The LU1014 Circlotron Power Buffer

XEN Audio
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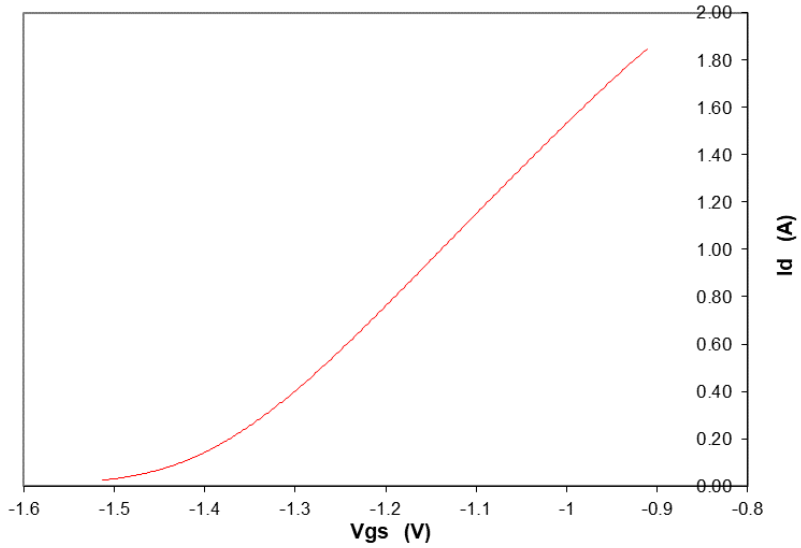
Just as people have been trying, in vain, to find equally worthy replacements for 2SK170 / 2SJ74 JFETs [1], attempts to find alternatives to the obsolete Semisouth power JFETs [2] have equally yielded no success. Even our remaining 8 pairs, not curve traced but only Vgs matched, were gone in 8 hours.

No wonder there has been a lot of buzz around the LU1014, the other "power" JFET known in DIY Audio [3.4.5,6]. Although now also obsolete, Nelson Pass still has thousands, and recently threatened to put his thousands in the DIYA store. And there are people who snatch up remaining thousands from Chinese dealers as well. There have also been various attempts to use them in other circuits than the Zen Variation 9. Few though, have been able to retain the Cascode-modulation that exploits the triode characteristics of the LU1014.



LU1014 Id vs Vgs in ZV9 Triode Cell

For more than a decade, various people have successfully built our DAO headphone amp based on the same LU1014 "triode-cell" as in the Zen V9, but at a reduced bias of 200mA. And the result seems more than satisfactory [7,8].

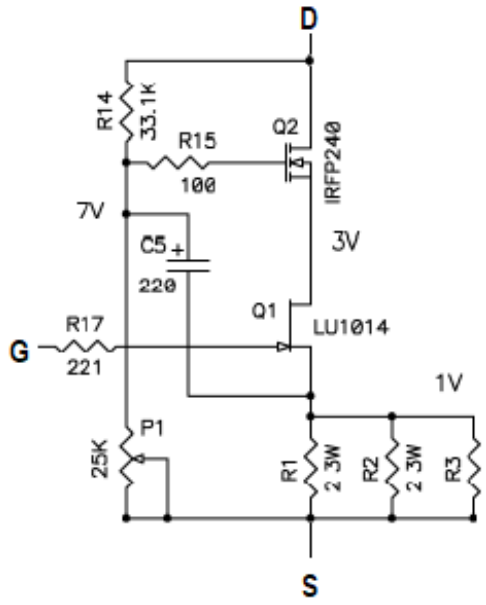
Especially, NicMac's Balanced DAO Circlotron Buffer has distortion levels below -95dB even highly loaded, and all without any global negative feedback [9,10].

So the natural question has been, why not do this for a power amp ?

The Challenges

This was the challenge put to me by NicMac in March 2022. And my immediate answer was that it was at least not so simple.

The LU1014's magic lies in the Triode Cell. And there is already a triode cell for power amp, namely that in the Zen V9 [11]..



The Original Zen V9 Triode Cell

Nelson did not use it as a buffer, but as a common-source gain device. This is because the output impedance when used as follower would be too high. The source resistor itself is already about 0.67R, on top of 1/Yfs from the LU1014 itself. So you are talking about 1R Zout. Even in push-pull on a 8-ohm speakers, damping factor is merely 16x. If you parallel 2x for 2.6A bias, you can get down to Zout of 0.25 ohm. And because of the cascode, you need extra voltage headroom as well, i.e. you clip at a much lower voltage before you come close to the rails. That, in turn, means a lot more heat for the same power.

But why can we not just remove the source resistor ?

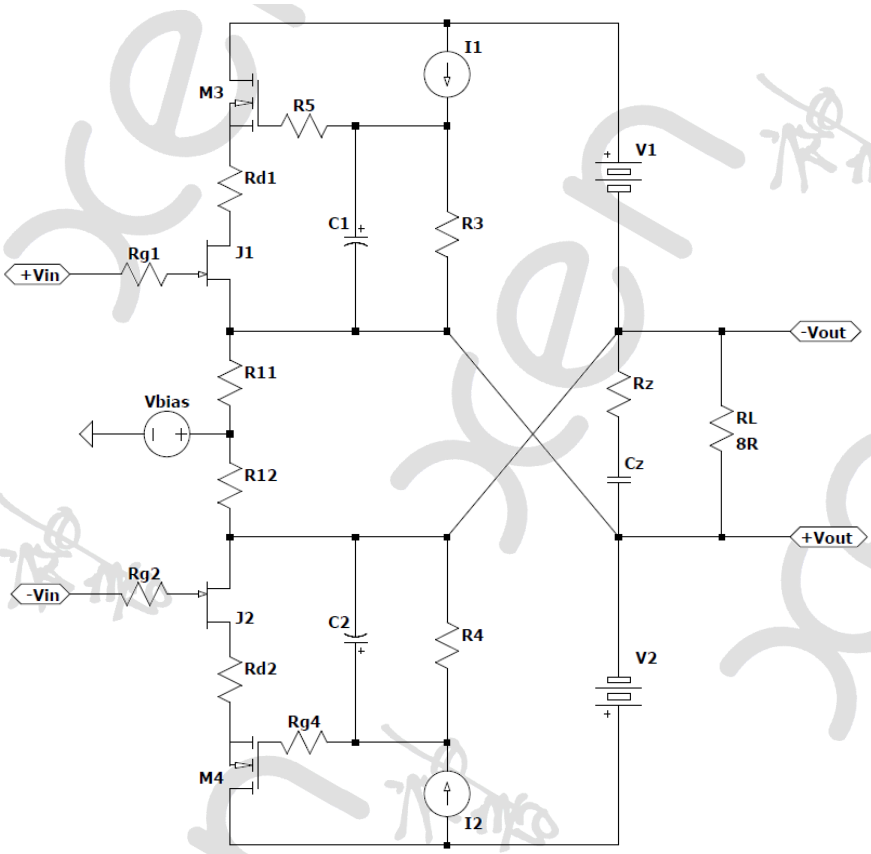
In the Zen V9 triode cell, the source resistor has 3 functions :

1) Together with the Yfs of the cascode MOSFET, it modulates Vds of the LU1014 to produce the triode effect.
2) The LU1014 has positive tempco, and needs a large-ish source resistor to stabilise bias and prevent thermal run-away.
3) It conveniently provides the negative Vgs needed by the LU1014 with a DC coupled input signal.

IF we can find workarounds for the above 3 functions, we can get rid of the source resistor altogether. Then Zout is purely 1/Yfs of the cascoded LU1014, which is in the order of 0.18R. But only IF.

Source Resistor and Negative Bias

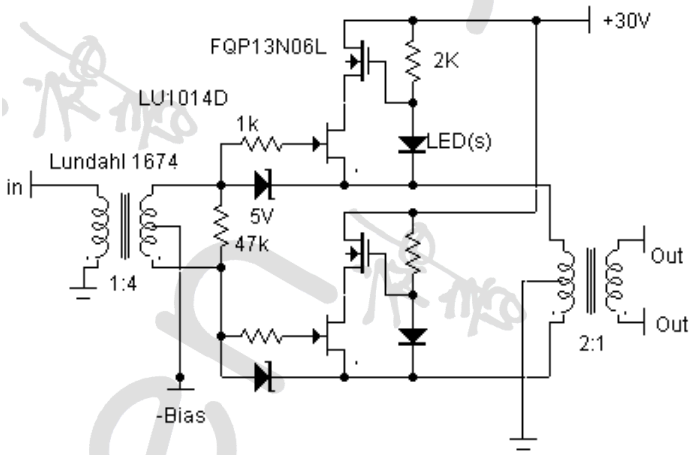
The basic LU1014 Circlotron circuit is essentially the same as the balanced DAO [12], but with a few subtle changes.



The triode cell Vds modulation still works if we move the same source resistor to the drain, below the cascode. That way, the Rsource is taken out of the equation of the output impedance. To provide a negative Vgs while input is at Gnd, we need to put the source (and hence also output DC) at a positive Vbias above Gnd. But for the speaker it is no issue. It only sees the differential output signal.

So two of the issues above solved, QED.

Incidentally, this circuit below [13] (from 2007) looks very similar, but one must love transformers, and perhaps might want to add the ZV9-Cascode as well. It can then also go to much higher rails.



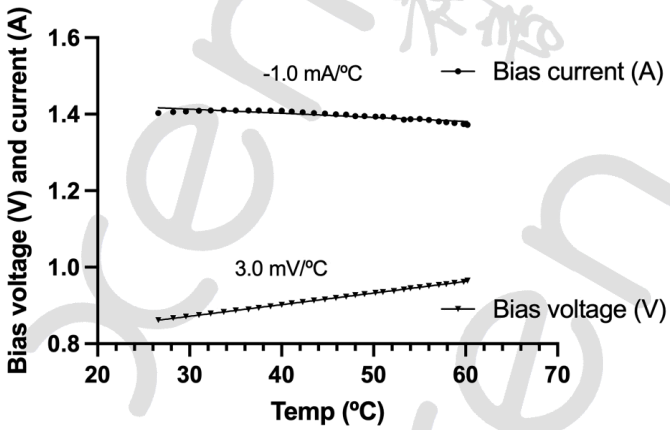
Bias Stability

But how about bias stability. Bias might drift with temperature. One may use the drain resistors for current sensing and then Nelson's optocoupler auto-bias trick ? That would work, but it limits the choice of Rsource and bias current values. So there has to be better ways than a bias feedback loop.

What is needed is to make Vbias adjustable to compensate for changes in Vgs with temperature. So the first thing is to figure out what how much bias current changes with temperature, without a source resistor, but in the triode cell.

NicMac did a lot of laborious work on that, and we can determine the thermal coefficient in our setup to be ~17mA/°C. Or, if we want to keep Id constant, we need to reduce Vgs (which is negative) by 2.9mV/°C.

After trying out quite a few alternatives, we finally settled on one circuit which gives us the exact compensation we need. This makes use of the known tempco of the BE junction of a bipolar transistor, in this case the Toshiba TTA00B. The BJT would have to be mounted on the heatsink, ideally as close as possible to the midpoint of the two LU1014s. After tweaking some resistor values, we can adjust both the bias voltage and its tempco to the values we want. Easily said, tons of work done before getting this far.



What's next ?

Now that we have sorted out the basic circuit topology, we can concentrate on optimising various parameters inside the triode cell to achieve low distortion. This is what has kept NicMac very busy for the last year.

References

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