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A discussion of some of the design problems in

High Power Amplifiers

In the coming months, "Electronics Australia" will be publishing a high power amplifier design. This article provides some of the background to the design and details the stringent operating requirements for the output stages.

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Amongst users of audio amplifiers there is a great deal of attraction and mystique about very high power amplifiers. Apart from their potential to produce an awesome noise, some of the attraction stems from their large size arid mass and last of all, their very steep prices. Well, why is it that these amplifiers are so expensive? After all, it is true to state that amplifiers which produce up to about 60 watts into 8 ohms or around 100 watts into 4 ohms are relatively easy to design and manufacture. But it is also true that very few high power amplifier designs have been published in electronics magazines. So perhaps the design of these powerful beasts really is fraught with problems.

The best way to appreciate some of these problems is to consider the design of a high power amplifier. Let us aim for a figure of 100 watts into 8 ohms, and just see what is required. To do this, we start at the output stage and then work back, until we reach the input stages.

An amplifier which is intended to deliver 100 watts into 8 ohms must be capable of delivering an output voltage swing of 80 volts peak-to-peak, or to put it another way, +40 volts peak. This means that the peak currents into the 8 ohm load will be 5 amps. On face values, these conditions do not present an insurmountable problem. For an output voltage swing of 80 volts we need to employ supply rails of +50 volts, or 100 volts overall. And if we draw the load line for a class B amplifier delivering this order of power into an 8 ohm load, we find that the peak dissipation in each output is about 78 watts.

Selecting a pair of transistors which can withstand collector-emitter voltage up to 100 volts and peak dissipation of 78 watts is not too difficult, provided the heatsink has sufficient thermal capacity. But the job is nowhere near that easy. If it was, there would be a lot more high-power amplifiers being produced. What makes it hard is the fact that nice, well behaved 8 ohm loads virtually only occur in the laboratory testing situation. In real life, the load is one or more loudspeakers with perhaps a crossover network. The result is a load which is highly complex and which is almost never purely resistive with a value of 8 ohms.

Fig. 1 shows the impedance curve of a typical loudspeaker mounted in a closed box. This shows a large peak at low frequencies, due to the mechanical resonance of the loudspeaker in the closed box and above the resonance, an impedance characteristic which dips to a value close to 8 ohms and then rises gradually in proportion to the frequency.

Fig.. 2 shows an electrical approximation of the same loudspeaker shows just how far removed a loudspeaker is from a simple 8 ohm resistor. But even there we are showing a relatively simple situation, because most loudspeaker systems, particularly those intended for high fidelity use, have more than one driver and a crossover network. The net result cm still be approximated by an electrical network, but it makes the circuit in Fig. 2 look very simple.

Most loudspeaker designers try to ensure that the impedance of their loudspeaker systems is reasonably flat and does not dip below about 80% of the nominal value, i.e., for nominal 8 ohm system the minimum is not less than about 6.4 ohms. And it is usual to. find that the DC resistance of the voice coil is not less than about 5.5 ohms. In practice, it is possible for the amplifier designer to simulate the behaviour of a loudspeaker sufficiently well by using a resistor of 5.5 ohms and a small series inductance of, say, half a milliHenry. This can be used to examine the effect of typical complex loads on amplifiers.

In fact, it is not even necessary to do physical tests. Having decided on the simulated loudspeaker load, the designer is then able to plot load currents and voltages and then the load lines. To demonstrate this, Fig. 3 shows the relationship between voltages and currents at the 100 watt level (i.e., 28 volts RMS) for load impedances of 5.5 ohms, 5.5 + j5.5 and 5.5+ jl0 ohms. The “j” figure is the reactance of the inductor at a particular frequency. This diagram shows not only the magnitude of the load currents, but also the phase difference between voltage and current.

It is this often large phase difference between the load voltage and current which makes an ordinary loudspeaker a far more stringent load than a simple resistor. Just how stringent can be seen in Fig. 4. This shows the load lines for an amplifier delivering 28 volts RMS to the above loads. The resistive load line (5.5 ohms) is essentially a straight line - it starts at the 50 volt mark on the voltage axis and slopes up to a point coinciding with 7.27 amps and 10 volts.

Each load line actually portrays the voltage and current conditions of the output transistors. Notice that, for the resistive load line, each output transistor swings between cut-off (i.e., no current) with a collector-emitter voltage of 50V, and a point where the transistor has a C-E voltage of 10V and is conducting at 7.27 amps. The peak dissipation on this load line is about 108 watts, corresponding with 30 volts and 3.6 amps. That peak dissipation is certainly a lot higher than the 78 watts mentioned above, when operating into an 8 ohm load. Note that the power delivered to a 5.5 ohm load with 28 volts applied is over 140 watts.

By contrast to the 5.5 ohm resistive load situation, the load lines for the reactive loads (5.5 + j5.5 and 5.5 + jl0) are curved, and they sweep across into the high voltage area of the graph. This curvature of the load line means that the peak dissipation is very much higher than for a resistive load. For example, with the more reactive load, 5.5 + j5.5 ohms, the peak dissipation on the load line is about 184 watts! (45 volts multiplied by 4.1 amps.)

On the same graph we have drawn the hyperbola showing the power dissipation of a 150 watt transistor. If we continue to plot these curved load lines (representing all audible frequencies applied to the load) we shall find some that exceed the 150 watt dissipation. So we find that, at the very least, we need to specify a pair of output transistors which can each withstand peak dissipation in excess of 150 watts.

To cope with this stringent load condition the output transistors must be very rugged, substantially free from second-breakdown effects and may need protection circuitry. In addition, the output transistors should be reasonably linear in their current-gain characteristic and should have adequate bandwidth.

But the situation gets worse. What we have not allowed for, so far, is overdrive and short-circuited loads. If overdrive of the above loads is taken into account, the output transistors must each withstand peak dissipation in excess of 200 watts. High mains voltages make these figures even higher. Clearly, we must find some very rugged power transistors and probably include an effective means of protection against overdrive, over-voltage and short-circuits.

At this point some readers may still be wondering why there is any difficulty in selecting high power transistors for a 100 watt amplifier. After all, there are complementary pairs of power transistors readily available with dissipation ratings up to 250 watts. The problem with many of these transistors, however, is that due to “second-breakdown” effects, the full dissipation rating of the transistors is not applicable at the higher voltages which must be used.

As an example of this effect, consider one pair of complementary power transistors which have a dissipation rating of 250 watts, maximum collector voltage or 140V and continuous current rating of 20 amps. On paper, that looks like an extremely rugged pair of transistors. But further examination of the specifications shows that the dissipation must be derated to under 150 watts at a collector voltage of 70V and to 100 watts at 100V. So as far as use in high power amplifiers is concerned, the power transistor with the highest nominal ratings may not be the most rugged.

By way of explanation, “second-breakdown” is an effect whereby, at high voltage and., high currents, the voltage distribution across the semiconductor chip causes current crowding and localised “hot spots” which can cause failure of the device.

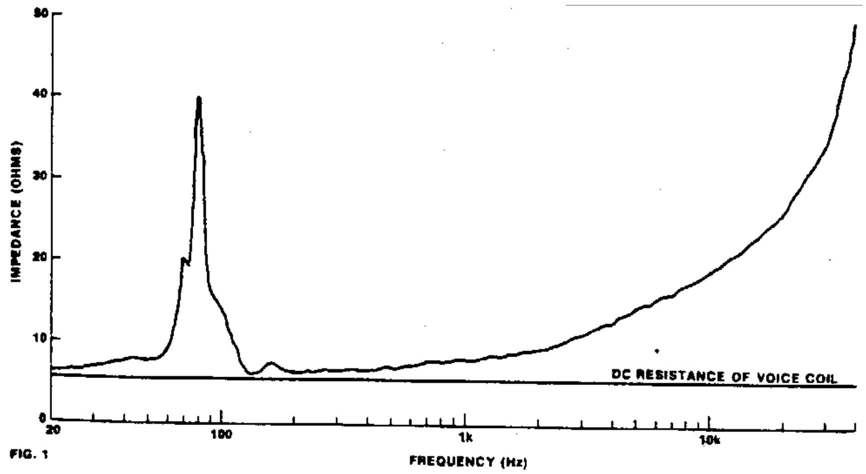
Summarising what we have discussed so far, we have found that an amplifier which is rated to deliver 100 watts into 8 ohm loads must be able to cope with reactive loads which may have a resistive component which is considerably less than 8 ohms. The reactance will cause appreciable phase shift between load voltages and currents and this, in turn, will cause the peak dissipation in the output transistors to be considerably higher than if the load was simply resistive.

But if there are difficulties in selecting suitable output transistors, the problem is actually worse for the driver transistors. While they are required to deliver only a twentieth (typically) of the output stage current, they must have similar voltage ratings to the output transistors. Second-breakdown effects usually apply a more severe constraint than for the heavy power devices, because the chip for typical driver transistors is usually quite small. The task of the driver transistors is made more difficult by the fact that the current-gain of the output transistors is usually reduced at higher frequencies. This means that the driver transistors must deliver higher currents and their dissipation is consequently increased.

We have not mentioned Darlington power transistors as a possibility for this application. After all, they are attractive because they eliminate the need for separate driver transistors and some of the bias resistors which would otherwise be required. However, at the time of writing, we know of no Darlington device which is rugged enough to guarantee reliable operation in a 100W/8 ohm amplifier.

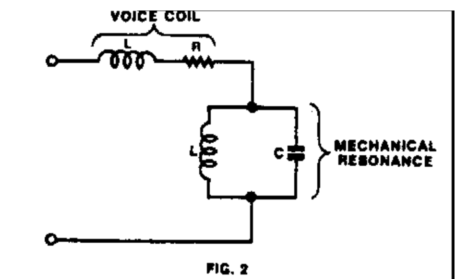
Well the foregoing should explain some of the stringent requirements for a higher power amplifier. No wonder many higher power amplifiers use multiple power transistors in parallel and series configurations. By comparison with the output and driver stages, the early stages of a higher power amplifier are relatively easy to design, but finding suitable transistors is still a problem. In the coming months we shall be describing a power amplifier with a target rating of around 100 watts RMS into 8 ohms. Watch for it.

List of Figures



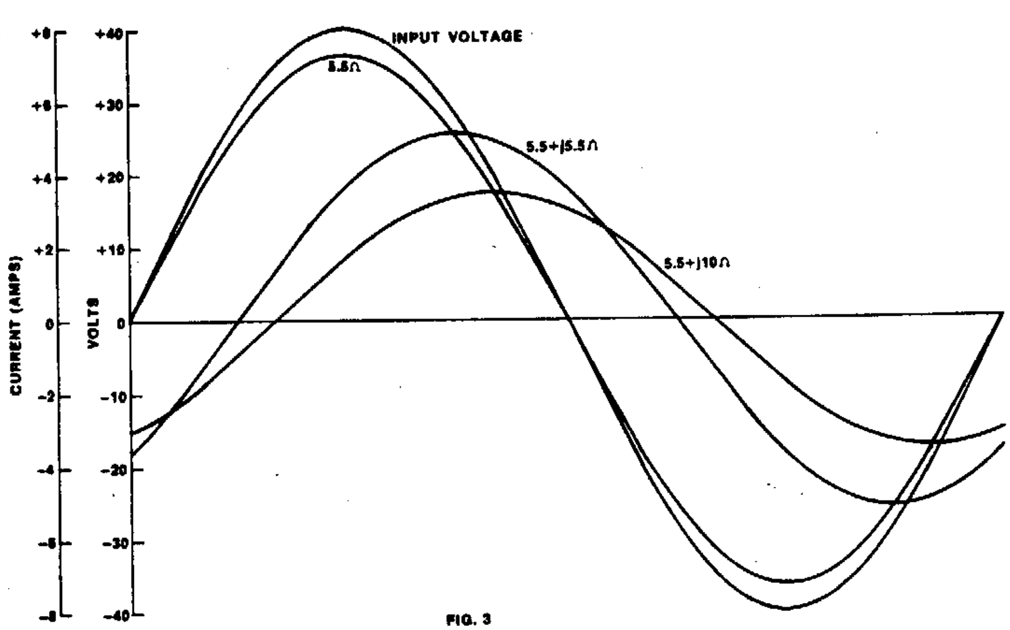
This graph shows the impedance curve of a single loudspeaker in a closed box.

Figure 1



The electrical analog for a loudspeaker.

Figure 2



These curves show the amplitude and phase difference for an input voltage of 28 volts RMS and the resulting currents into loads of 5.5 ohms, 5.5 + j5.5 ohms and 5.5 + j10 ohms. These inductive loads have phase lags of approximately 45 and 61 degrees.

Figure 3

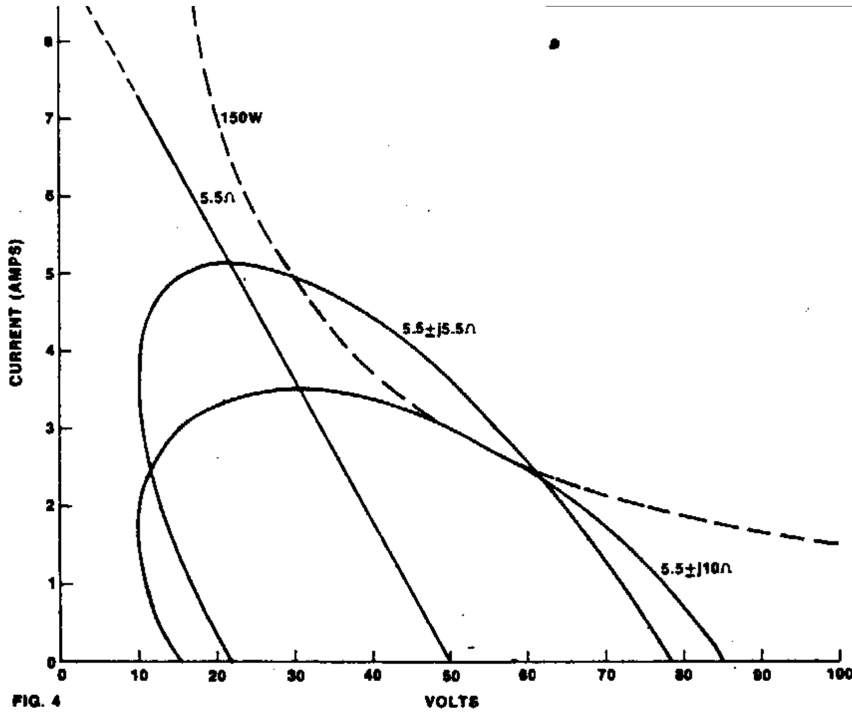


FIG. 4

The curved load lines for reactive loads produce peak dissipation figures. and to 100 watts at 100V.

Figure 4