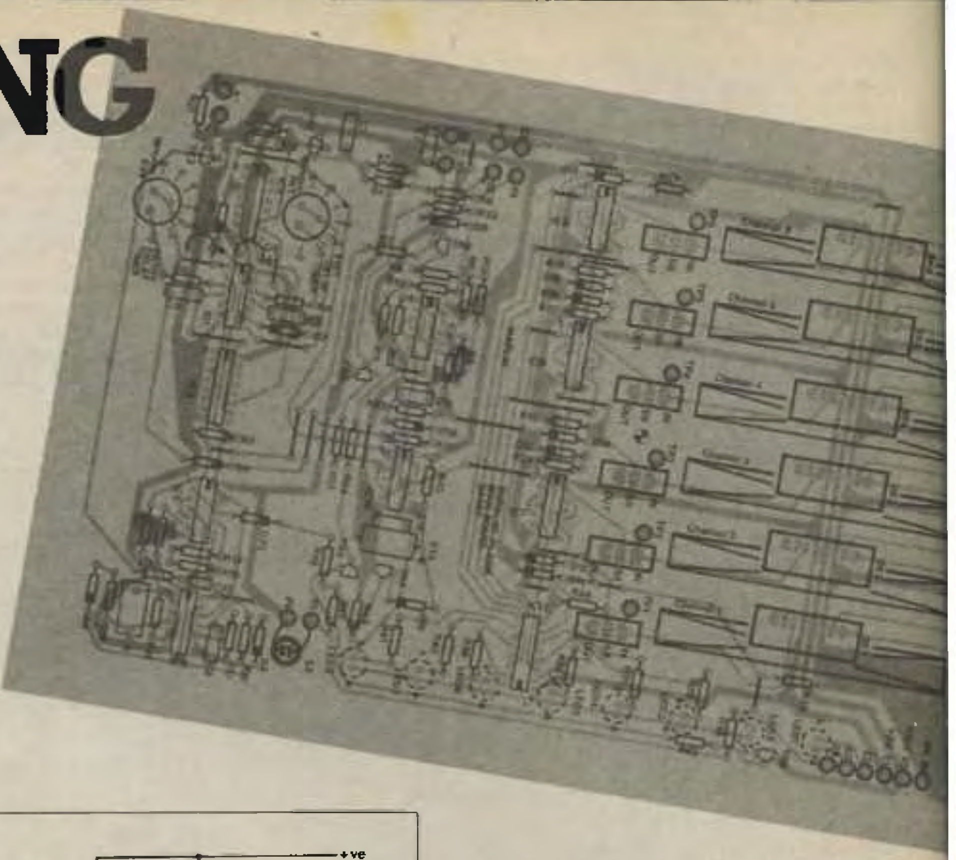
STARTING POINT

by Robert Penfold

Introducing the fundamentals of electronics for the constructor.



Classes of Amplification

The amplifiers considered so far in "Starting Point" have all been of the type where a transistor has been used in one of the three amplifying modes with a resistor as the collector or emitter load, as appropriate. A simple arrangement of this type is perfectly suitable for use in low level stages where powers of no more than a few milliwatts or so are involved, but the inefficiency of this class of amplifier is a severe drawback when an output power of a few hundred milliwatts or more is required.

For example, if we consider the simple output stage shown in Figure 1, this is a straightforward common emitter stage having R1 to provide base biasing, R2 as the collector load resistor, and input and output DC blocking provided by C1 and C2 respectively.

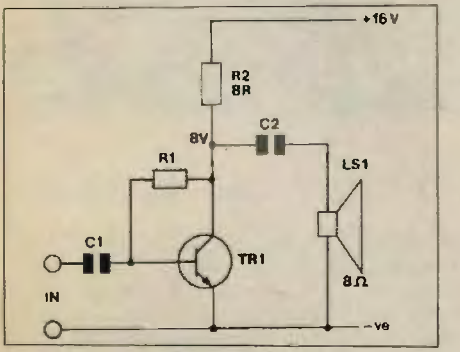


Figure 1. Simple Class A output stage.

As usual, the circuit is biased so that Tr1 has a collector potential of half the supply voltage, and with 8 volts across 8 ohm load resistor R2 there is obviously a current flow of 1 amp through R2 and Tr1. This gives an input power of 16 watts, with R1 and Tr1 each dissipating 8 watts.

The maximum output voltage from this stage is about 16 volts peak to peak, and will be a little less than this in practice since even with Tr1 switched fully on there is still likely to be a potential of about 1 volt at its collector. No practical transistor can produce a collector potential much below this figure when operating at a high collector current. We are also assuming that the circuit is driving an infinite load impedance, whereas it is in fact driving a load impedance of just 8 ohms. The load impedance is, in fact, equal to the 8 ohm output impedance of the amplifier, and this causes the output voltage to be loaded to just half the unloaded figure. In other words the maximum theoretical output voltage swing is only 8 volts peak to peak under load, and in practice would not even be as high as this. In terms of RMS output voltage this is only about 2.83 volts.

The output power of an amplifier is E^2/R where E is the RMS output voltage and R is the load impedance. In this example E^2 is equal to 8, and dividing this by the 8 ohm load impedance obviously gives an output power of 1 watt RMS. In other words an input power of 16 watts is required to give a maximum output of only 1 watt RMS!

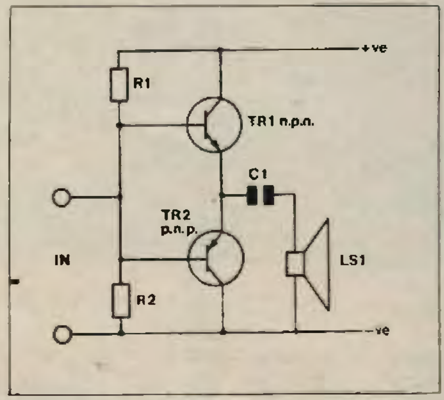


Figure 2a. Basic Class B (AC coupled) output stage.

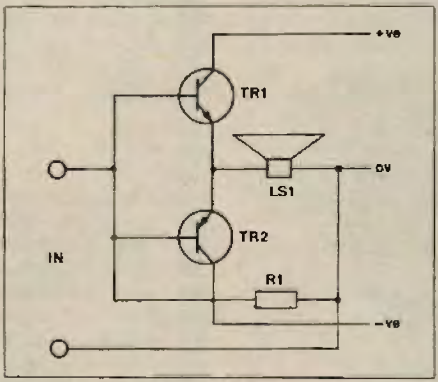


Figure 2b. Basic Class B (DC coupled) output stage.

Higher output power can be obtained by reducing the value of R2 so that the output impedance of the amplifier is reduced, and the loaded output voltage is increased. However, this would cause the input current and power to rise, and would actually decrease efficiency. Increasing the value of R2 would reduce the input current and power, but would also give a lower loaded output voltage and maximum output power, and would again actually produce a reduction in efficiency.

There are a number of ways of improving the efficiency of simple amplifiers of this general type, which are known as 'Class A' amplifiers, but the efficiency of a true Class A stage is always rather low. The disadvantages of this low efficiency are the need for a substantial and expensive power supply to give even quite modest output powers, the need to use high power components in the output stage, and the generation of a substantial amount of heat. Battery operation also tends to be a little impractical using primary cells since the high current consumption results in expensive batteries becoming exhausted at an alarming rate.

Class B Operation

Virtually all audio power amplifiers use some form of Class B operation, and Figure 2 (a) shows the basic Class B output stage on which most modern designs are based. Figure 2 (b) shows the DC coupled output version, and operation of the two circuits is essentially the same. However, the DC coupled version is a little easier to understand and we will therefore consider the operation of this circuit.

The circuit has dual balanced supplies, and the loudspeaker connects between the output of the amplifier and the 0V rail. Tr1 and Tr2 are both emitter followers and therefore each provide approximately unity gain. R1 biases the input and output of the amplifier to the 0V rail potential, and under quiescent conditions there is thus no voltage present across LS1.

If a positive input signal is applied to the circuit Tr1's emitter goes positive and Tr1 supplies power to LS1. The output impedance of the circuit is very low and despite the low load impedance Tr1 can supply virtually the full positive supply potential to LS1. Tr2 is cut off and plays no active role with a positive input signal.

With a negative input signal Tr1 is cut off and it is Tr2 that supplies power to LS1. Once again the output impedance is very low, and almost the full negative supply voltage can be delivered to LS1.

This system gives much better efficiency than a Class A circuit since the maximum peak to peak output voltage is virtually equal to the sum of the two supply voltages, and the supply current is equal to the output current. Thus the average supply current varies in sympathy with the output, and is zero under quiescent conditions. This avoids high current consumption and heat generation under stand-by or low volume conditions, and when the amplifier is fully driven it is possible to obtain an efficiency of over 70%. This contrasts with the high continuous current consumption and low efficiency of a Class A circuit.

Quiescent Bias

In practice the circuits of Figure 2 would give very poor results due to what is termed "crossover distortion". This comes about due to the base-emitter potential of about 0.6 volts that is needed before a silicon transistor begins to conduct. This makes it necessary to have an input signal of at least +0.6 volts before there is any output signal at all! Even with an output signal from the circuit there is severe distortion as the low voltage part of the waveform is absent. A triangular input waveform as shown in Figure 3(a) would emerge from the circuit as shown in Figure 3(b).

Crossover distortion is normally overcome by incorporating some additional components at the input of the output stage, as shown in the circuit of Figure 4. Here the driver and output stages are effectively merged together, and practical designs are invariably of this type. Tr1 is the driver stage and Tr2 plus Tr3 are the complementary emitter follower output stage. The amplifier is biased by R1 and R2, and the purpose of D1, D2 and RV1 is to give a quiescent bias voltage across the bases of Tr2 and Tr3.

RV1 is adjusted so that the bias fed to Tr2 and Tr3 is just sufficient to bring them to the threshold of conduction so that Tr2 is switched on if the drive voltage even marginally positive, and Tr3 is switched on as soon as the drive voltage from Tr1 starts to go negative. In practice it is usually necessary to use a slightly higher bias than this so that under quiescent conditions there is a small but significant current flowing through Tr2 and Tr3. This is necessary due to the comparatively low gain of practical transistors when they are only marginally above the threshold of conduction, and the relatively small but nevertheless significant amount of crossover distortion that this would produce. By biasing the output devices beyond this low gain part of their transfer characteristics this crossover distortion is avoided.

It may, in fact, be necessary to use quite a large quiescent bias current through the output transistors in order to produce really low crossover distortion. Circuits of this type are generally called Class AB amplifiers, and this is simply because at low and medium output powers one transistor acts as the amplifying device and the other output transistor acts as its emitter load. This is, in fact, a form of Class A operation, and it is only at high powers that one transistor is cut off while the other drives the load, and true Class B operation is obtained. It is from this mixture of Class A and Class B operation that the term Class AB is derived.

Most practical designs use only a low quiescent bias current through the output transistors, and this is quite understandable since Class AB working obviously partially loses the advantages of Class B operation. Also, although Class AB amplifiers avoid crossover distortion this advantage is offset by an increase in other types of distortion.

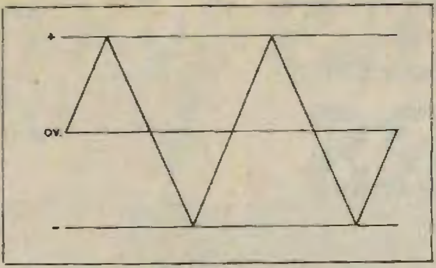


Figure 3a. Triangular input waveform.

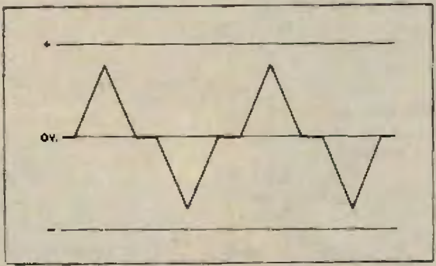


Figure 3b. Output waveform, showing crossover distortion.

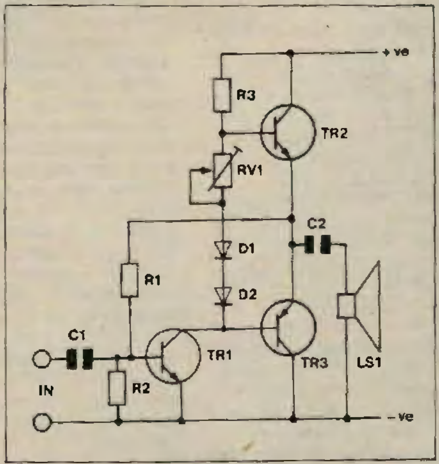


Figure 4. Practical Class B power amplifier configuration.

Practical audio power amplifiers almost invariably use a low quiescent bias plus a generous amount of negative feedback to reduce crossover distortion and other types of distortion.

Thermal Runaway

The bias voltage supplied across the bases of Tr2 and Tr3 is extremely critical, with a marginally low potential giving severe crossover distortion and a slightly high bias producing a very large quiescent current through the output transistors. The position is made worse by the heating that occurs in Tr2 and Tr3 when the amplifier has been in use for a short while. Bearing in mind that Tr2 and Tr3 will inevitably have to handle substantial power levels a significant amount of heat generation in these transistors is inevitable.

As Tr2 and Tr3 heat up, their base-emitter threshold voltage decreases, and the quiescent bias current increases. The increasing bias current produces further heating in the output devices which, in turn, gives an increase in the bias current, and this regenerative action continues until the output devices overheat and are destroyed unless suitable preventative measures are taken. This thermal feedback is called "thermal runaway".

D1 and D2 are used to prevent thermal runaway, and they achieve this by sensing the rise in temperature of the output transistors. They may actually be mounted on the same heatsink as the output transistors in order to ensure that they rapidly and properly sense the temperature changes. The voltage developed across D1 and D2 varies with temperature, and decreases as temperature is increased. This gives a strong stabilising effect on the quiescent bias current with the bias voltage automatically decreasing as the output transistors heat up.

There are other ways of providing thermal stabilisation, such as using a transistor in the amplified diode configuration, or a negative temperature coefficient thermistor. Whatever method is used the circuit must be carefully designed as there is otherwise a likelihood of over-compensation and consequent crossover distortion when the output transistors heat up, or insufficient thermal stabilisation which would simply result in slower thermal runaway!

Most low and medium power audio amplifiers these days are based on an integrated circuit, and thermal stabilisation is not a problem here since the output transistors and the temperature sensing components are on the same chip. This enables very predictable results and very accurate stabilisation to be easily obtained.

Power MOSFETs are becoming increasingly popular for use in the output stages of high power audio amplifiers, and amongst other advantages they require no thermal stabilisation. These devices have a positive temperature coefficient, like bipolar transistors, at low operating currents. However, this changes to a negative temperature coefficient at currents of more than about 80mA. In other words, with a bias current of less than about 80mA an increase in temperature produces a small increase in the quiescent bias current, but at more than about 80mA an increase in temperature results in a decrease in bias current. The quiescent bias current therefore tends to be self-stabilising, and thermal runaway cannot occur.

Class C

Class C amplifiers are not often encountered, and are only applicable to radio frequency circuits. With this type of amplifier the amplifying device is reverse biased so that it only conducts during quite a small part of each output cycle. The load for the amplying device must be a tuned circuit which "rings" at its resonant frequency and effectively fills-in the missing part of the output waveform. A mechanical analogy of this is the periodic striking of a bell to produce a continuous ringing sound.

The advantage of Class C operation is the very high level of efficiency that can be attained, but a lot of filtering is normally needed at the output to produce a really pure output signal.

There are other modes of operation, and Class D for example is a form of high efficiency audio power amplifier. However, these other modes of amplification tend to be quite complex and are mostly just variations on one of the operating modes already described. Class D for example, uses what is really just a Class B output stage, and it is the preceding and following circuitry that give the higher efficiency.

It is worth noting that although the circuits shown here use only a single device in the output stage, or a single device in each half of the output stage in the Class B designs, practical circuits often employ two devices in the Darlington Pair configuration or some similar arrangement. This is often necessary in order to produce a really low output impedance so that large output currents can be easily provided with only a modest drive current. ■