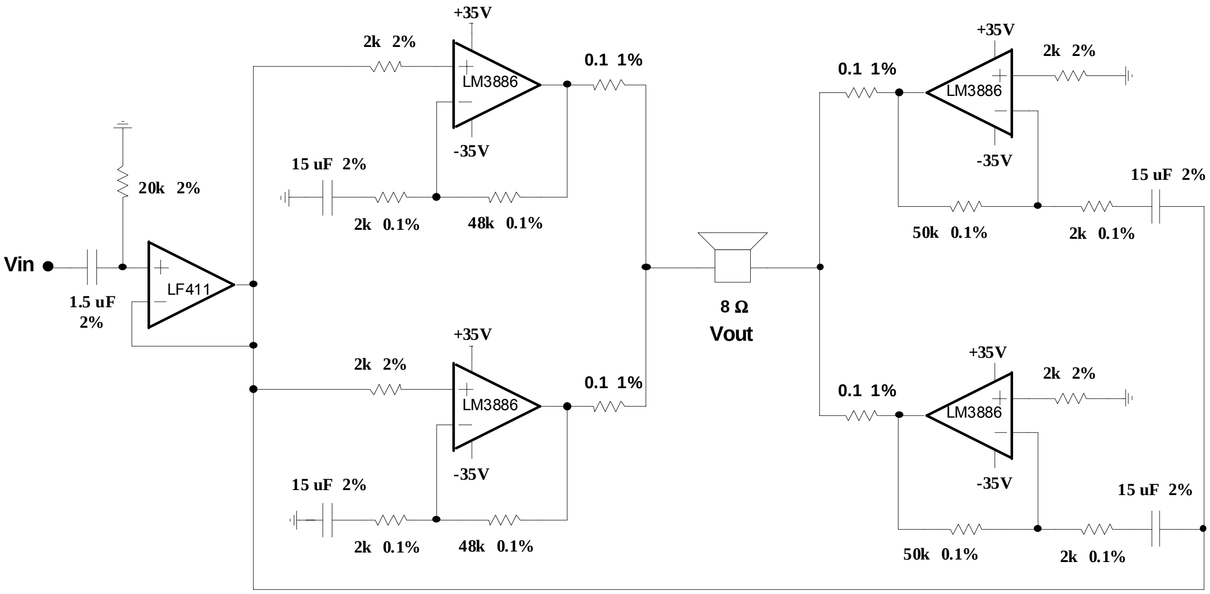
Inverting amp $V_{oo} \max = \pm 10m\left(1 + \frac{50k}{2k}\right) \pm 0.2\mu \times 50k = \pm 0.27V$



As you can see, DC offsets can cause a large DC current to flow between two parallel amplifiers.
To reduce the maximum DC current one can increse the 0.1W resistors or resort to the scheme used in step F.

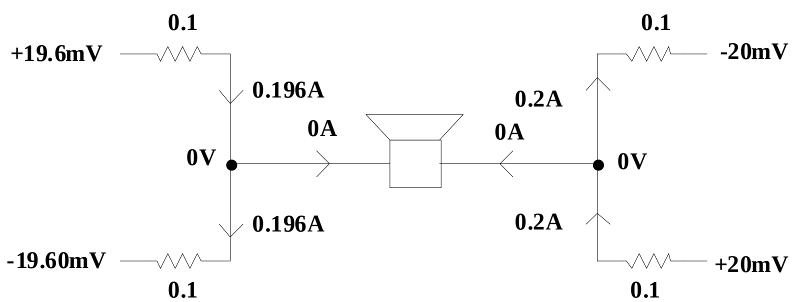
11 F) Let's use a cutoff frequency of 5 Hz so we do not attenuate LF audio signals. All of the C_E's will introduce a cutoff frequency

$$F_C = \frac{1}{2\pi\ R_E C_E} \Rightarrow C_E = \frac{1}{2\pi\ F_C R_E} = \frac{1}{2\pi \times 5 \times 2k} = 15.9\ \mu F \rightarrow 15\ \mu F\ std$$



Non-inverting amp $V_{oo}\ \max = \pm 10m\left(1 + \frac{48k}{\infty}\right) \pm 0.2\mu \times 48 = \pm 19.6mV\ \max$

Inverting amp $V_{oo}\ \max = \pm 10m\left(1 + \frac{50k}{\infty}\right) \pm 0.2\mu \times 50k = \pm 20mV\ \max$



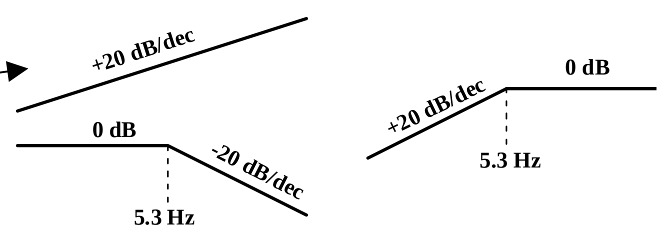
A picture is worth a 1000 words …

Now worst case DC currents are reasonable.

NOTE: One needs the input DC blocking capacitor shown above to remove any DC component from the signal, otherwise the load may have to absorb a large DC current.

11F) __Gain Response of input amplifier__

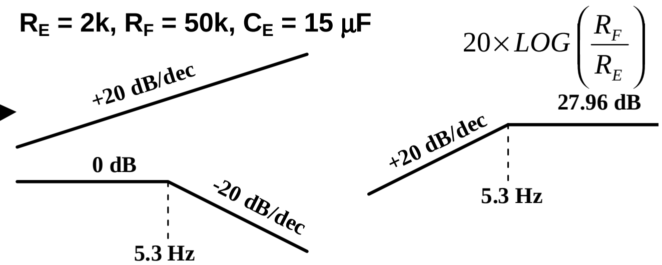
$$\frac{V_o(S)}{V_{in}(S)} = \frac{R_{in}}{R_{in} + \frac{1}{SC_{in}}} = \frac{SC_{in}R_{in}}{SC_{in}R_{in} + 1}$$



$$SC_{in}R_{in} + 1 = 0 \quad S_p = -\frac{1}{R_{in}C_{in}} \quad \omega_C = |S_p| = \frac{1}{R_{in}C_{in}} = \frac{1}{15\mu \times 20k} = 3.3\bar{3}\ \ r/s \quad F_C = 5.3\ Hz$$

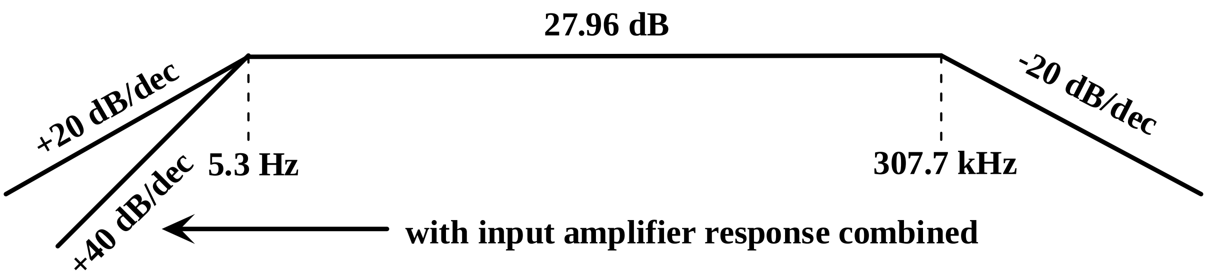
Gain Response of inverting amplifiers $R_E = 2k$, $R_F = 50k$, $C_E = 15\ \mu F$

$$\frac{V_{o\,(S)}}{V_{in\,(S)}} = \frac{-R_F}{R_E + \frac{1}{SC_E}} = \frac{-SC_E R_F}{SC_E R_E + 1}$$



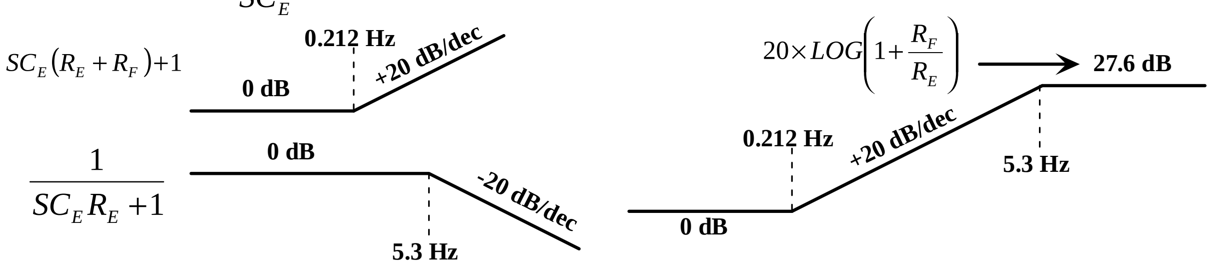
The HF frequency gain will start dropping off because of the GBW of the LM3886's.

$$F_{HI} = \beta_{V\,(HF)} \times GBW = \frac{R_E}{R_E + R_F} \times GBW = \frac{2k}{2k + 50k} \times 8M = 307.7\ kHz$$



Gain Response of non-inverting amplifiers $R_E = 2k$, $R_F = 48k$, $C_E = 15\ \mu F$

$$\frac{V_{o\,(S)}}{V_{in\,(S)}} = 1 + \frac{R_F}{R_E + \frac{1}{SC_E}} = 1 + \frac{SC_E R_F}{SC_E R_E + 1} = \frac{SC_E(R_E + R_F) + 1}{SC_E R_E + 1}$$



The HF frequency gain will start dropping off because of the GBW of the LM3886's.

$$F_{HI} = \beta_{V\,(HF)} \times GBW = \frac{R_E}{R_E + R_F} \times GBW = \frac{2k}{2k + 48k} \times 8M = 320\ kHz$$