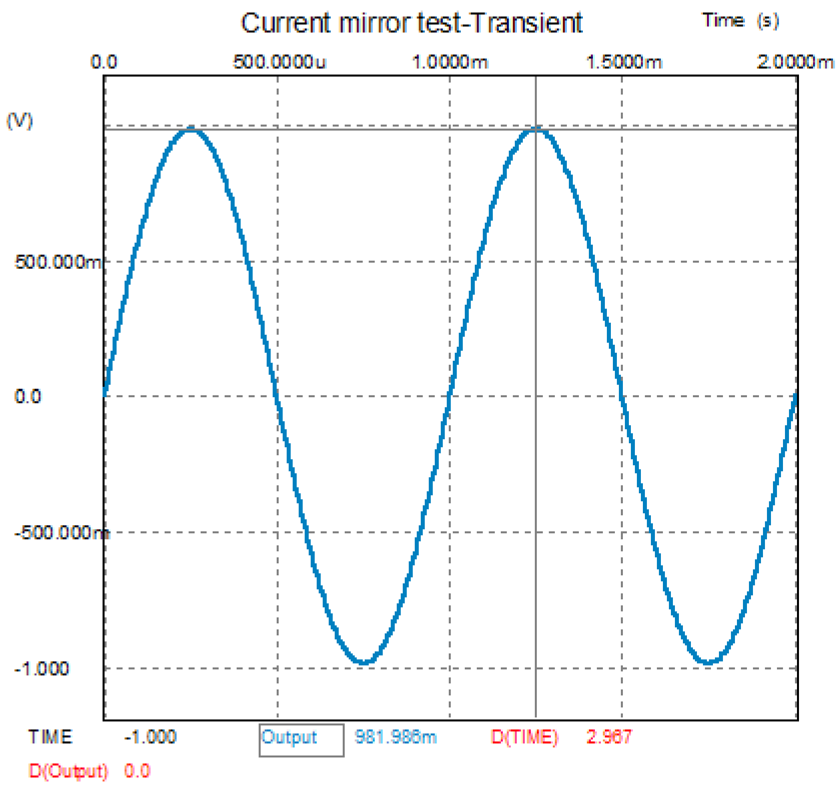
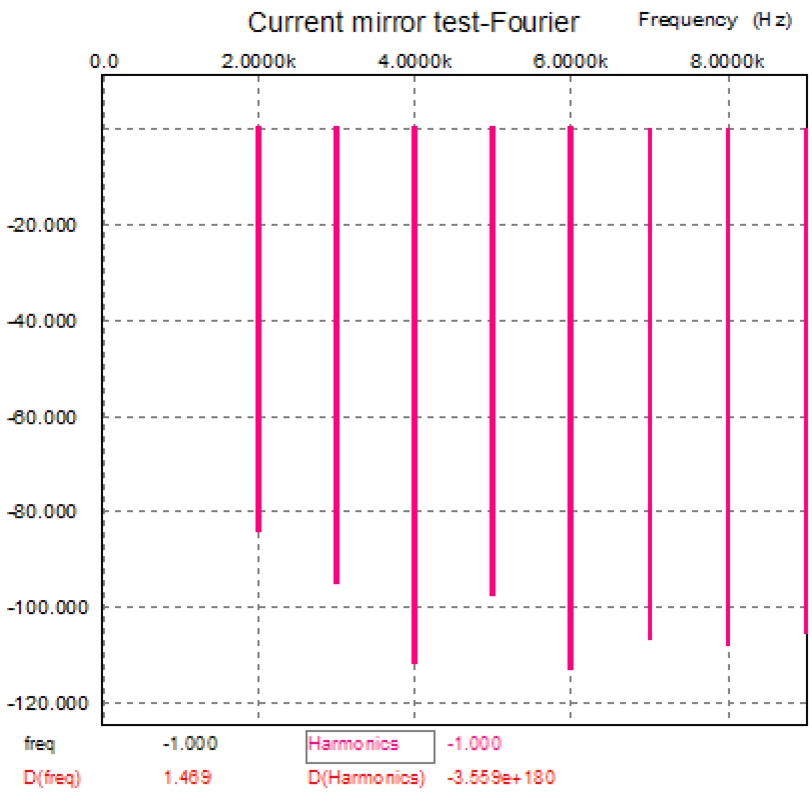
04 January 2005

Reflections on perfect reflections

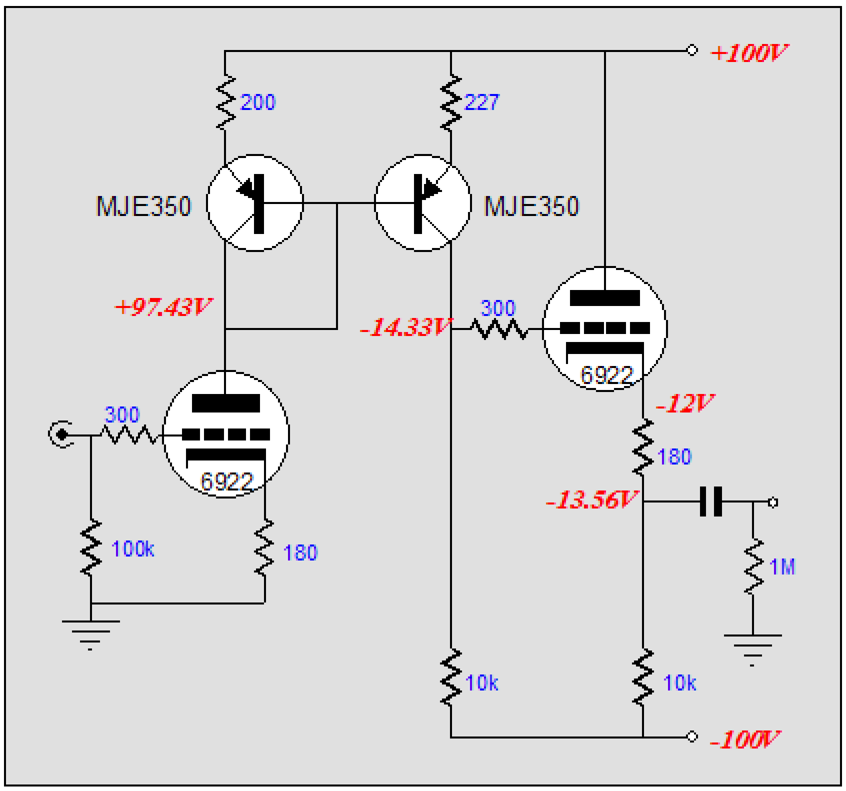
In the post script to the last blog, "Perfect Amplifier and Perfect Reflections," I gave a closer approximation to a complete formula for calculating the reflected plate resistor. Much is still missing, as the transistor-based current mirror entails its own set of formulas. As a quick quasi-reality check, I ran a SPICE simulation on just the current mirror, and then, a check on the entire circuit.

The results were interesting. First of all, a current mirror based on the MJE350 (or any other transistor) does not perfectly mirror the current flowing into it, but it comes close. With the 200-ohm emitter resistors, 98% of the current is mirrored. For example, if 1mA of varying current goes in, 0.98mA of varying current comes out. The distortion with a 0.1mA varying current signal (equals 0.98 volts across the 10k resistor) is about 0.01%.

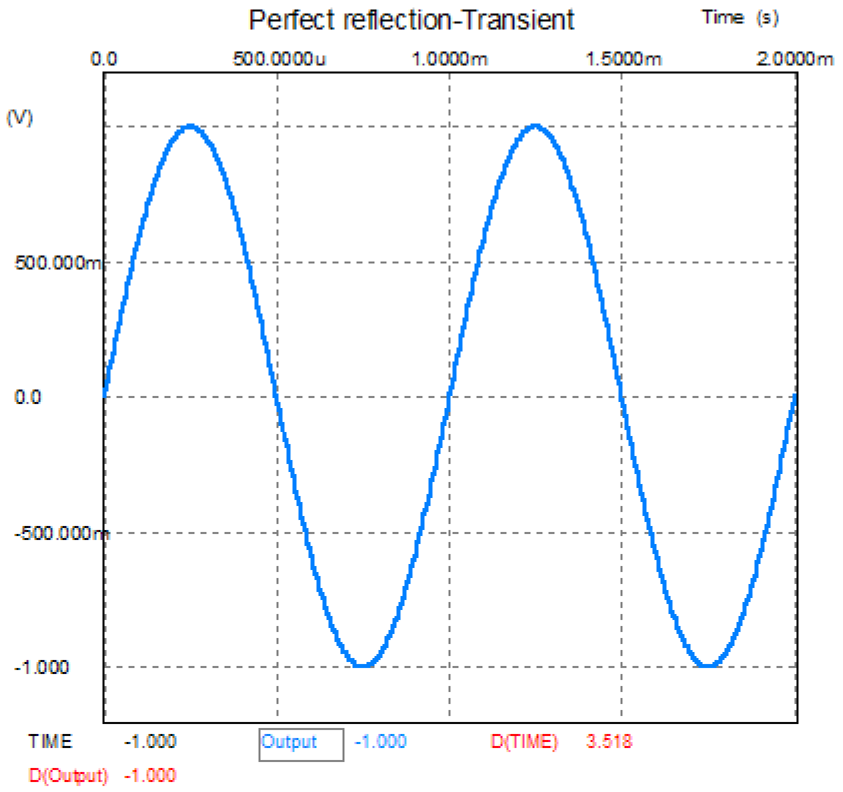


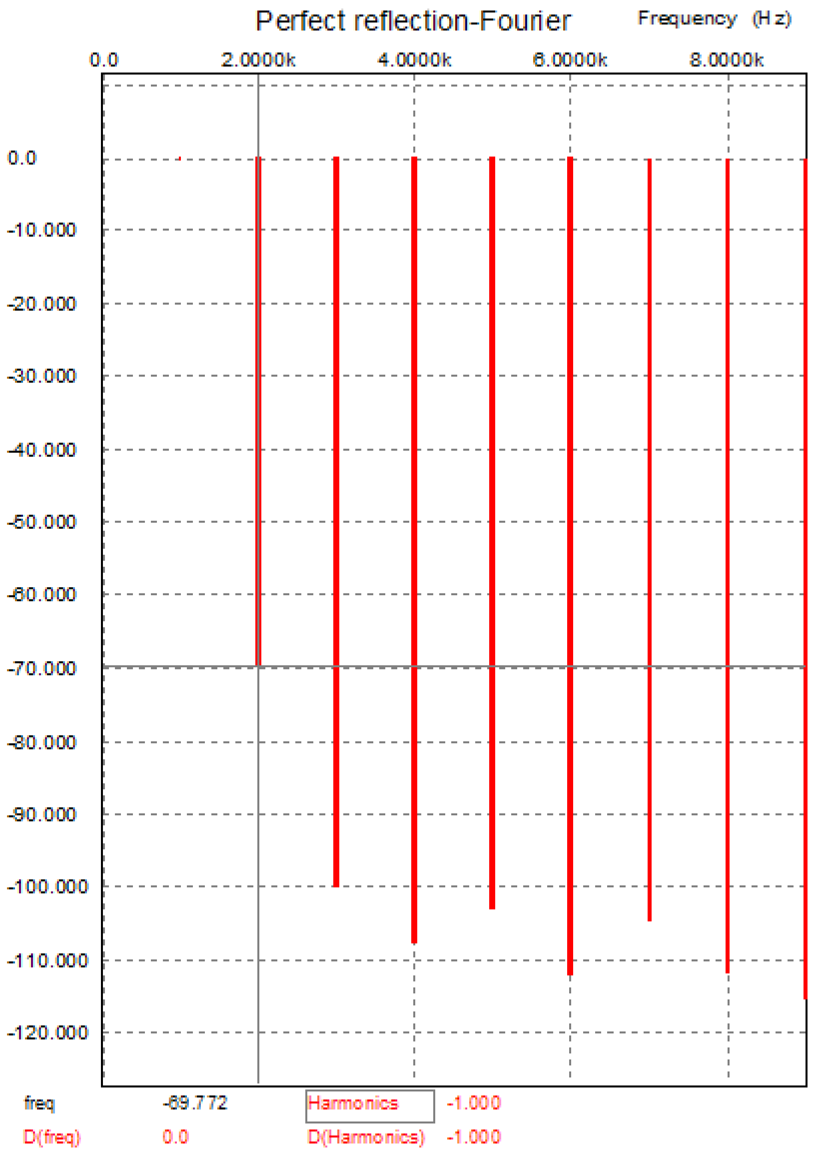


When using a transistor-based current mirror, I always match the transistors, believing it critical, besides my VOM holds a hfe test, which makes the matching painless. Well, using unmatched transistors, with one having twice the beta as the other, only slightly increased the distortion and reduced the current mirroring efficiency by less than one percent, so maybe I have been overly nervous.

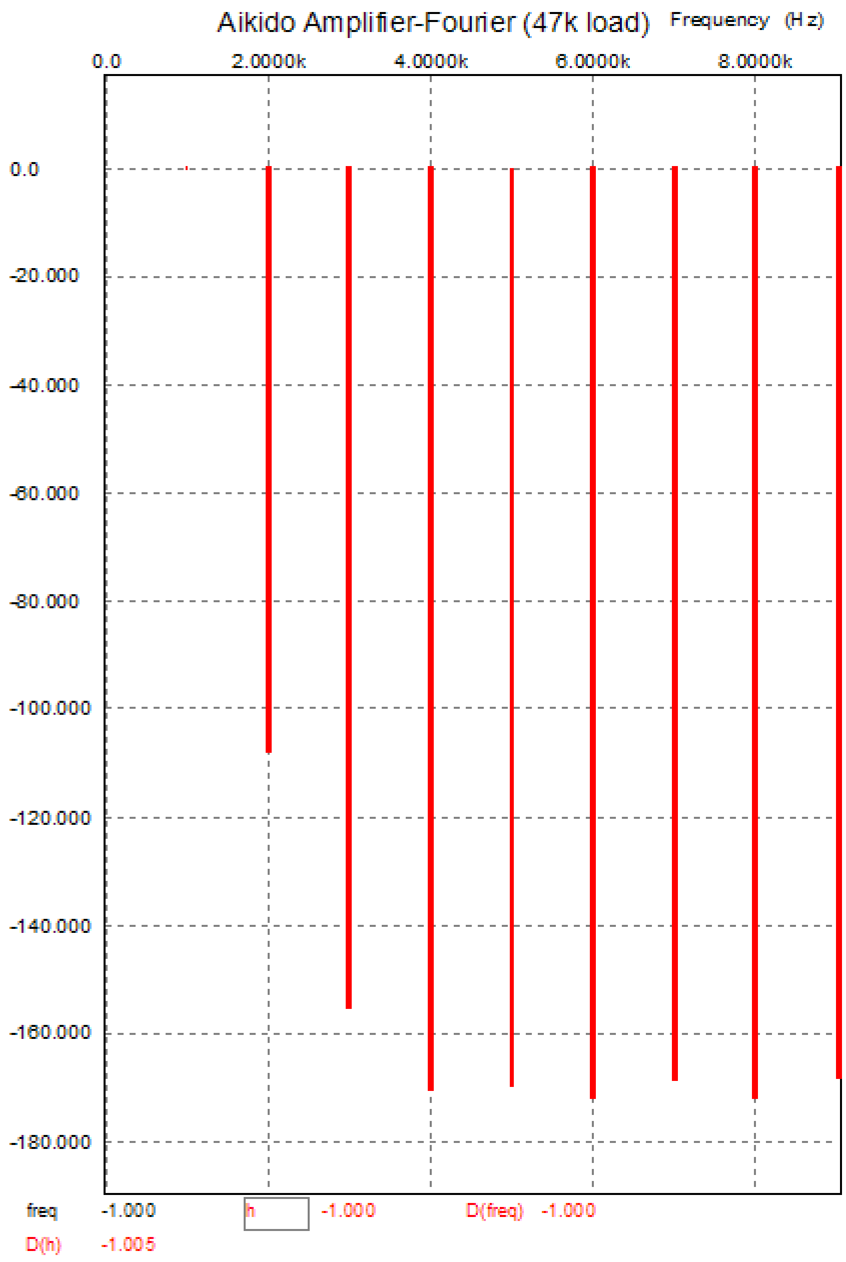


The entire amplifier (using 6922s and some tweaking) performs fairly well in simulation (real results may—and invariably do—vary).

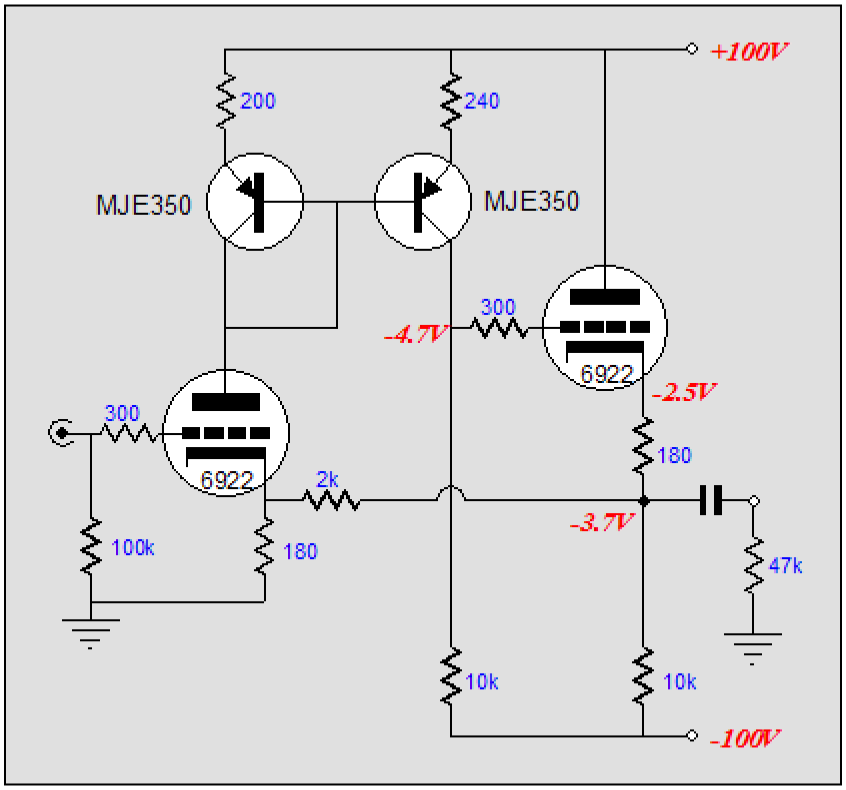




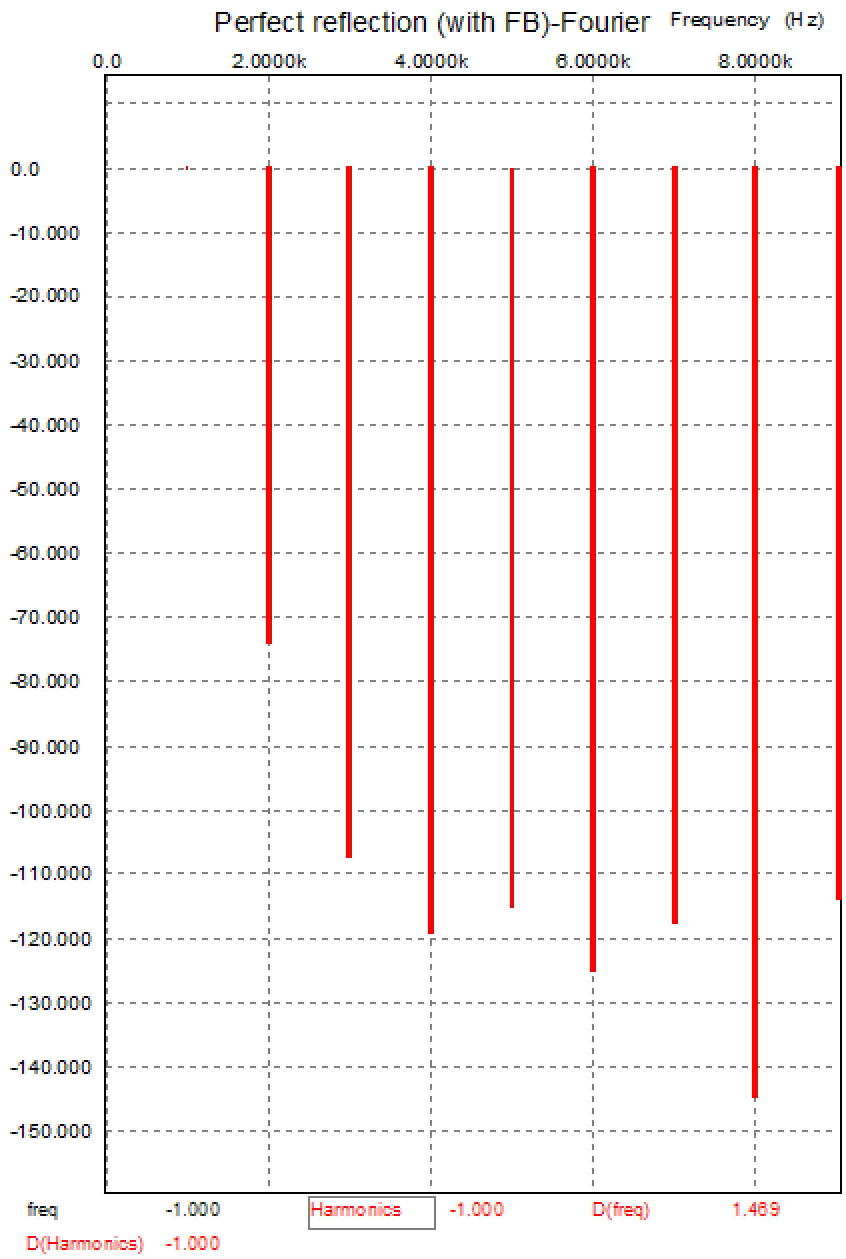
The PSRR figure is an impressive -50dB and the gain is a high 28 (+29dB). Compare the graph above with the Aikido amplifier's Fourier graph.



The winner is obvious in terms of distortion; both tie in output impedance; and the Aikido (using all 6922s) only has a gain 0f 16 (+24 dB). What if we swapped some of the current-mirror-based amplifier's gain for linearity?



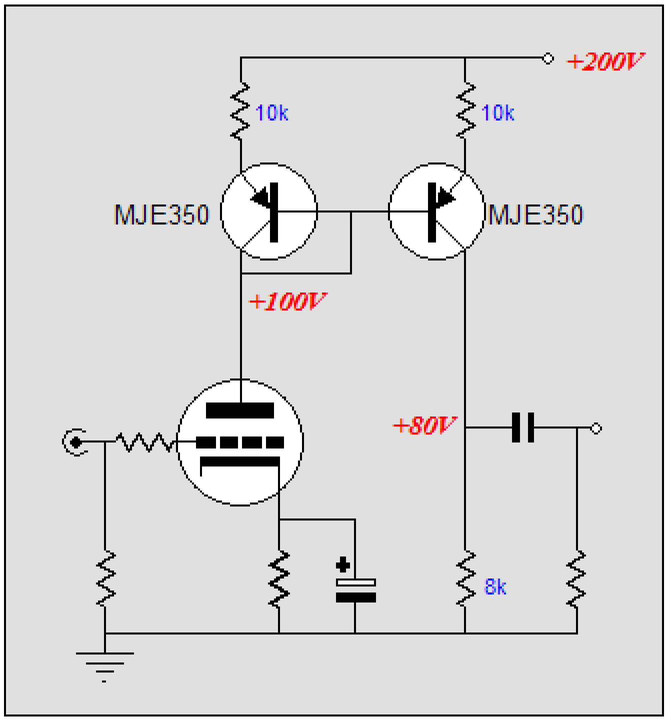
Since the output is in phase with the input, and since the amplifier puts out so much gain, a feedback loop is easily added and needed to bring down the gain to 8, which equals +18 dB (this more than enough, as +6 to +12 dB of gain is all that most line stages need).



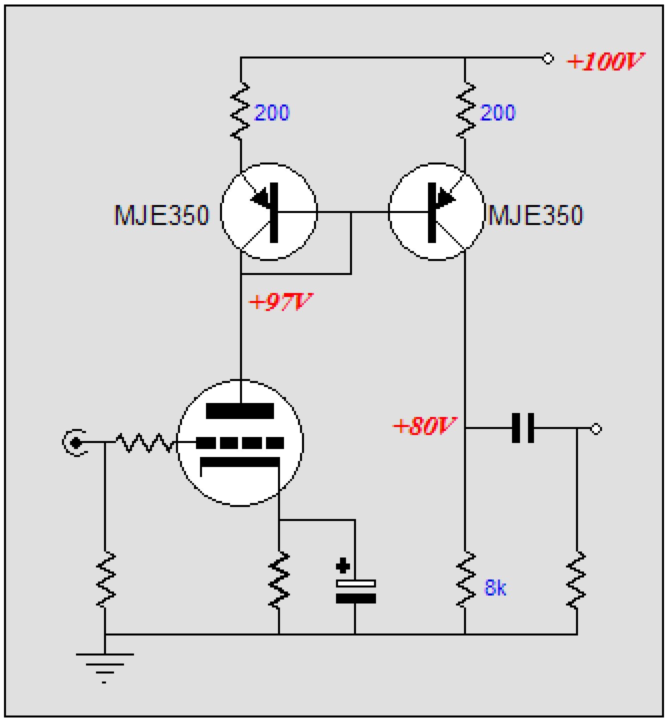
Good enough for most, but the Aikido amplifier's low distortion is haunting.

Cascoded current mirror

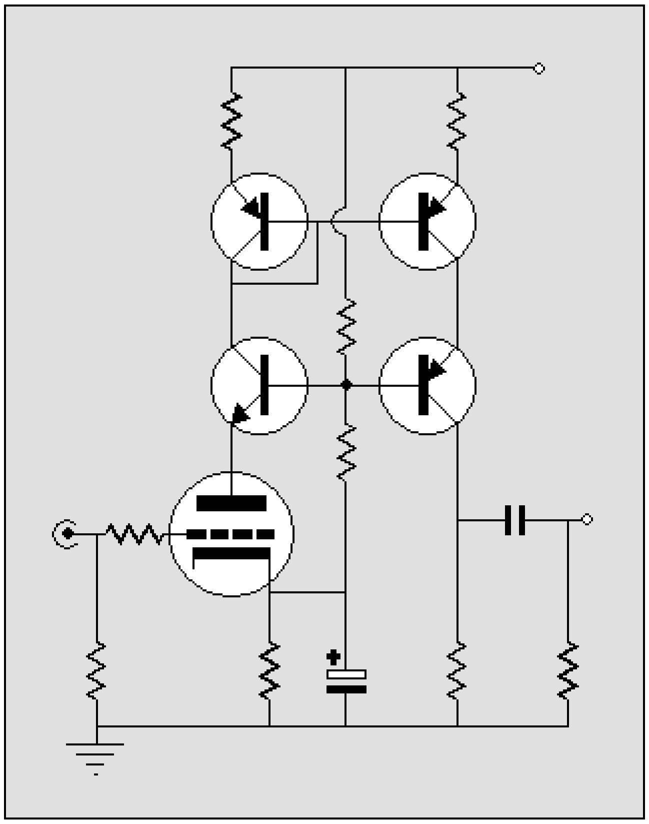
Loading a tube with a current mirror effectively creates a cascode amplifier, in that the plate undergoes little current voltage, although the current may vary wildly. However, this is only true when the current mirror’s emitter resistors are low in value. For example, with 10k emitter resistors, the plate will swing large voltages that will reintroduce the Miller-Effect capacitance and greatly reduce the gain.



On the other hand, when the emitter resistors are low in value relative to the triode's rp, say 100-200 ohms, then the Miller-Effect capacitance disappears and the gain climbs close to gmRa.

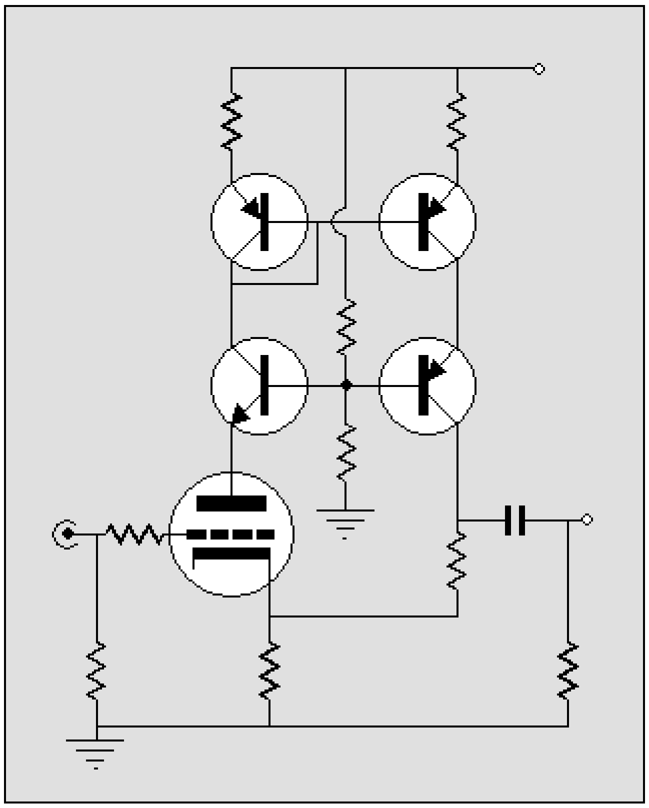


Now the question is What if we cascode the current mirror?

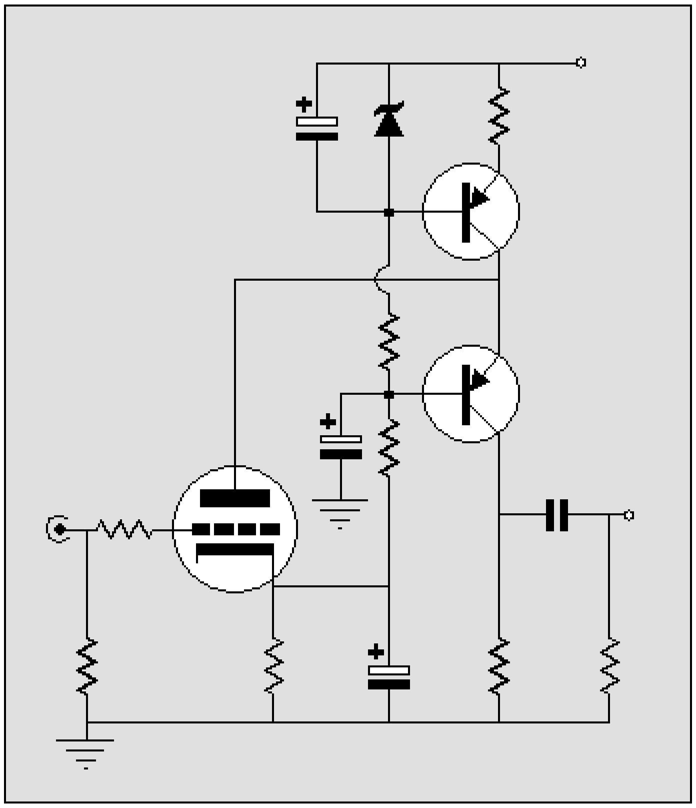


One advantage that immediately comes to mind is that we can now use low-noise, low-voltage transistors in the current mirror portion of the circuit. Second, we could use multiple PNP transistors in series to allow even high voltages to be used. Last, the cascoding would greatly improve the PSRR figure when used with a monopolar power supply, as the triode would not see any of the B+ noise on its plate.

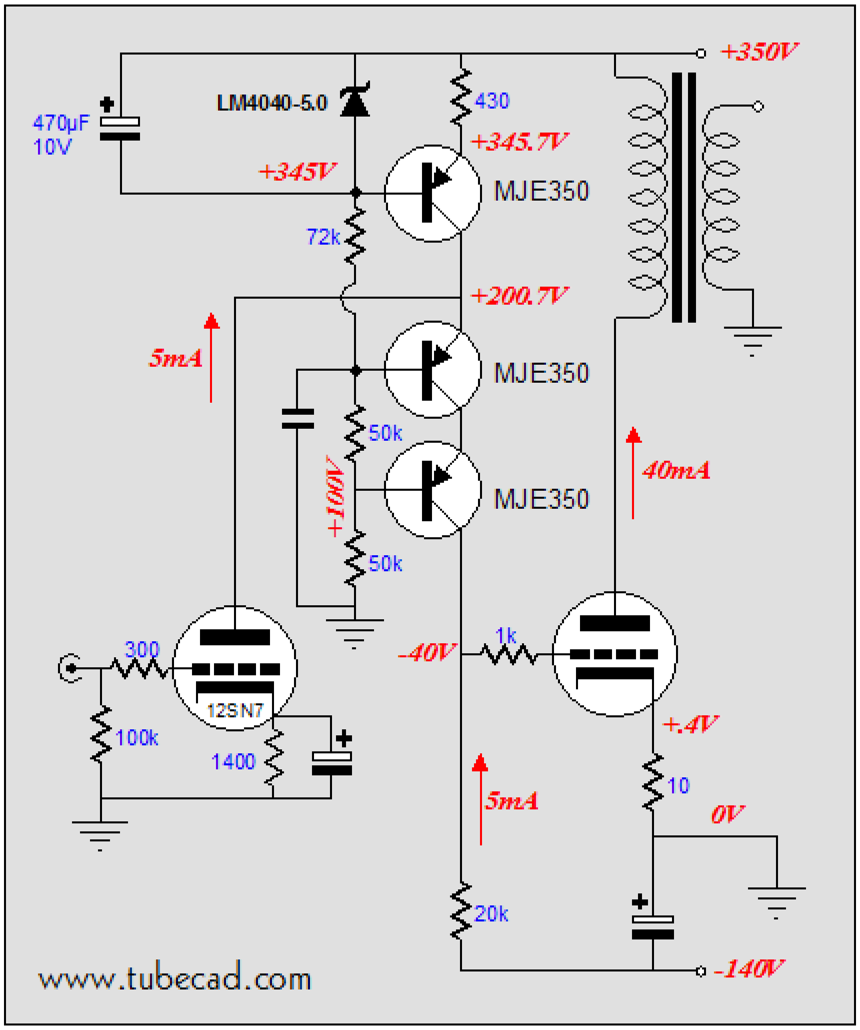
Since this topology does not invert the phase of the input signal, we can use the cathode as a negative input for applying feedback.



Still, the problem this topology faces is that it does not improve upon a grounded-cathode amplifier's PSRR. Inverting the cascode and adding a constant-current source will take care of the PSRR troubles, as the B+ noise cannot make across the constant-current source.



A truly low-noise cascode offers some real advantages for preamps and line amplifiers. One use for this circuit that comes to mind is that of an input stage in a single-ended amplifier.



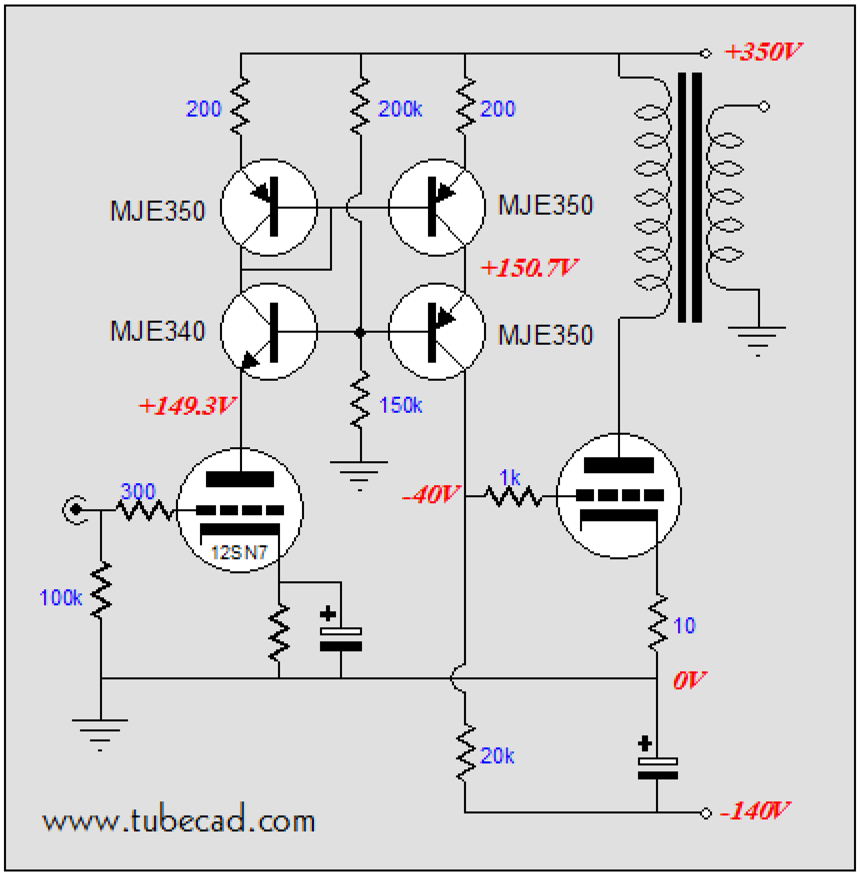
Two MJE350s are used in the cascode portion of the circuit, decreasing the likelihood that the high voltages with the amplifier will kill one of the fragile transistors.

The output tube's grid (the tube could be a 300B or triode-connected 6550) directly coupled with the input stage. Such an does eliminate the need from a coupling capacitor and its associated headaches, but it also introduces a real safety issue: What happens at startup and what happens if the input tube is removed from its socket?

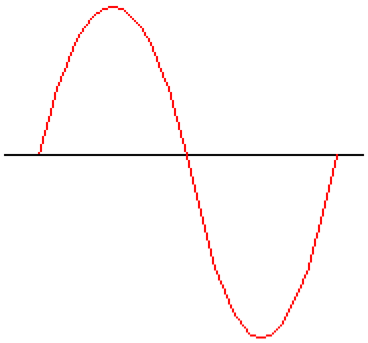
At startup, the 470µF bypass capacitor across the IC voltage reference saves the day, as it must slowly charge up to the reference's voltage, which will allow the input and output tubes to heat up enough to start conducting. Removing the input tube presents a much greater danger, as the constant-current source will eventually come up to its full 10mA of current draw, which against the 10k resistor will develop +60 volts at the output tube's grid (not a good idea). One work around would be to bridge the grid to ground via a reverse biased diode. The diode would not conduct as long as the grid was negative relative to ground (+0.7 volts to be more precise), although this might make for some hard clipping.

A better workaround might be to replace the input tube's cathode resistor with a relay's winding. Now, until the first tube is conducting enough to actuate the relay, the output tube's grid could be shorted to the negative power supply rail.

Interestingly, the cascoded constant-current source did not suffer from this problem, as the input stage defines the current flow, not a constant-current source. In other words, without an input tube, there's no conduction and the output tube’s grid is pinned to the negative power supply rail. Much safer. But there’s a problem hidden here as well.



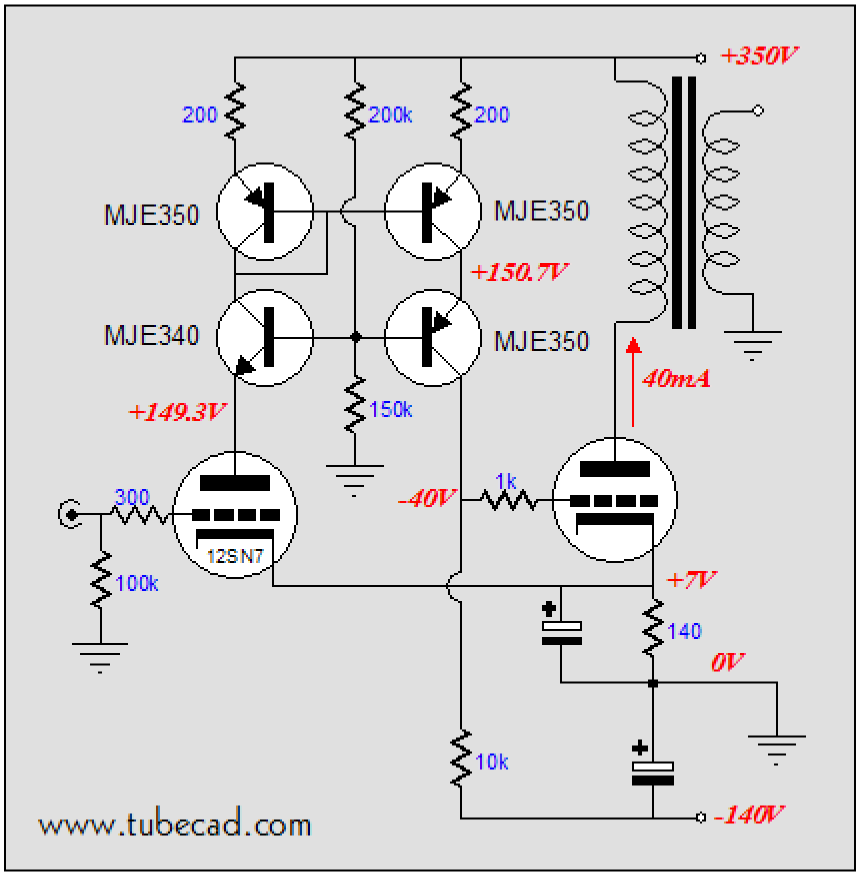
No tube is perfectly linear. All triodes are easier to turn on than they are to turn off. This make for a strong 2nd harmonic distortion component.



But if two triodes are cascaded, wherein one turns on as the other turns off, much of the nonlinearity vanishes. However, in the opposite case, wherein one turns on as the other turns on, the nonlinearity compounds, making for much more distortion. Well, in the current mirror arrangement, the phase is preserved, which means that the input stage works in the same current phase as the output triode, compounding the nonlinearity; whereas the inverted cascode stage inverts the input signal, which means that the input stage works in the opposite current phase as the output triode, reducing the nonlinearity. (Paradoxically enough, using a more linear amplifier, like the Aikido amplifier, can yield more distortion at the loudspeaker because it is so linear and it can't pre-bend the signal for the output tube bend in the opposite direction. Absolutes make little sense in complex mixes.)

So you must chose safety or sound. Or, why not add a coupling capacitor to the inverted-cascode-stage-based amplifier and get both safety and good sound?

Well, here's one reason against that move: the current-mirror-based amplifier allows for an easy DC feedback loop to be applied from input stage to output stage, automatically correcting the output's idle current.



If the output tube draws too much current, the input tube conducts less, which decreases the voltage across the load resistor, which in turn decreases the output tube's conduction. The opposite situation is easy to imagine.

So, which is best now? It depends—the only answer I or anyone else can give. But it is best to know what is possible and what are the consequences. (Does this mean that I have to give up my guru credentials?)

//JRB