Analyzing the Dynaco Stereo 120 Power Amplifier

The Stereo 120 Power Amplifier came out around 1966. It was the first powerful (60 watts per channel) solid state amplifier in wide production. Each channel was done with just 6 transistors, so every transistor had to do a lot. This paper analyzes the amplifier's design.

A good companion to analysis is a clear drawing of the circuit. The one that Dynaco provided in their manuals is a bit confusing. I've laid out something that I think is easier to understand in Figure 1 on page 3. Keep a copy of Figure 1 handy as we will refer to it extensively in the discussion that follows. Note that some of the part numbers were handy for simulation, but are not the actual types specified in the Bill of Materials.

There's a lot going on in the amplifier. We'll break the amplifier into sections, and give each section its own heading.

Input Circuits

C1, 5 µF, is the input blocking capacitor. Assuming the input impedances is around 100K Ohms, this capacitor makes a high pass filter that is -3 dB at 0.31 Hz, which is way below the bottom of the audio band. R1 and C2 make a low pass filter that is -3 dB at or below 225 kHz. This can help prevent radio frequency interference on the input.

Main Gain

Q1 and Q2 provide the main gain. Compared to more modern amplifiers, Q1 is equivalent to the input differential stage, with the input signal applied to Q1's base and the feedback signal applied to Q1's emitter. Q2 performs the VAS function (Voltage Amplifier Stage). The combination provides large forward gain, such that the addition of feedback can lower the overall distortion.

C13, 68 pF, limits the main gain stage bandwidth, and is equivalent to Cdom in modern amplifiers. C15, 27 pF, provides a bit of fast feedback that bypasses the output stage. It helps amplifier stability some at the cost of a bit of distortion.

Output Stage

The output stage has unity voltage gain at best, but large current gain. Q3 and Q4 are the output stage drivers. Q5 and Q6 are the output transistors. C4 couples the main gain stage to the output stage. C3 is a bootstrap capacitor that supplies positive feedback from the output stage to the main gain stage, increasing the gain of the main gain stage.

C4 is kind of a handy thing. It prevents DC problems in the input stage from wreaking havoc and destruction on the output stage. Later amplifiers went to direct coupling as people became more comfortable with transistors.

C3, the bootstrap capacitor, is also a very inexpensive way to get a lot more forward gain at a very low price. In today's amplifiers, C3, R6, and R7 are often replaced by a current source.

Output Stage Biasing

The output stage biasing was always a bit of a sore point in the Stereo 120. Dynaco pointed out with some pride that there was no quiescent current in the output stage. At the time, that was probably a good thing for survivability. Many output stages with quiescent current were subject to thermal runaway, destroying amplifiers, power supplies, and speakers. The downside is that the Stereo 120 is prone to crossover distortion.

The output stage biasing loop starts at the bottom of R27, goes through the Q5's base-emitter junction, Q3's base-emitter junction, Q4's base emitter junction, R28, D3, and D2. Written as a loop, we have:

$$Ic5*R27+Vbe5+Vbe3+|Vbe4|+Ic4*R28=Vd3+Vd2$$

For the moment, assume Ic4 and Ic5 are zero. Then the left side has 3 Vbe's, and the right side as two Vd's (diode voltage drops). This says that the three transistors won't have enough voltage to be turned on, at least at room temperature. As you push power into a load, Q3, Q4, and Q5 warm up. Their Vbe drop at 2 mV/C with increasing temperature. When they get hot enough, some quiescent current will flow. If they get too hot, the amplifier might enter thermal runaway. Dynaco tried to prevent that by specifying the voltage drop across D2 and D3 with 140 mA flowing.

The rise of quiescent current with warmup decreases crossover distortion. This would certainly make an amp sound more musical. This is perhaps where the high end hi-fi passion for warmup or break-in got its start. You'd think that modern amps wouldn't have this problem, but many amps still have output stage biasing that is far from stable over temperature.

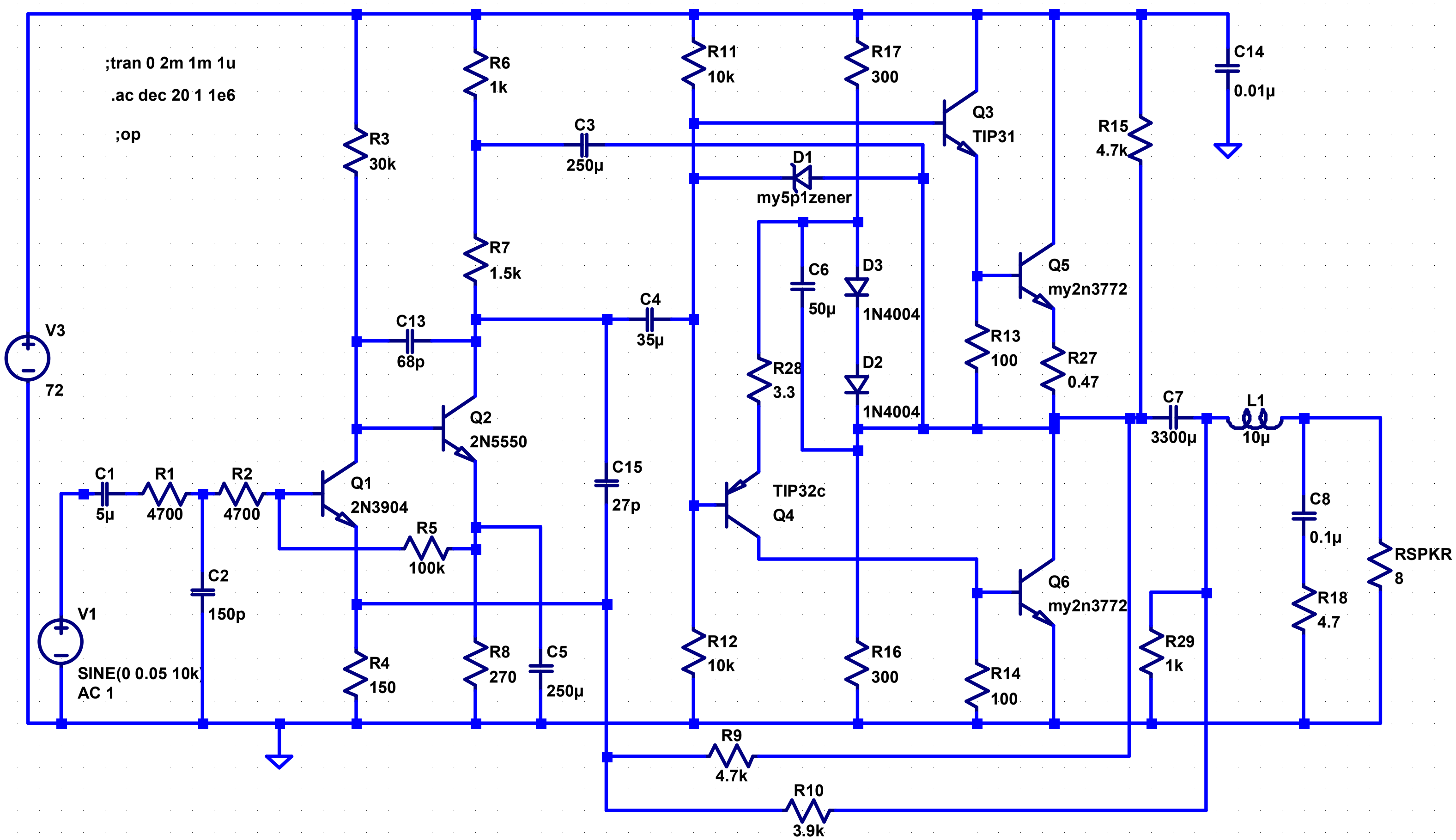

Figure 1 – Schematic of one channel of the Dynaco Stereo 120 Power Amplifier

Output Stage Protection

D1 and R27 limit positive peaks of load current. At high currents, Q3 might have Vbe=1.0 volts and Q5 might have Vbe = 1.6 Volts[1]. The positive current limit is then:

$$\frac{5.1-1-1.6}{0.47}=5.31 Amps$$

R17 limits negative peaks of load current. Assume Q6 is turned on so that its collector is near ground. The current available to feed Q4, which feeds base current into Q6, is something less than 70/300=233 mA. Assuming Q6 has β=25 at high collector currents[2], the maximum negative load current is 25*0.233=5.83 Amps.

Still, the negative peak current isn't really well controlled. If Q6 has high β at high current, then the current limit could approach 15 Amps. The saving grace is that the current is somewhat limited by the 3300 μF output capacitor. After 20 milliseconds with 5 Amps of current, C7 would have completely discharged. Of course, this makes things harder for Q5 when the input reverses, but the positive peak current limit is much better defined.

Feedback and Gain

There are two feedback resistors, R9 and R10. R9 is inside C7, and R10 is outside C7. R10 extends the low frequency cutoff of the amp by making C7 appear larger. Roughly, the gain of the amplifier from the base of Q1 to the output is given by:

$$Gain=1+\frac{R9 \parallel R10}{R4}=15.2$$

There's a slight attenuation at the input owing to a voltage divider between R1, R2, and R5. That drops the gain by a factor of:

$$Input\_Loss=\frac{R5}{R5+R1+R2}=0.914$$

The overall gain from the input is the product of the two:

$$Overall\_Gain=15.2 \cdot 0.914=13.89$$

The calculated overall gain cross-checks nicely with the rated sensitivity of 1.5 Volts RMS input for a 60 Watt (8 Ohm) output, corresponding to 21.9 Volts RMS across 8 Ohms. 21.9/13.89=1.57 volts RMS, rather close to the quoted 1.5 Volts RMS.

[1] This large Vbe comes by assuming Ic5=4 Amps, β≈40, so Ib5=0.1 Amps. The base resistance of a 2N3772, according to the model, is 8 Ohms. That adds another 0.8 volts to the intrinstic 0.8V of Vbe at high currents.

[2] The Bill of materials calls for β=60-90 at Ic=1 Amp. Typically, the β droops at high currents, so 25 might be reasonable around 5 Amps.

It’s interesting to note that the feedback is actually current mode feedback, rather than voltage mode feedback. This is owing to the use of the single transistor, Q1, rather than a differential pair.

<u>Cross Conduction in the Output Stage</u>

The user’s manual instructs us to set up high frequency measurements at low levels, then performing them quickly at high levels. Why is this? The old slow output transistors were subject to significant cross-conduction at higher frequencies, like a 10 or 20 kHz high level sine wave input. That made for a current in both Q5 and Q6 that doesn’t appear in the load, wastes power supply power, and could lead to the failure of the output transistors. In controlled amounts, it’s called quiescent current. In the undesired cross conduction case, it can cause the power supply to go into current limiting.

Replacing the 2N3772’s with something more modern, perhaps an MJ15003, greatly diminishes the amount of cross-conduction at high levels and high frequencies.