A 100 Watt Audio Amplifier Employing The LM3876

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Introduction

Building a medium-power audiophile-grade power amplifier is a relatively simple project thanks to a relatively new IC, the National Semiconductor LM3876. The chip is essentially a power operational amplifier optimized for audio applications, with claimed delivery of 56 W into 8 ohm loads at a THD less than 0.06 % over the audio spectrum. That's fairly impressive performance for a monolithic IC – better than some discrete designs. In addition, the LM3876 has built-in protection against overheating and short-circuited outputs – so the resulting amplifier should be very reliable and "consumer proof." The LM3876 is designed to drive 8 ohm or higher loads.

The Project

The project involved two aspects – evaluation of the LM3876 characteristics and production of a prototype amplifier using a recycled chassis. Two identical LM3876 PA modules were constructed as shown in Figure 1. These were wired by hand "dead bug" style on a copper ground plane, then bolted temporarily to a heat sink for testing. The chassis to be recycled was a Tektronix oscilloscope calibrator (see Figure 2) that was a discard from the electronics lab (I liked the robust construction of the chassis and it's slide-open construction.)

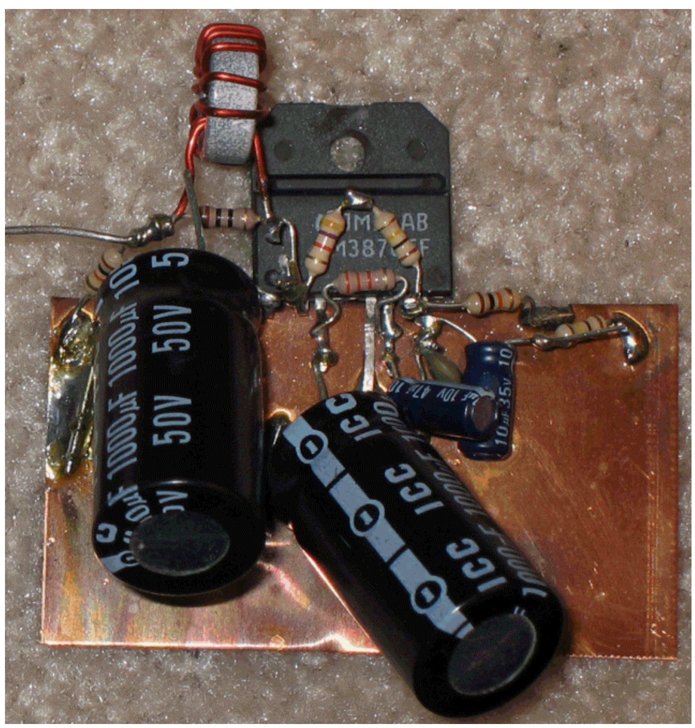

Figure 1: One of the LM3876 power amplifier modules

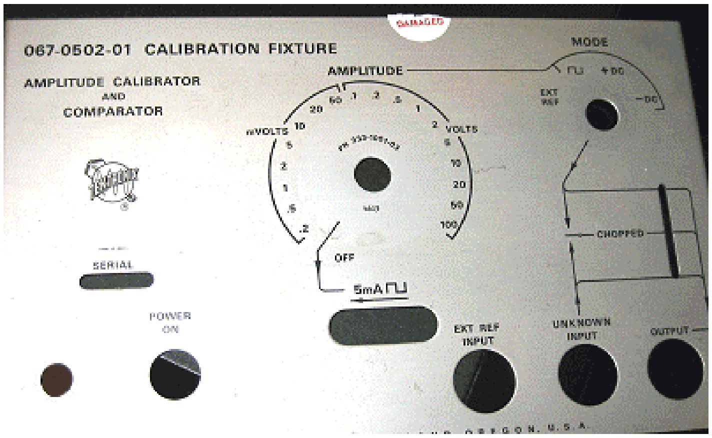

Figure 2: Original front panel from Tektronix "project box"

Circuit and Construction

Figures 3 and 4 show the complete amplifier. It's not very complicated, but since high voltages and currents are present, care must be taken during construction and testing. In Figure 3, the line voltage is applied through fuse F_1 to power transformer T_1 (this should be a magnetically shielded unit to minimize hum pickup; I happened to have a spare power transformer from a 1977 Realistic STA-90 receiver on hand!) Capacitors C19, C16, C21, C22, and C17 are present to filter RFI. Do not use capacitors of lesser voltage ratings here! Bridge rectifier D_1 is mounted to the chassis for heatsinking. C15 and C20 filter the DC for consumption by the amplifier. Notice the lack of voltage regulation; it isn't needed. The amplifier ICs contain their own individual reference supplies and regulators. Note the chassis tie point in Figure 3. *All ground connections from the amplifier PA modules, capacitors C15 and C20, and the power transformer secondary center tap converge at this point, which should be grounded to the metal chassis by a heavy wire.* This is the main DC ground and bonding point for the entire unit.

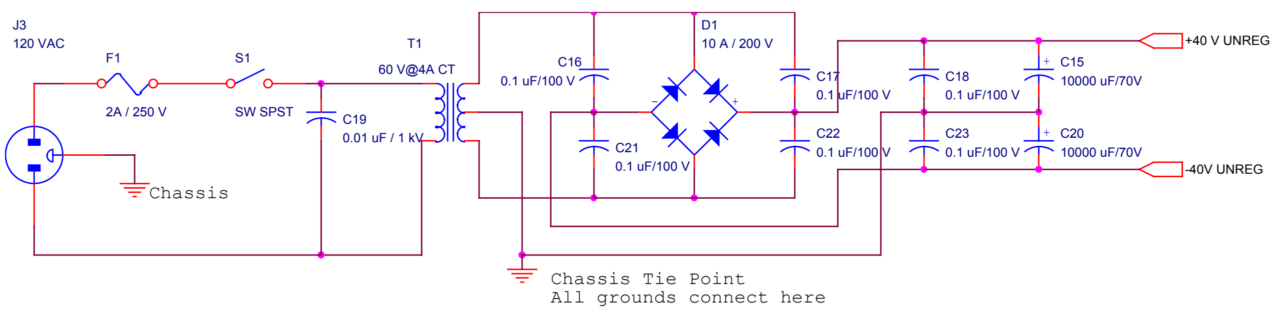

Figure 3: Power supply

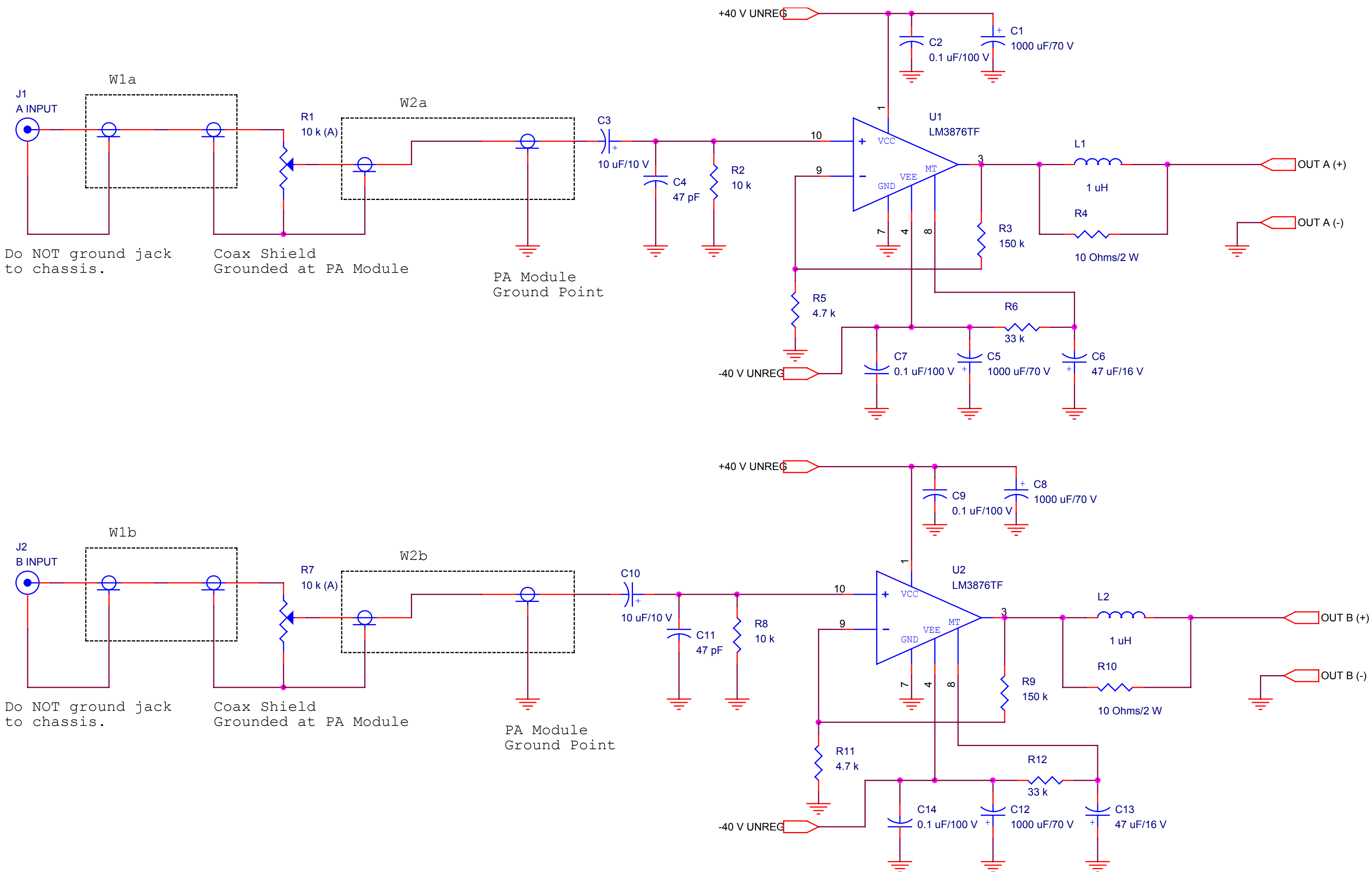

Figure 4: Amplifier

In Figure 4, the input signal is applied at J_1, passes through the gain control R_1, then passes through DC blocking capacitor C_3 into the amplifier IC. R_2 provides biasing for the non-inverting input and C_4 is an RF bypass. R_3 and R_5 determine the amplifier voltage gain (about 31 dB in this unit). L_1 and R_4 provide high-frequency decoupling from the IC to the load, to prevent oscillation in the presence of a capacitive load. R_6 and C_6 form the time constant for the IC's power-on mute function, which suppresses power-on pops by disabling the internal bias supplies until the power supply voltages have fully stabilized. C_1, C_2, C_5, and C_7 provide additional power supply filtering and should be mounted directly onto U_1's power supply pins.

The datasheet "typical application" for the LM3876 specifies a DC blocking capacitor in series with R_5 marked "C_i." This capacitor is likely unneeded, as the DC offset at the LM3876 inputs is very small. In the prototype constructed, the *output* DC offsets were measured at –30 mV and –35 mV, which will have no impact on operation. A larger number of LM3876s would need to be sampled to determine if this holds true for *all* parts.

All grounds on the PA module return to the copper ground plane, which in turn is connected to the system ground bond point by a single #12 stranded conductor. In addition, the shielded cables W_{1a} and W_{2a}, which connect the PA module to the input level control and input jack, are grounded *only* at the PA board, and nowhere else. The input jacks are *not* grounded directly to the chassis; they get their ground connections from their respective PA modules. Use insulated-ground RCA or BNC connectors for J1 and J2. If the input jacks are tied directly to chassis ground, a ground loop with bizarre symptoms might appear – for example, the system may pick up hum when the preamplifier volume is fully closed.

Input, output, and power supply connections must be kept separate. This circuit has high gain, and significant currents flow in the power supply and output leads. Careless wiring could easily allow signals to cross-couple, which at the least will increase distortion, and at the worst, might lead to oscillation. Figure 5 shows the wiring underneath the completed amplifier chassis, and Figure 6 shows the layout from the top. Note that the shielded input cables run partially underneath the upper brace and aren't completely visible in this picture. The speaker leads (black and red) are twisted to further reduce magnetic coupling between the output and input circuits.

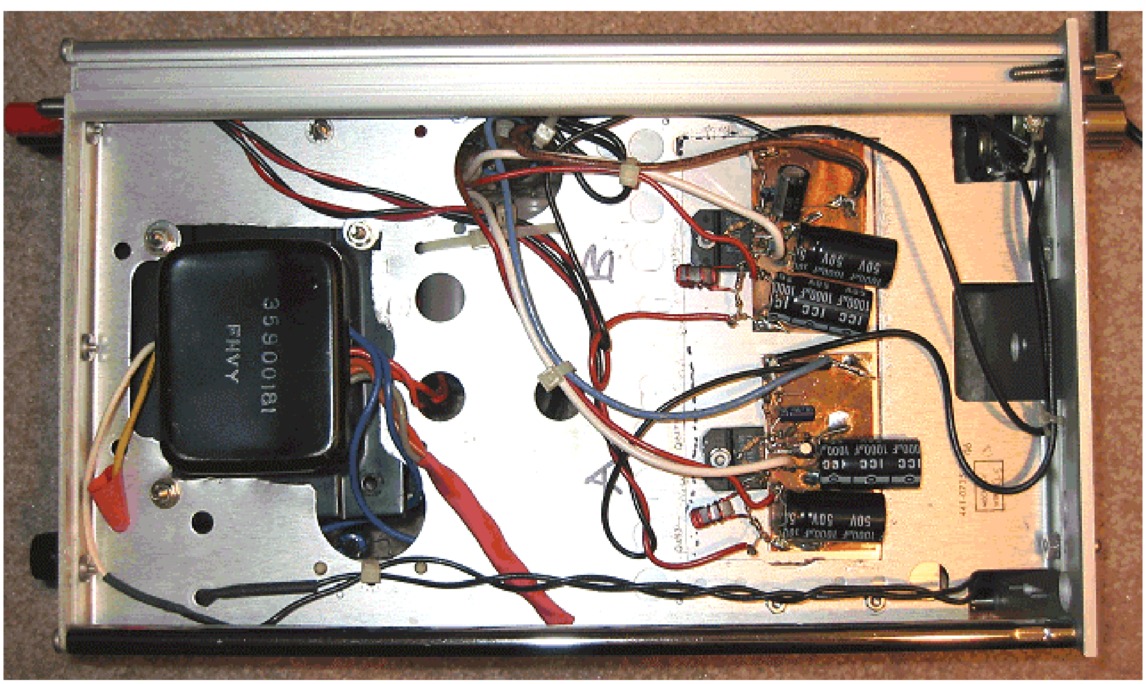

Figure 5: Wiring under the chassis

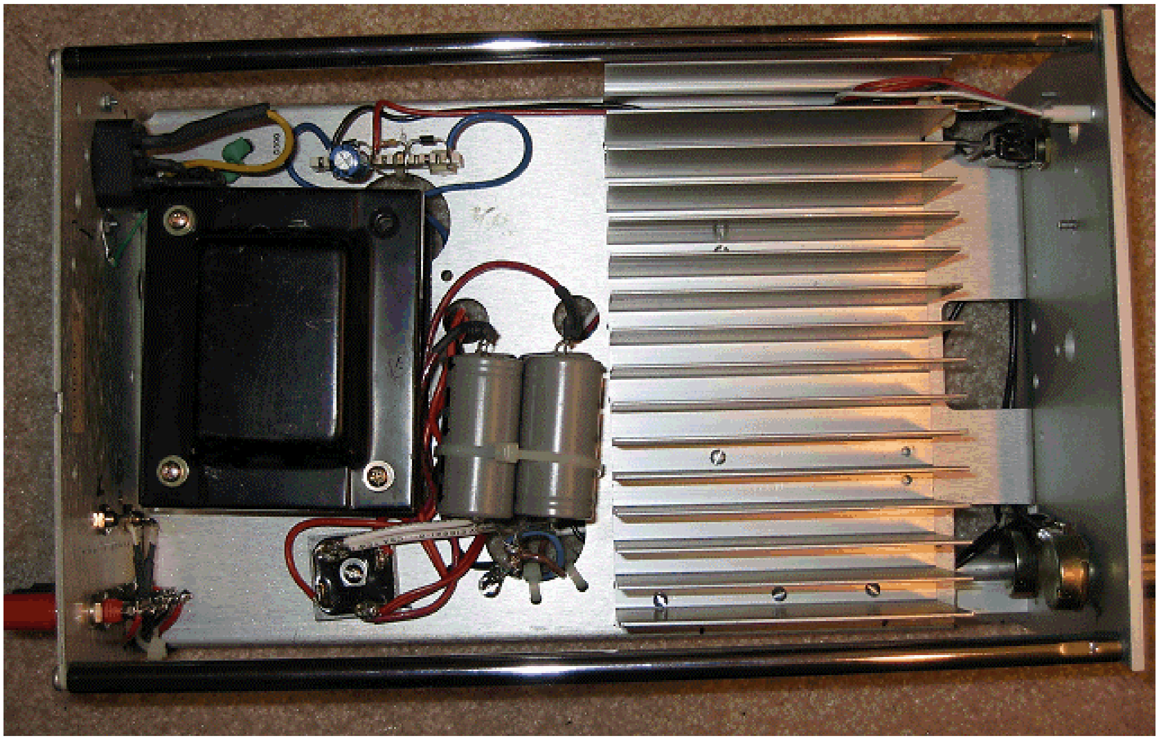

Figure 6: Top view of the amplifier layout

In Figure 6, note the large heatsink. This is absolutely required for the LM3876 ICs, which dissipate a large amount of power when the amplifier is under load. Figure 7 shows the chassis while under construction, and Figure 8 shows the front of the completed unit.

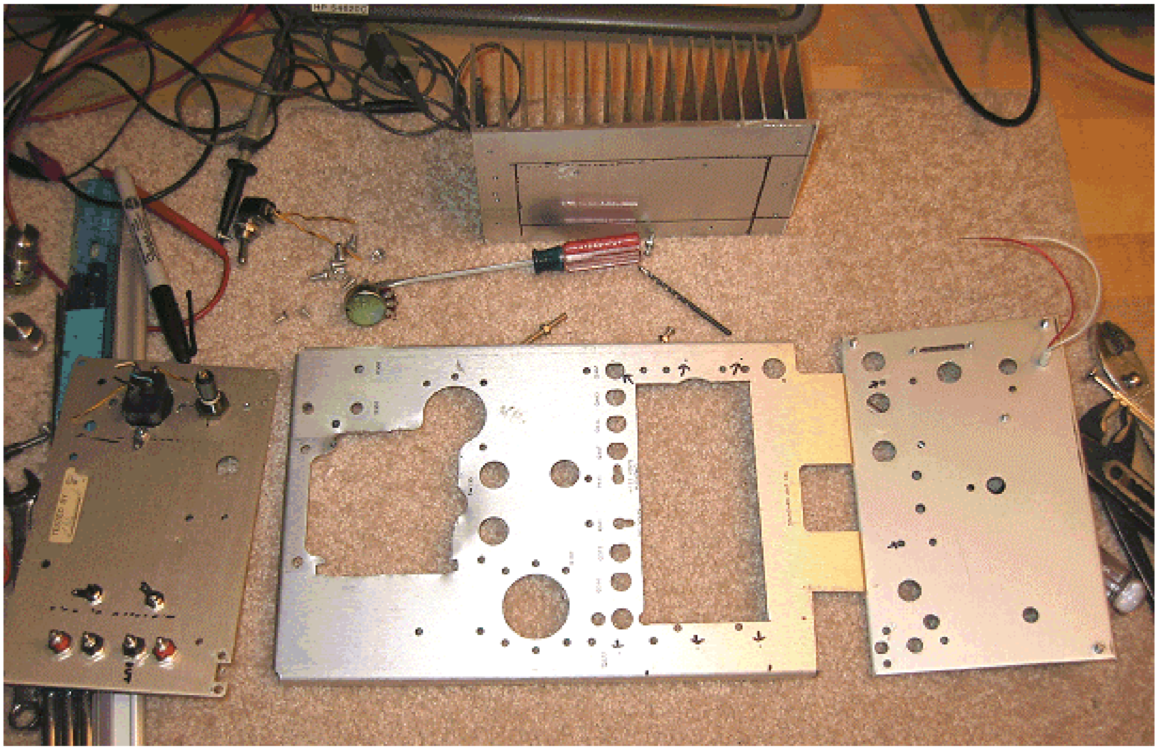

Figure 7: Under construction

Figure 8: Front panel of completed amplifier

Performance

The amplifier performed very well in bench tests. With both channels driven, better than 50 W/channel at very low distortion was available from 20 Hz to 20,000 Hz (2nd and 3rd harmonic distortion products were less than 50 dB below the fundamental energy at any frequency in this range). The upper –3 dB point of the amplifier was at 50 kHz, measured at 50 watts output. The output noise level was very low; with open-circuited inputs and the LEVEL controls fully open, only a few mV RMS noise was present at the output, which was inaudible through the connected speaker system.

The heat transfer ability of the plastic packaged LM3876TF was evaluated. The manufacturer claims θ_{JC} (junction to case) of 1 °C/W, and a maximum allowed junction temperature of 150 °C. The amplifier was operated for 20 minutes at full output (one channel only) into an 8 ohm load to let thermal soaking occur. The heatsink next to the part measured 48 °C, and the hottest portion of the IC case measured 70 °C. Assuming worst-case dissipation of 50 W, the junction temperature was approximately (70 °C + (50 W)(1 °C/W)) or 120 °C, well below the rated maximum but still quite hot. The θ_{CS} (case to heatsink) thermal resistance could be estimated at about 0.45 °C/W from this data, indicating that the device was correctly mounted to the sink (the manufacturer's data sheet indicates a nominal 0.5 °C/W thermal resistance to the heatsink for this device.)

Conclusion

It's certainly easy to build high-quality amplifiers with these devices. The inability to drive 4-ohm and lesser loads is a drawback, however; this could be remedied by adding a class AB emitter follower stage to the unit. However, in doing this, additional protective circuitry would have to be constructed, and that certainly defeats the purpose of using this part. Alternatively, to drive multiple sets of 8 ohm speakers, multiple LM3876s could be employed. This is reasonable; the part is less than $5.00.

This project also demonstrates the difficulties that arise when attempting to heatsink plastic-packaged semiconductors. It illustrates the worst case scenario – a single device that has only the surface area of one plastic package to rid all possible heat. Even with an infinite heatsink, power dissipation is ultimately limited by the total thermal resistance between the die and heatsink, which is dominated by the plastic insulation on the package.

In other words, it's hard to beat the "good old" TO-3 metal package, even though the plastic version of this package, the TO-3P, is now pretty much in vogue. θ_{CS} for the TO-3 package can be as low as 0.2 °C/W.

In a discrete amplifier employing individual transistors, a designer can afford the extra thermal resistance because the power is spread across multiple devices. In addition, the designer can build massively parallel output structures to further spread out the load and greatly widen the safe operating area (SOA) of each transistor. An extreme example of this is the Peavey PV-1500, which uses *six* individual TO-220P transistors in its class AB output stage (2SC-5200 x3, 2SA-1943 x3), each of which is rated at 16 amps *maximum* collector current. The RMS load current at maximum output for this amplifier (500 W into 4 ohms) is 11.18 A, while under this condition, the RMS collector current for *each set* of three transistors is only 5.6 A. This might seem like overkill, since each transistor only sees 1/3 of this RMS current (1.86 A), for a safety factor of (16 A / 1.86 A) or 8.5 : 1 – but at elevated transistor temperatures, this safety factor dwindles as the SOA shrinks.

The LM3876 has built-in true SOA protection, unlike many of its predecessors. The IC measures its die temperature as well as the load being demanded, and limits the final collector current accordingly (or even shuts down if things really get too hot). This should eliminate many failures, however, only time and use (abuse!) will reveal the truth.