Beyond The J Fringe...

by Nelson Pass

I particularly like to work with Jfet transistors. They embody some of the best qualities of Tubes, Mosfets and Bipolar transistors, particularly if you are building audio circuits. Many audioDIYers got their introduction to Jfets with Erno Borbely's great articles in 2015, JFETs: The New Frontier, parts, 1 & 2 where he gave some great examples and touched on a number of design considerations. The premier examples used the Toshiba Jfets 2SK170 and 2SJ74, still regarded as the best of the audio Jfets, now unfortunately discontinued by Toshiba and available at high multiples of their original price, either as new old stock (and some fakes) and also duplicated by Linear Systems as LSK170 and LSJ74.

Despite the high prices, these parts are in short supply, mostly because they are difficult to make, but their combination of low noise, high gain and linearity makes them very attractive for high end audio use. They come in different grades, the Toshiba examples being GR, BL, and V, with Idss values of 2.6 to 6.5 mA, 6.0 to 12 mA, and 10 to 20 mA respectively. The Idss figure is the current that passes through the Jfet from the Drain to Source when the Gate pin is attached to the Source pin and voltage is applied to the Drain, usually 10 volts.

Idss is the current that flows through the Jfet, Drain to Source, when the Gate voltage is the same as the Source voltage. Conventional wisdom has it that you can operate these transistors up to their Idss figures, which would mean up to 6.5 mA for the GR, 12 mA for BL and 20 mA for V grade. Toshiba and Linear Systems data sheets shows detailed information for performance of these parts but only up to their Idss current, and the impression is left that you would not want to use them beyond that, the result being that many DIYers prefer the higher Idss parts.

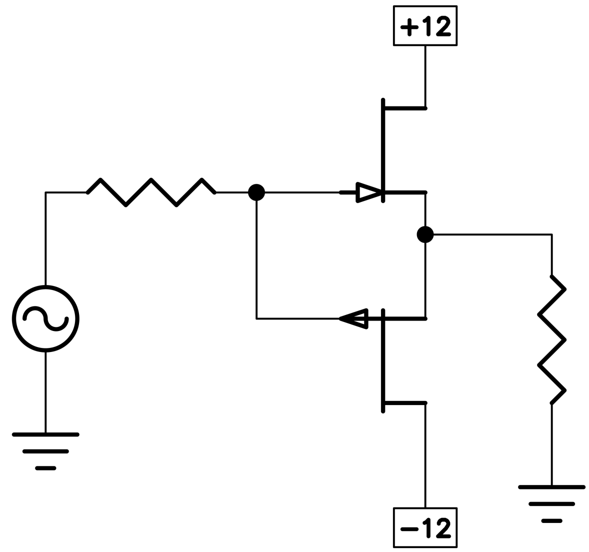
But the shortages of these Jfets gives us a strong motive to examine the performance of the parts with the lower Idss figures. The question is: What is the downside of exceeding Idss with audio circuits, and how far can you go before take performance or reliability hit?

If you understand that the Gate to Source junction of a Jfet looks like a diode when forward biased, then you might appreciate how the normally infinitesimal Gate current gets large and it's no longer much of a FET past that 0.6V diode voltage. At Idss where Vgs is zero, the Gate current is something like 1 nA (1 billionth of an amp), but as the voltage is increased, this current increases and above 0.6V current is flowing copiously (microamps!) where it starts to resemble a bipolar transistor.

Erno Borbely was not shy about biasing his Jfets at Idss and operating them at peaks of twice that without excessive distortion, so perhaps that region above 0.0 volts and 0.6 volts is worth exploring. A micro-amp of Gate current implies a voltage variation of 10 mV with a 10 Kohm signal source impedance. Some of that 10 mV is linear, and some is not, but you can imagine distortion on the order of 1% or so at this point.

Of course in real audio circuits at these signal levels, there is often clipping somewhere else.

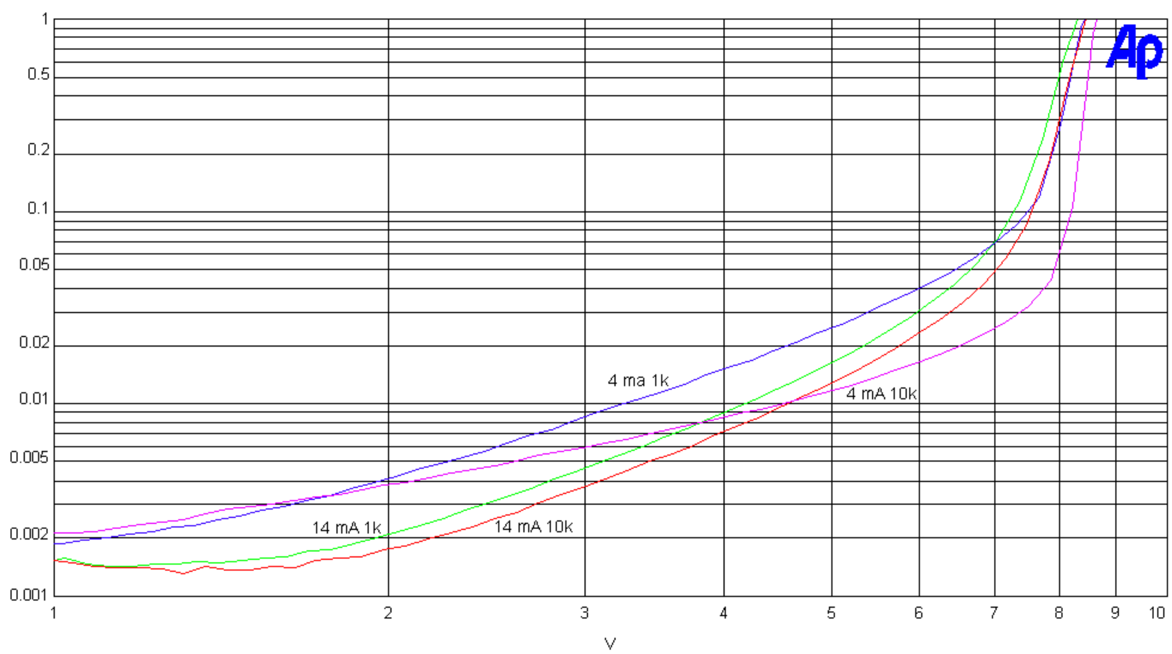
So cobbled up a couple of test circuits. Below is a simple push-pull follower circuit (aka "buffer") with pair of high quality matched complementary Jfets, the Linear Systems 2SK170 and LSJ74, replacements for the long discontinued Toshiba 2SK170 and 2SJ74.



The load resistor is 1 kohms (1 thousand ohms) or 10 kohms and the impedance of the signal source is 600 ohms or 10 kohms, and I swept the 1 Khz source signal from 1 to 10 volts.

This isn't one of those sophisticated circuits that gets the .0000X% distortion numbers and we are not looking for low distortion per se – we want to see the differences in distortion for different Idss Jfets, different loads, and different source impedances

Here's what I got:



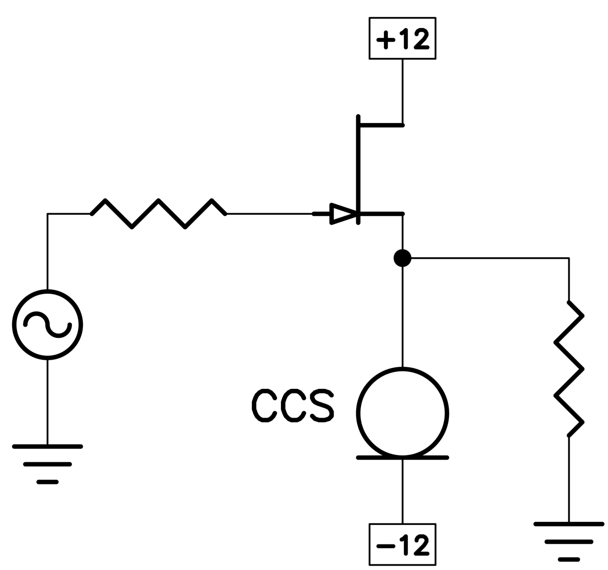
The four curves you see are labeled for the Idss and load impedance. What you don't see is the curves which compared the 600 ohm source vs the 10 kohm source. No point in that – they were the same.

You can see that with the 10 kohm load that there are some differences – below 4 volts the pair biased at 14 mA are better, but the 4 mA pair has lower distortion above about 4 volts. At a 1 kohm load the higher biased parts shows some advantage, but it's clear to me that any of these parts are good, and better than the competition in this regard. Normally you would expect lower distortion at the higher currents because the transconductance of Jfets is proportional to the current, and that normally translates into lower distortion. At the same time, the lower Idss parts appear to have less sensitivity to the variations of Vds, as seen in the 4 mA pair into 10 kohms at the higher output voltages.

The fact that the curves were unaffected by the source impedance tells me that Gate current is not an issue. At 7 volts rms, we are seeing 10V peaks, and are reminded that the supply is only 12 volts, so that the increase in distortion above 7 volts is mostly voltage clipping.

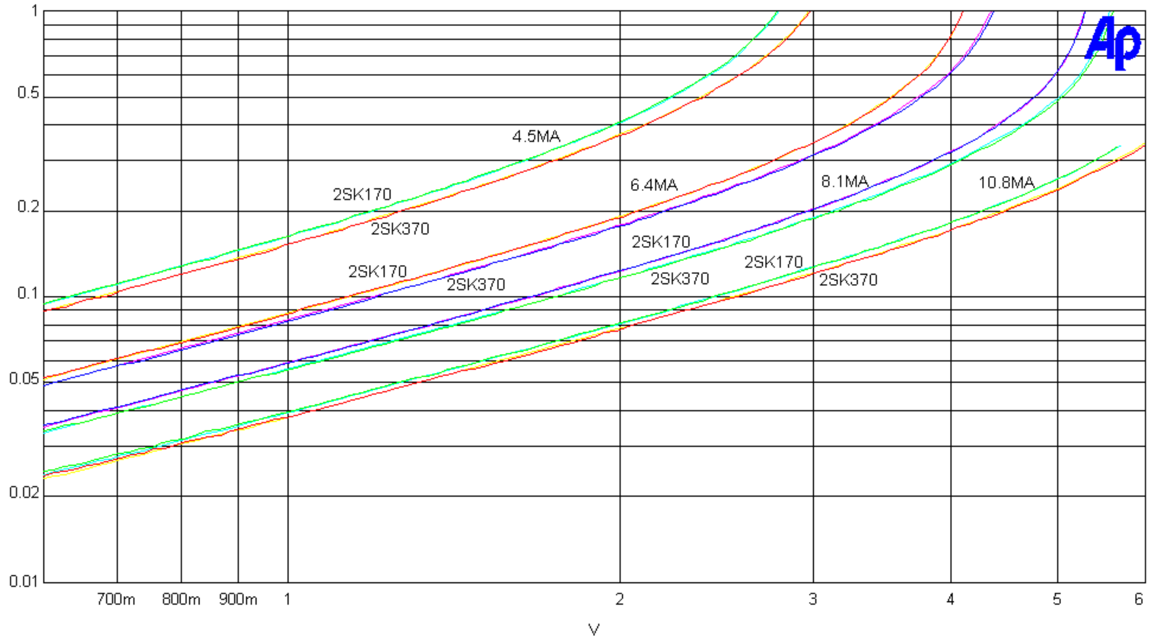
Interestingly, the 4 mA Jfets are still delivering at 10 mA peaks into 1 kohm, more than twice their Idss.

I was interested in obtaining some data with single-ended followers, so I also put together this test circuit, where a single Jfet is biased by a constant current source (A high Idss 2SK170 with degenerating resistor). Again, different Idss devices, 2SK170 and 2SK370 (same chip, different package), one with Idss of 10 mA, the other 5 mA. Again the load was 1 kohm, and the source was 10 kohm or 600 ohms.



In this case we again see that the curves for the 600 ohms vs 10 kohm source impedance overlay each other, and there is no substantial difference.

We also see that there is not much difference between the 10 mA and 5 mA Idss parts. Interestingly, the 5 mA parts had slightly lower distortion under all conditions, but this may have been the result of the degenerating resistor on the constant current source.



Into 1 kohms we see that the big differences are in the amount of bias, and the higher the better. Biased at 10.8 mA, we see that the 5 mA part does very well. When you add the 10.8 mA of the constant current source to the 8.4 mA AC peak it performs better than I would have expected, delivering more than 19 mA peak on a 5 mA Idss. In fact it did clearly as well as the part with twice the Idss.

There is a conclusion that I will draw - that the GR grade (or A grade with LS) are very well suited for audio use, and you can exceed the Idss numbers of these parts without significant penalty

This means that you can routinely use the lower Idss parts, which are cheaper and more available. In some cases they appear to have slight superiority, and if we are using them in self-biased circuits they often can be operated without degeneration, which as I have pointed out elsewhere has some advantages is audio amplifiers.

I am using these parts in appropriate locations, and I am suggesting that DIYers let go of some *audio nervosa* and start using them too.

And sleep well at night.