WHY CAR AMPS USE DC-DC CONVERTERS

Why do modern car hifi amplifiers all seem to include DC-DC converters? Basically because the only source of electrical energy is the car's main or auxiliary battery, which delivers DC and at a relatively fixed low voltage — nominally 12V, but typically 13.8V. This is not nearly enough, when we want to have an amplifier which drives the speakers with the kind of audio power that people want, say 100 watts or more.

We can see why this is so with a few quick calculations. If we have an amplifier with a conventional 'series push-pull' output stage, operating from a rail-to-rail DC voltage of 13.8V as provided by our battery, this voltage automatically becomes the absolute maximum peak-to-peak AC voltage **Vpp** that can be supplied to the speakers (Fig.1). So the maximum RMS audio voltage (**Vrms**) that this kind of amplifier can provide to the speaker is:

$$\begin{aligned} Vrms &= Vpp/(2 \times \sqrt{2}) \\ &= 13.8/2.828 \\ &= 4.88V \end{aligned}$$

This is a theoretical figure, of course. It assumes that the amplifier's output transistors are 'perfect' and have no 'on resistance' or saturation voltage drop, so they can indeed deliver the full rail-to-rail voltage. But practical transistors aren't perfect, so the actual output voltage would probably be 10% less.

Even with perfect transistors, though, the maximum output power **Po** that this amplifier could deliver to a speaker would be:

$$\begin{aligned} Po &= Vrms^2/Rs \\ &= 23.8/Rs \end{aligned}$$

where Rs is the speaker impedance. So if we used a standard hifi speaker with an impedance of 8 ohms, the absolute maximum power we'd be able to get out of our amplifier would be 23.8/8, or a measly 2.98 watts!

Even when we use standard 'car audio' speakers with an impedance of 4 ohms (half that of standard hifi speakers), the maximum theoretical power that this kind of amplifier can supply to each speaker is still very modest:

$$\begin{aligned} Po &= 23.8/4 \\ &= 5.95W \end{aligned}$$

Clearly if you connect two 4-ohm speakers in parallel to lower the total load impedance still further to 2 ohms, this will roughly double the total output power again. But you'll still end up getting a bit less than 12 watts.

Get the idea? The limiting factor is the way the battery voltage determines the amplifier's peak-to-peak output voltage, so the only way to get more output power is to use a lower output impedance — i.e, more speakers in parallel. And this is a messy approach, not only because multiple speakers can take up a lot of space, but because the lower the load impedance becomes, the higher the current that the amplifier must supply (and in turn draw from the battery). So you have to use thicker and thicker cables, to reduce the electrical losses caused by cable resistance. (Lower impedance speakers are also less efficient, as well...)

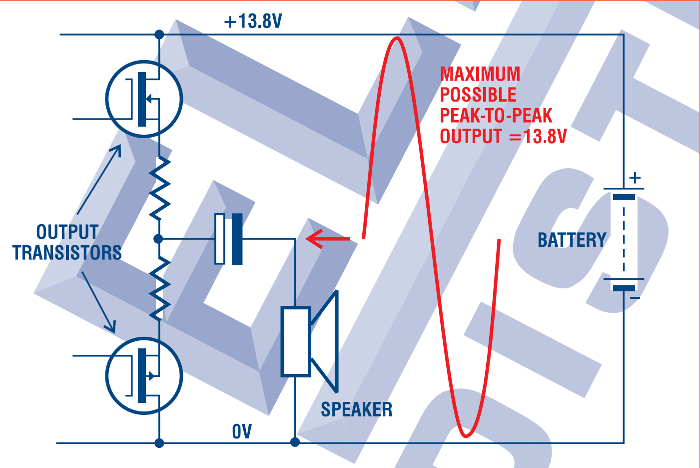

Fig.1: When an amplifier with a standard 'series push-pull' output stage runs from 13.8V DC, this becomes the absolute maximum peak-to-peak output.

Bridged-mode output

One way of alleviating this problem is to use an amplifier with a 'bridged-mode' or 'H' output stage (Fig.2). Here the amplifier has what are in effect two push-pull output stages, with one side of the speaker connected to each. The two output stages are then driven with signals in opposite phase, so that one side of the speaker is pulled high while the other side is pulled low — and vice-versa for alternate half cycles.

The nett result is that because the battery voltage now determines the maximum *peak* output voltage for each half cycle, rather than the total peak-to-peak output voltage, the amplifier is now able to deliver **double** the peak-to-peak voltage to the speaker (theoretically, at least):

$$\begin{aligned} Vpp &= 2 \times Vbattery \\ &= 27.6V \end{aligned}$$

Which means that the maximum RMS output voltage is also doubled:

$$\begin{aligned} Vrms &= Vpp/(2 \times \sqrt{2}) \\ &= 27.6/2.828 \\ &= 9.76V \end{aligned}$$

In turn, and because the power output is proportional to the **square** of the RMS output voltage, this means that our maximum output power has now risen by a factor of *four* times. So even using our 4 ohm speaker we can now deliver:

$$\begin{aligned} Po &= Vrms^2/Rs \\ &= 9.76^2/4 \\ &= 23.8W \end{aligned}$$

Which is a reasonably healthy increase, of course. And we can double it yet again, by connecting two 4-ohm speakers in parallel to halve the load impedance — giving 47.6W.

But that's about as far as we can go, still using our 13.8V battery voltage. And that figure of 47.6 watts is of course only a theoretical maximum; you can't achieve this sort of efficiency with real-world output devices. Yet even this theoretical figure is still a long way short of the hundreds of watts that car audio enthusiasts want, as you can see.

A better answer

So how *can* you make an amplifier that provides hundreds of watts of audio, and into readily available 4-ohm speakers? You've probably guessed already: it's only by increasing the amplifier's supply voltage — so it's no longer held back by that 13.8V or

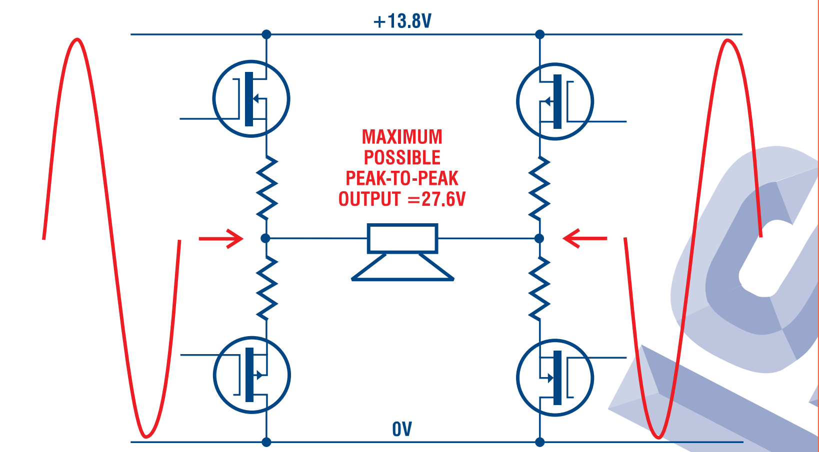

Fig.2: One way to get more output from an amplifier running from low voltage DC is to use a bridge-mode output stage. With each side of the speaker driven by opposite-polarity signals, the maximum peak-to-peak output now becomes TWICE the supply voltage.

27.6V limit on peak-to-peak output voltage.

This, then, is the reason why modern car hifi amplifiers have DC-DC converters inside them. It's the only way they can provide the higher rail-to-rail voltage they need to generate that much higher output power (Fig.3). The DC-DC converter simply steps up the 13.8V battery voltage to a somewhat higher voltage (usually in the form of balanced positive and negative rails), for the amplifier itself.

How much higher do the new supply rails need to be? It's not too difficult to work out the approximate voltages, working backwards from the power output.

Let's say we want our amplifier to be able to deliver up to 150 watts, into a 4-ohm speaker. First we work out the RMS output voltage across 4 ohms that corresponds to 150 watts:

$$\begin{aligned} V_{rms} &= \sqrt{(P_o \times R_s)} \\ &= \sqrt{(150 \times 4)} \\ &= \sqrt{600} \\ &= 24.5V \end{aligned}$$

Next, we work out the corresponding peak-to-peak voltage level:

$$\begin{aligned} V_{pp} &= V_{rms} \times 2 \times \sqrt{2} \\ &= 24.5 \times 2.828 \\ &= 69.3V \end{aligned}$$

This is the total voltage swing needed from our amplifier's output, when it's delivering 150W into the 4 ohm speaker. Which means that the amplifier's supply voltage rails will need to provide at least this voltage difference — or in other words, the rail-to-rail voltage will need to be at least 70V. In other words, supply rails of +/-35V.

Of course this is again a theoretical figure, and doesn't allow for the on-resistance or saturation voltage of the amplifier's output transistors. So in practice the supply rails will generally be a few volts higher, to allow for the losses. For a practical 150W car amplifier, then, the DC-DC converter will probably step up the 13.8V battery voltage to say +/-38V.

Getting even more

What if you need even more power from one of these higher-voltage amps? Can you again increase it by using 2-ohm speakers, or by using the two channels of a stereo amp and using them in bridged-mode? Yes, it's generally possible to do either, if you do need even more output power.

Most modern car amplifiers have output stages designed to be able to drive 2-ohm loads, and they're usually also fitted with a switch which effectively converts them from two stereo channels into a bridged-mode mono amp. So they're able to deliver considerably more power into a pair of 2-ohm speakers, or even more power again into a single 4-ohm speaker.

There are two things to note about this, though. The first is that because of extra losses introduced in the DC-DC converter, as well as those in the amplifier output stages, you don't get twice as much power into 2-ohm speakers, or four times into a 4-ohm load in bridged mono mode. As in many other areas, there's a kind of 'law of diminishing

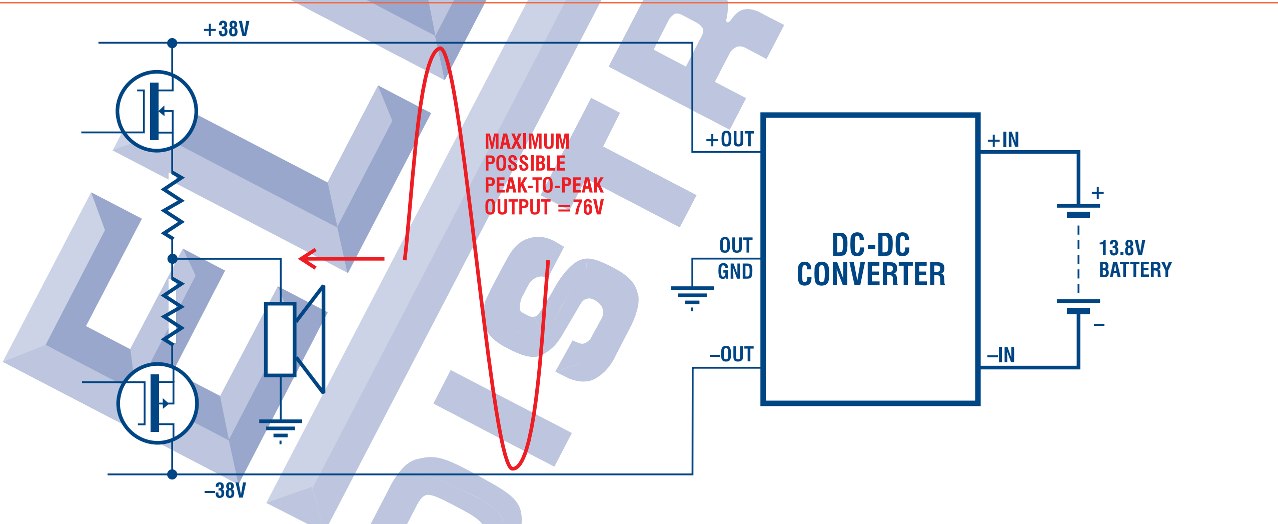

Fig.3: But the only way to get REALLY high power output with a battery supply is to use a DC-DC converter to step up the battery voltage to a much higher value, so that the maximum peak-to-peak output voltage can now be as high as we wish...

returns' — the more you try to get, the larger the difference between theory and reality.

So with a typical amplifier capable or delivering 150W per channel into 4-ohm speakers, you might get say 230W per channel into 2-ohm loads (not 300W), and only 450W into a 4-ohm load in bridged-mode mono (not 600W). Don't forget that 2-ohm speakers are also somewhat less efficient than 4-ohm or 8-ohm types, as well; so you lose a bit there as well...

The other point to note is that you might expect to be able to increase the amp's output even further, by using it in bridged-mode mono to drive a 2-ohm load. In most cases you can't do this, however, because the output stages aren't able to supply the necessary **current**.

The reason for this is that when you connect a speaker or other load to a bridged-mode pair of output stages like those shown in Fig.2, it appears to each of the output stages as if it has an impedance of *half* its actual value. That's because when one stage applies an output voltage **Vo** to its side of the load, a matching but opposite voltage of **-Vo** is applied to the other side by the second stage — so the load actually has double the voltage across it, and hence draws double the current. So as far as each side is concerned, it *acts* like a load of half the impedance.

Hence a 2-ohm speaker connected to an amplifier operating in bridged-mode mono will appear like a 1-ohm speaker to the output stages, and draw more current than they can comfortably or safely deliver. You might even cause expensive damage, if you try this and drive it for maximum possible output.

Now you know why the specification of most stereo car amps generally shows the output into stereo 4-ohm and 2-ohm loads, but the bridged-mode mono output into only a 4-ohm load. These are generally the only three practical options.

No miracles

It's important to bear in mind that although the DC-DC converter in a modern car amplifier allows the amp to deliver a lot more audio power into your speakers, by stepping up the battery voltage, there's no magic at work here. All of that increased audio power ultimately still has to come from the same energy source: ***your battery***.

Even in theory, all the DC-DC converter does is convert the battery's low voltage energy into the equivalent energy at a higher voltage. So if the amplifier is delivering 300 watts of audio into your speakers, it has to suck at least the same amount of DC power from your battery — and at a lower voltage, which means higher current. Think of the converter as the equivalent of a transformer, as far as DC is concerned...

In fact it's easy to work out the *minimum* current that the amp will need to draw from the battery. You simply divide the output power in watts by the battery voltage. For example if it's delivering 300W (150W x 2) of audio, the battery current will need to be at least 300W/13.8V = 21.7 amps.

Of course this is again a theoretical figure, which assumes that the DC-DC converter and the amplifier output stages are both perfectly efficient. In the real world *neither* of them is, so the actual battery current will be somewhat **higher** than you get from this simple calculation.

Although there has been a lot of success in improving the efficiency of DC-DC converters, the maximum overall efficiency of a typical car stereo amp (measured in terms of audio watts out for DC watts in) is still only about 70% or so. It's likely to be even lower with 2-ohm loads and in bridged-mode mono, too: nearer 60%. This means that the actual battery current will tend to be between 43% and 66% higher than it would be for the 100% efficiency we assumed earlier.

So when our typical 150W x 2 amplifier is delivering full power into two 4-ohm loads, its battery current is likely to be nearer 31A than 21.7A. And when it's delivering 450W into a 4-ohm load in bridged-mode mono, the battery current is likely to be around **54 amps**!

Use FAT cables...

This brings us to the last main point to remember about modern high-powered car amplifiers. Because all of that energy is being supplied at low voltage from our battery, the currents flowing in the battery cables are very high. This means that to get optimum performance from your amp, it's important to use very stout battery cables: cables with lots of copper to conduct the current.

Why is this so important? Well, remember that the DC-DC converter in these amplifiers is very much like the DC equivalent of a transformer. Remember too that the maximum output power of the amplifier itself tends to be proportional to the **square** of its supply voltage. So if the voltage at the amplifier's battery terminals drops by 10%, the converter's output rails will also tend to drop by 10% — and the amplifier's output power will in turn tend to drop by nearly 20% (0.9 x 0.9 = 0.81).

So the output of our 300W amplifier will tend to drop down to only 243 watts, with only a 10% drop in voltage at its battery terminals. That's a drop of only 1.38 volts. And guess how little cable resistance you need to produce a voltage drop of 1.38V, when a current of 31 amps is flowing?

Right — only **0.045 ohms** (1.38/31) — 45 milliohms, or thousandths of an ohm. And you need even *less* cable resistance to produce this drop when the current rises to 54A: 0.025 ohms (25 milliohms).

Quite apart from reducing the effective power output of the amplifier, the cable resistance also tends to throw away a significant amount of the battery's stored energy, as heat. If you work it out using Ohms law, you'll see that with a 1.38V drop the cables will be dissipating just on 43W with a drain of 31A, and almost 75W at 54A.That's battery energy being completely wasted..

So if you don't want to reduce the effective power output of your car amp, or waste some of the valuable battery energy just heating up the cables, use cables with as much copper as possible. The idea is to get their voltage drop down to no more than 1-2% of the battery voltage if possible, when the amplifier is drawing its maximum current. Typically this corresponds to a resistance of less than 10 milliohms.

Incidentally we're really talking here of **all** of the wiring and hardware between the battery terminals and the amplifier's DC input terminals — not just the cables themselves. So don't forget the battery terminal clamps, distribution blocks, inline filters, fuseholders and so on.

Needless to say, Electus Distribution can supply not only a range of high powered car amplifiers and speakers, but also a full range of battery fittings and cables to allow you to get top performance from them. For example there are two types of high-current power cable available, one with a 4.05mm bundle of copper conductors and a resistance of 2.5 milliohms/metre, and the other with a 7.7mm bundle of conductors and a resistance of only 0.97 milliohms/metre. Both types are available with either red or black insulation, for polarity coding — see the Jaycar catalogue or website for more details.