QUASAR PROJECT KIT # 3048 - INTRODUCTION TO POWER AUDIO AMPLIFIERS

Using complete amplifier chips like the LM386, TDA2004, etc. ARE modern, quick and easy but they teach nothing about how power amplification actually work. Here is a Class A & AB amplifier made from individual components. It will deliver several watts of power into an ordinary 8 ohm speaker. It provides hands-on learning about audio topics such as cross-over distortion, bootstrapping, complementary pairs, and push-pull. We have given a description of these topics.

ASSEMBLY INSTRUCTIONS

Solder in the lowest height components first, then work up to the highest. The 10K pot is connected to the PCB by some 3 strand cable which you have to supply to the length you require.

Add the power transistors BD139 & BD140 last. Make sure to get the BD139 & BD140 in the correct way around and in their correct positions - the metal back of the package goes in above the bar marked on the overlay. Screw on the heat sinks **before** you solder them into the board. You will find that both transistors must be soldered some distance **above** the board so the heat sinks do not touch any of the other components. Join the two 9V battery snaps together in series to make the 18V DC. (Solder together one red lead to the black lead of the other snap.) The metal plates of both power transistors are joined to their collectors so there is no need to insulate the heat sinks.

SETUP

First remove the heat sink of Q6. This will allow easy access to the trimpot. The first setup step is to adjust the trimpot to remove any crossover distortion in the power transistors. Because the amount of bias applied to transistors increases as the resistance increases, start by rotating the pot fully clockwise. This should give a resistance of zero. Do this before turning on the power to avoid giving too much bias.

Ideally to do this adjustment you should apply a 1 kHz sine wave input. (If you have Kit 3023 you can use that.) As you listen to the speaker gradually rotate the pot until the distortion disappears. The increase in sound quality should be quite obvious. However check that you have not set the bias too high which will cause quiescent current to flow. If the power transistors feel quite hot to touch without any input signal then the bias is set too high.

If you do not have a sine wave input then a second method is to monitor the current drawn by the amplifier as the resistance is increased. Put an ammeter into the circuit. Increasing the pot resistance will increase the current, but the rate of increase will become much more rapid as Q5 & Q6 turn on more. The elbow in the rate of current drawn should occur about 14mA.

As we will discuss below the pot resistance for no crossover distortion should be about 22 ohms. If the battery voltage falls below 18V the resistance will increase. If you use 9V power supply the resistance needed will be about 180 ohms. This is why a 200R pot has been used. If you will always use an 18V supply then you can use a lower value pot for greater accuracy.

WHAT TO DO IF IT DOES NOT WORK

Poor soldering is the most likely reason that the circuit does not work. Check all solder joints carefully under a good light. Next check that all components are in their correct position on the PCB.

CIRCUIT DESCRIPTION

The power module has been designed for a maximum input signal of about 50mV. With a signal larger than this the 10K volume control acts as a potential divider to reduce the signal and prevent distortion. For smaller signals you will need to use a pre-amplifier. Or you could increase the value of the 10K feedback resistor R5 and so increase the amplifier gain above 11 (the ratio of (R3+R5) to R3.) Do not reduce R3 which will also affect the frequency response of the amplifier.

There are various classes of amplifiers which can be used to drive a loud speaker. The text books list them: class A, B, AB & C. The classes are defined in terms of the amount of bias which is applied to the amplifier input. Class A is permanently and fully biased on, while Class C only conducts on the peaks of the signals. In this design we have used Classes A and AB.

First Stage. Q1 & Q2 are arranged as a complementary pair in a common emitter mode. This gives a high voltage amplification. However, it has a high output impedence which means it is not suitable for driving an 8 ohm speaker directly. R1 & R2 apply sufficient bias to keep the transistor pair permanently turned on. The amount of bias places them in the middle of their conduction range so that they react to both positive and negative swings of the input signal. There is continuous current flowing whether or not a signal is actually present and being amplified.

To reduce the wastage of quiescent current another class of amplifier, Class B, uses a pair of complementary transistors which are not quite biased on. The signal is amplified by using the NPN transistor to react to the positive voltage side of the input signal while the PNP reacts to the negative side. At any instant only one transistor is turned on. This is called push-pull; when the NPN transistor (like out Q5) turns on the output voltage is pulled up towards the positive supply rail, while turning on the PNP (Q6) pushes it towards ground. Class B solves the quiescent current problem of Class A amplifiers, but introduces another - crossover distortion. Because the first part of the signal is used to complete the turn-on bias for each transistor you introduce distortion in the output whenever the input signal swings between positive and negative, or negative to positive. Enter Class AB Amplifiers.

Second Stage. Class AB also uses a pair of complementary transistors acting in the same push-pull arrangement, but it adds sufficient bias between the base-emitter junctions to just turn on both transistors when there is no signal flowing. When a signal is applied one of the transistors will turn on more and the other turned off. A diode in series with an adjustable resistance (as in our circuit), or the controlled output voltage of another transistor is normally used to apply precise bias. If the bias is too small then there will still be some distortion; but if it is too large an increased quiescent current will flow which will waste power.

In the schematic you can see that the second stage of our amplifier is set up as an emitter follower with the load connected to the emitter of the transistor rather than the collector as in the first stage. The voltage at the output 'follows' the voltage at the input. They are the same value except from a 0.65V drop across the base-emitter junction. The advantage of the arrangement is that it produces a large output current at a low output impedence. This is ideal for driving a speaker.

Now let us look at the bias needed to remove the crossover distortion which is the special feature of Class AB amplifiers. Because our circuit uses two Darlington pairs in the final amplifier stage, the bias needed to just turn on Q3 - Q6 should be about 2.6V (4 x 0.65V.) This is supplied by the voltage drop across the green LED and the trimpot. After adjusting the pot to remove crossover distortion you you should have the following circuit values: the bias voltage is about 2.05V - 1.93V across the LED and 0.12V across the pot; a collector current of 5.44 mA and a pot resistance of 22 ohm.

Overall Description. Q1 & Q2 form a complementary pair for the audio voltage amplification. The advantage of using two transistors for this stage is that the arrangement has a very high input impedence and hence does not load down the input signal. That means it draws very little current from the previous stage. The load for transistor Q2 is the green LED, the pot resistance plus R4. Note that R4 is not joined directly to the ground rail (as you might expect) but indirectly via the speaker. This is called bootstrapping, a topic we will shortly return to.

The pairs of transistors Q3/Q5 & Q4/Q6 form a current amplifier. The small valued R6 & R7 help to stabalize the circuit. Voltage changes across these resistors act as negative feedback and help to counteract any alterations in current caused by temperature, or differential gains in different transistors. There is also a negative feedback loop provided by R5.

Bootstrapping. This is a technique which allows you to unlock or separate the AC & DC operations of an amplifier in order to get an increased power output. In some ways it is like the operation of an inductor which has a low DC resistance but a high AC impedence. The smaller DC resistance of the bootstrapped load does not restrict the current flow, while the higher AC impedence results in a large voltage being generated across the load. And combining high current with high voltage gives high power (P=E x I).

In general, bootstrapping provides positive feedback from the output to the input of a unity gain amplifier in such a way that a particular point of the circuit is 'pulled up by its own bootstraps'. The signal voltages at the opposite ends of the bootstrap rise & fall together, with virtually the same AC signal appearing on both side, providing a higher impedence load for the driver transistor than its ohmic value would indicate. Let us look at how this works for our circuit.

Resistor R4 is the bootstrapped load. Because it is connected after the capacitor C3, the bootstrap is effective only for the AC signal and the extent of the multiplying effect will be determined by the true voltage gain of the nominally unity gain amplifier. Suppose the amp has true unity gain. Then the voltage gain at both ends of resistor R4 would be exactly the same. With no AC voltage drop across R4 no current would flow through it so it would have an effectively infinite resistance. Now suppose that the voltage gain is a more realistic 0.9. This means that the voltage at the top & bottom of R4 would be 1V and 0.9V respectively making the voltage drop across it 0.1V. This is only one-tenth of the full V which would occur across R4 if it were connected directly to ground. Hence, R4's 'bootstrapped' resistance is 10 times greater than its 1K5 value. So to the driver transistor Q2, R4 now provides an AC load impedence of 15K. The closer the gain approaches unity the greater the effective impedence provided by the bootstrap.

The advantage of such a setup is that Q1 & Q2 achieve a higher AC voltage gain because their output is developed across a higher value load resistor. If R4 were not bootstrapped but simply connected to ground the value of R4 would have to be increased to 15K to achieve the same effect. But such an increase would result in the base currents of Q4 & Q6 (which also flow through R4) developing a far larger voltage across the resistor. This voltage could easily be large enough to turn off Q2 on the negative sections of the signal preventing its voltage swing going anywhere near ground.

Calculation. An 8 ohm speaker dissipating 1W of power draws an RMS current of 354 mA ($P=I^2R$), or a peak current of 500mA (354 x sqrt2). If the current gain of each transistor Q4 & Q6 is 30 (typical) then the base current of Q4 is 556 uA. This small current still produces a voltage drop across 15K of 8.3V, restricting the negative output voltage swing to only 0.7V (9 - 8.3V). Clearly the driver transistor Q2 will shut down long before the amplifier delivers a peak load to the speaker.

Hence the advantages of bootstrapping - the multiplied resistance of the load resistor - gives us an increased AC voltage gain from the first stage of the amplifier without decreasing the AC current from the second stage. This results in higher output power.

Supply Voltage. This calculation also explains why increasing the supply voltage will increase the volume of the output. A higher supply voltage means that the input signal to the power stage can have a greater voltage swing before clipping which results in a greater swing for the output. If the same current still flows then doubling the voltage (RMS) will double the output power. To show this the power output of the module was measured at various supply voltages. To do this the speaker was replaced by a 5W, 8 ohm resistance, a 1kHz signal was the input and the output viewed on a CRO. The pot was adjusted for each voltage.

Next the amplitude of the input signal was adjusted to achieve the maximum output signal without distortion (by looking at the output on the CRO.) Then the AC voltage across the load resistor was measured. This gave an approximate RMS value. The power dissipated in the 8 ohm load was calculated from $P = V_{rms}^2/R$. This gave the following results:

VCC	VRMS	Power
9V	1.70V	361mW
12V	2.34V	684mW
15V	3.13V	1.22W
18V	3.67V	1.68W

So it can be seen that any increase in supply voltage gives a substantial power increase. Doubling its value gives four times the power. This is why very large power amplifiers (hundreds of watts) need very high supply rail voltages.

Web Address & Email. You can email us at **sales@quasarelectronics** for problems or requests. See our Web page at:
http://www.quasarelectronics.com

COMPONENTS

Resistors, 5% carbon:		
1R2	R6 R7	2
100R	R3	1
1K5	R4	1
1M	R2	1
2K7	R8	1
820K	R1	1
10K	R5	1
10K pot		1
200R Koa trimpot		1
0.1 uF capacitor	C5	1
Electrolytic capacitors:		
10uF	C1	1
47uF	C2	1
100uF	C3 C4	2
BC548B	Q1 Q3	2
BC558B	Q2 Q4	2
BD139	Q5	1
BD140	Q6	1
5mm Green LED		1
5mm Red LED		1
Speaker 8 ohm, 3"		1
9V battery snap		2
SPDT PCB switch		1
2 Pole Terminal blocks		3
Heat sinks HS103		2
Nut & bolt set		2
3048 PCB		1

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