Fusing Output Valves

by Peter van Willenswaard

It all started when a Jadis Orchestra landed on my workbench. One of the EL34 output valves had blown, the normally silver coloured getter had turned white completely. These things happen. Valves are a bit like living creatures: they have a limited life span and some of them fall ill prematurely. So far nothing out of the ordinary.

When I opened the amp, I noticed the remains of a trimpot, including some melted solder, lying on the bottom cover of the amp. Its value was only just readable: 1k. The official schematic diagram is rather rudimentary, so it gave me no clue as to where this trimpot had come from.
Inspection of the circuitry showed some burnt remains near the heater wiring to the EL34s. In the Jadis Orchestra the heaters of the 4 output valves are wired in series and fed with about 24 V, so comparison between the affected channel and the channel that seemed still intact wouldn't be of any help here. Further inspection revealed that it the 1k trimpot must have been soldered across the heater wires, with the wiper contact of the trimpot connected to ground: the classical way to minimize hum. But I had never seen such a trimpot melt before, so I was greatly puzzled. At 24 V the dissipation into 1k is about 0.5 W, which a standard plastic trimpot should be able to handle (if only just). There is no conceivable reason to suppose that the heater voltage had gone up spontaneously for a while. So what on earth had happened?

It took me quite a while before I could reconstruct the chain of events which led to this result. Mr. Jadis decided to protect the power valves with a fuse in series with the combined cathodes of each output channel. This seems sensible but it now appears it is not. Think of what happens if a valve looses its vacuum. The valve will develop full conductivity. Now the fuse blows. The cathode will be lifted to a voltage near the +500 Volt of the HV supply present at the anode. The insulation between cathode and filament will not survive this attack for very long because the maximum Ufk of an EL34 is just 100 Volt. A short-circuit will result there (between cathode and filament) and a new current path is created for the High Voltage. Happily the current, on its way to ground, found the 1 k trimpot, otherwise the high voltage supply, the output transformer and/or the mains transformer could have blown.

Once I had established this explanation, it dawned on me that the Jadis Orchestra is not the only amplifier exposed to these dangers. Take the widely sold Audio Innovations 500 amplifier for instance. There are no visible fuses in the cathode circuitry here, but look at figure 1.

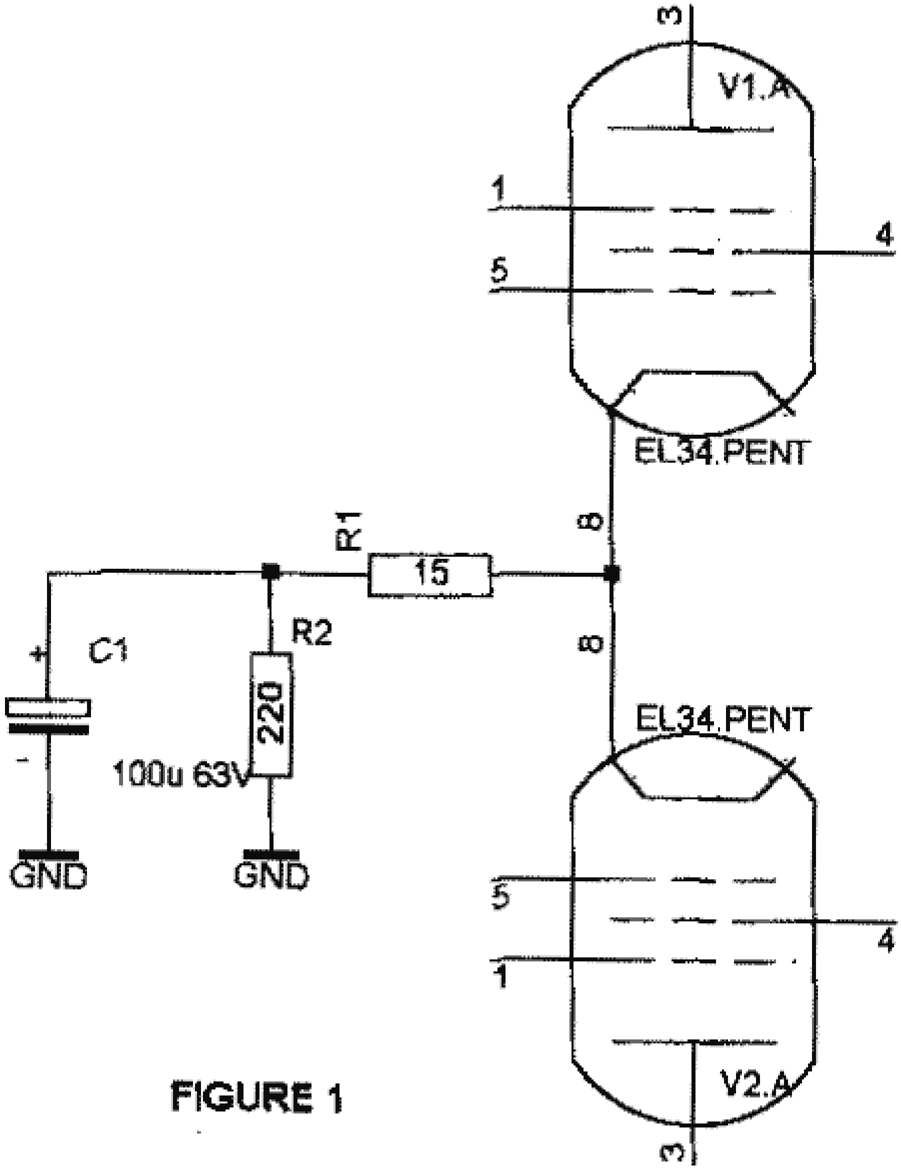

FIGURE 1

In most schematic diagrams of the AI 500 resistor R1 is not drawn, but it is physically there in all but the very early versions of this amp. R2 is a hefty 7 or 10 W wirewound resistor but for R1 deliberately a 0.25 W carbon film type was chosen. In normal operation the current through the 15 ohms of R1 is about 130 mA, which means a 1.95 V voltage drop and results in precisely 0.25 W dissipation. Should an EL34 fail, R1 gets overheated and blows, thus acting as a fuse.
A similar 'fuse resistor' is also found in the Audio Innovations 200 and 800. I'm naming AI models here because I'm very familiar with them, but I have seen this protection scheme in several amps of other manufacturers as well.

The EL34 heaters in the 500 are not connected to ground via a trimpot like in the Orchestra, but directly at a centre tap on the heater winding of the mains transformer. So, if the same valve failure as described above with the Orchestra would happen in the 500, something else will have to burn. Note that before the cathode can reach something like +350 V, the 63 V rated electrolytic capacitor C1 will have to blow; and it does, I've seen it several times. Once that it out of the way, and a short has developed between heater and cathode, in my experience what will burn is the 47 ohm 7 W resistor between the two 200 uF 400 V reservoir caps in the HV power supply, or the diode bridge there, or both. (The mains fuse rarely blows in these cases. Remember that in a valve amp half the mains current is purely for the heater circuit, the other half for the HV supply, so if only one valve starts to draw more than usual from the HV the total mains current only rises slightly. Even if a valve shorted completely, it would probably less than double. Moreover, mains fuses be chosen overrated to withstand the initial current of the mains transformer at switch-on. In practice mains fuses only blow when the mains transformer fails.)

So where is the best place to insert a fuse to protect an amp against output valve failure? The answer is of course: somewhere in the anode circuit. The easiest way in case of the AI 500 is a fuse in series with the 47 ohm 7 W wirewound resistor between the 220 uF reservoir caps, see figure 2.

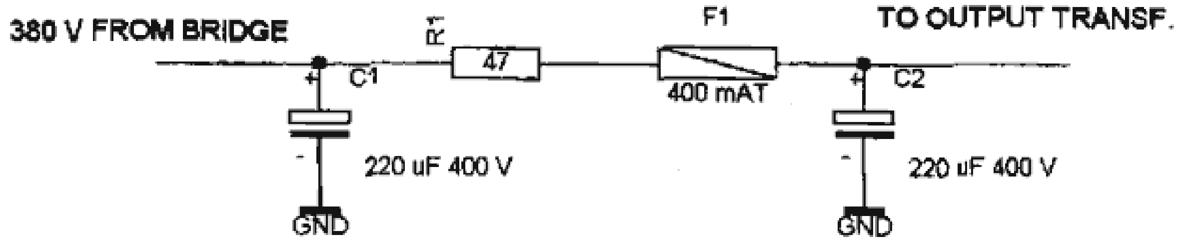

FIGURE 2

As two channels are to be fed from this point, a little over 300 mA is to be expected here in normal operation (260 mA for the four EL34s, 40 mA for the ECC88s plus a few mils for the ECC83s). A 400 mAT should do the job. If its should blow after several times of switch-on, go for a 500 mAT. Always use slow-blow (T) fuses as their parasitic resistor value will modulate far less with current than fast (F) ones, hence minimize audio quality degradation. By the way, the 15 ohm 0.25 W resistors can be shorted out now: the fewer number of components in the signal path, the better.
An even better protection is acquired if each channel is given its own fuse, see figure 3. It's the route I followed in the Jadis Orchestra.

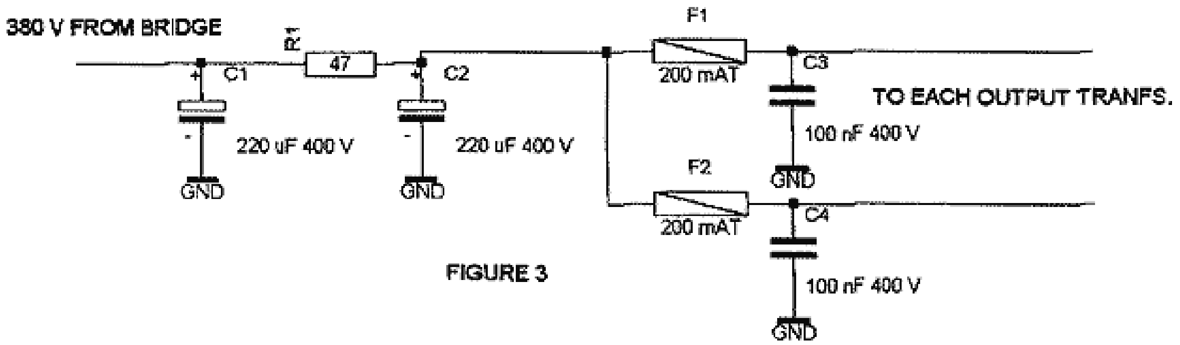

FIGURE 3

As the fuse is now closer to the audio circuitry signal-wise, it is a good idea to add a 100 (or higher) nF 400 V (630 V in case of the Orchestra with its 500+ Volt HV) bypass cap after each fuse, as shown. Paper-in-oils will be excellent here, film caps are less expensive and will be satisfactory too. As the current is now split in half, 200 mAT fuses are the choice here for the class-A AI 500. The Orchestra, however, runs in class-AB and will draw higher peak currents at full power, so 250 mAT is advised there.

As an aside, it is interesting to know of what sort of peak currents output valves are capable. Suppose the coupling cap between the driver valve and the output valve's grid 1 severely leaks or fails altogether. The output valve is then forced into its saturation current region. I mimicked this by measuring various valve with their g1 and cathode strapped together. As I guessed twice the nominal current value wouldn't be a problem and my adjustable HV supply has a 200 mA ceiling, I didn't even try an EL34. So I went for a used but good EL84, which easily reached 200 mA at 300 V of anode voltage, against 48 mA in normal operation. It didn't even glow red for the short time I tried this, which shows the robustness of valves. Next came a well-used EL95 which measured 18 mA under textbook conditions (against 24 mA according to the datasheets) and this one finally levelled out at some 170 mA at 300 V. Yes, it turned very red, but at 50 W of dissipation (against a 6 W maximum rating according to the datasheet!) it is forgiven.

In view of these current capabilities, maybe using one fuse per output transformer is a bit of a luxury. Your choice.

Finally, I listed the maximally allowed heater-to-cathode voltages (Ufk) for a number of output valves.

Model:	Ufk:
6V6	90V
EL34	100V
6L6	180V
EL84	200V
6550	200V
KT88	250V
5881	260V

The 6V6 and EL34 are especially low. Remarkable is the difference between the closely related 6L6 and 5881. The EL84 is rather high at 200 V and relatively safe in case of valve failure as in class-A the EL84 is often operated at just 300 V HV. None of the valves will eventually survive failure against the 400 to over 500 V of HV normally encountered in audio amps.