Alternative Configurations of the simple JFET Source Follower

KYB 23-8-2008

I. Introduction

Like many, I have been reading the excellent article of Erno Borbely, JFETs New Frontiers, umpteen times, and have been using the simple JFET source follower circuits in line level applications for years, mostly before and after filters, but also as preamp output stages. A while ago, I also published a headamp circuit based on the single-ended N-FET circuit (Fig. 15C in the Borbely article), using cascaded LU1014 as active devices. At least one example was built, and the owner was exceedingly happy with the results. Lately, Nelson Pass used a variant of this in his B1 preamp, and a thorough theoretical treatment from Feucht is widely available on the internet.

My default circuit is, however, the Curl complementary source follower, using a pair of 2SK170 / 2SJ74 with matched Idss, as shown in Borbely's Fig. 16C. Compared to the above-mentioned single-ended configuration, it has about double the current driving capability, as well as good even-harmonics cancellation, as both devices contribute (almost equally) to the output current load. The circuit is equally simple as the single-ended configuration. A high power version of this configuration is of course the First-Watt F4 by Nelson Pass, using complementary MOSFETs with a front-end biasing circuit. What a pity that we do not have P-type power JFETs or depletion-mode MOSFETs.

There have been a few occasions that I have had to use the single-ended version for specific applications. This is largely because of the relatively high Cgd of the P-JFET 2SJ74, which can limit bandwidth somewhat when driven by a high impedance source, such as the last stage of a 3rd order passive filter. For example, the bandwidth is only 45kHz when driven by a source impedance of 100k. Using the SE configuration will improve this by a factor of 7, to some 300kHz.

There is of course no free lunch. In the SE version, only one (the top) JFET is providing the output current, and thus has increased distortion and higher output impedance, especially when driving load impedance loads of 1k or less. It just seems such a waste that the lower JFET only acts as a constant current drain.

Recently, a source follower circuit published by Scott Wurcer with modulated current source has retriggered my interest in the search for improvements to the 2 configuration mentioned above.

II. Known alternative Approaches

1. The White Follower

One approach to turn this lower JFET into an active current source was shown in Fig. 16A of Borbely's article, based on the White Cathode follower. A current sensing resistor is incorporated between the top rail and the JFET drain, and a simple C-R filter acts as a level shifter to drive the gate of the lower JFET actively. When dimensioned properly, this not only doubles the current driving capability, but also allows near-perfect even-harmonics cancellation. Unfortunately, the White follower has one big drawback – it also passes all top-rail noise to the lower JFET gate. Also the C-R shifter would be struggling to drive the somewhat high input capacitance of devices such as the cascaded LU1014, or depletion N-MOSFETs such as DN2540, etc.

2. The Taylor Follower

A few hours of "Googling" returned an excellent article on cathode / source followers at TubeCAD. Especially interesting is the Taylor follower. This uses a current sensing resistor at the top rail, similar to the White follower, but replaces the C-R level shifter using an active device, e.g. a small PNP bipolar transistor. This solves the rail-noise problem elegantly, at the expense of slightly increased complexity.

3. Others

A couple of other ideas can also be found on the internet, such that that from Scott Wurcer, and the one described in US Patent US5399989. They are however somewhat more complex, and do not have the minimalistic elegance of those mentioned above.

III. A Couple of new Ideas ?

1. Complementary Follower with low Input Capacitance

It occurred one day by accident that the problem of the Curl complementary follower could be gotten around by driving the gate of the P-JFET not by the input, but by a source resistor of the N-JFET, commonly used to ensure that the N-FET is not unduly positively biased (Fig. 1).

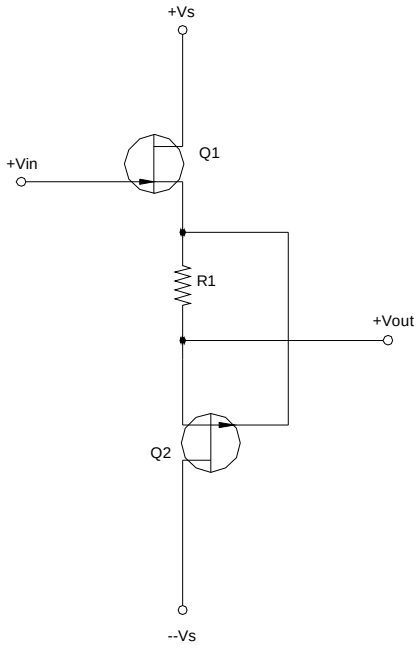

Fig. 1 Low Input Capacitance, Complementary JFET Follower

Q1 2SK170BL, Idss 10mA
Q2 2SJ74BL, Idss 10.5mA

R1 14.85R

Q1 DC bias 6.6mA
Q2 DC bias 6.6mA

Current modulation ratio $i_1 / i_2 \approx 3$
Distortion @ 1V, 1k load 0.056% (2^{nd} & 3^{rd})

Here, R1 senses the current through Q1, and converts this to a gate drive voltage to drive Q2 in the opposite sense. The negative current of Q2 is never the same as Q1, except in cases where its transconductance $Y_2 >> (1 / R_1)$. With the values showed, i_2 amounts only to 1/3 that of i_1. Not ideal, but it can be had for no additional expense. So it is still a worthy improvement to the SE configuration, with distortion levels reduced by some 30%.

The Idss of Q2 has to be slightly higher than Q1, only because its transconductance is also higher, and hence has a slightly larger reduction in bias with the same source degeneration voltage as Q1.

This circuit, like the Curl complementary follower, does require a P-device which is complementary to the N-device, and hence cannot be use for the likes of LU1014 or DN2540.

2. Simplified all-JFET Taylor Follower

A P-JFET can of course be use instead of the bipolar transistor in the Taylor follower. And a quick attempt shows that the Vg of the P-FET is not too far off the top rail voltage (Fig. 2).

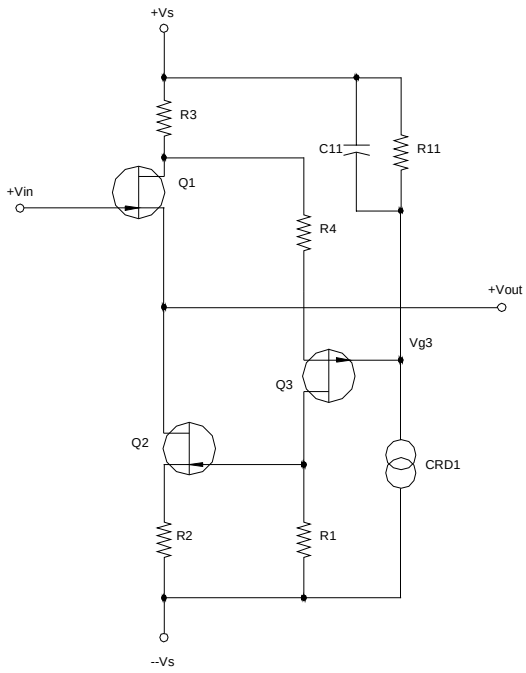

Fig. 2 Single-Ended, N-JFET Taylor Follower

Q1	2SK170BL, Idss 10.0mA	
Q2	2SK170BL, Idss 10.0mA	
Q3	2SJ74BL, Idss 8.0mA	Vg3 at 952mV from +ve rail (432R//220uF @ 2.2mA)

R1	227R
R2	68.1R
R3	68.1R
R4	64R

Q1 DC bias	10mA
Q2 DC bias	10mA
Q3 DC bias	3mA

Current modulation ratio $i_1 / i_2 = 1$

Using a long-tail JFET such as the 2SJ103 for Q3, I managed to set the Vg of Q3 to equal the top rail voltage, thus eliminating the entire biasing circuit (R11, C11, CRD1). The result is surprisingly good (Fig. 3).

The current contribution of Q2 is now almost equal to that of Q1, and the distortion is much lower than any of the previous circuits, indicating near-optimum even-harmonics cancellation. The residual distortion is almost entirely third order.

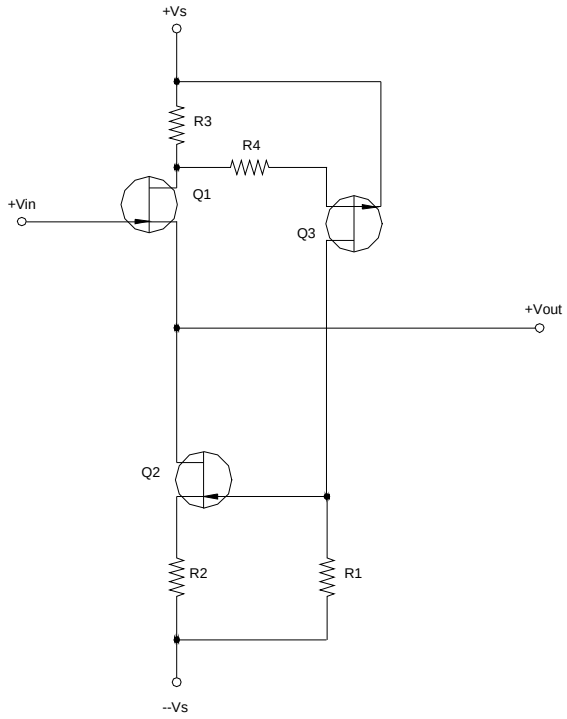

Fig. 3 Simplified, all-JFET Taylor Follower

Q1 2SK170BL, Idss 10.0mA
Q2 2SK170BL, Idss 10.0mAb
Q3 2SJ103BL, Idss 10.0mA

R1 597R
R2 120R
R3 148.5R
R4 120R

Q1 DC bias 10mA
Q2 DC bias 10mA
Q3 DC bias 2mA

Current modulation ratio $i_1 / i_2 = 0.82$
Distortion @ 1V, 1k load 0.005% (almost entirely 3rd)

There is no reason why the Taylor follower cannot be used for higher-current devices for Q1,2. The simplified version does limit the choice of current and resistor values, whereas the version in Fig. 2 enjoys full design flexibility.

3. Current sensing SE Follower

Even though the performance of the simplified Taylor follower is hard to beat, I was still contemplating alternative circuit topologies. Then I remembered Nelson Pass using a current sensing resistor in his “Aleph” current source, as described in US Patent US5710522. The result is the circuit shown in Fig. 4 :

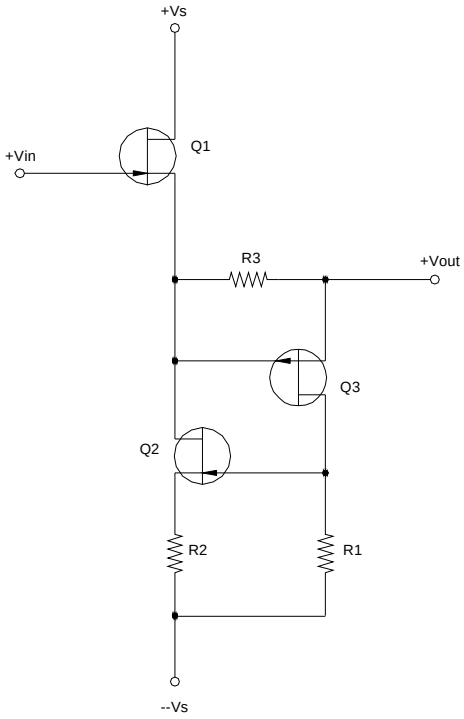

Fig. 4 Current Sensing, Single-Ended, N-JFET Follower

Q1 2SK170BL, Idss 11.5mA
Q2 2SK170BL, Idss 10.0mA
Q3 2SJ74GR, Idss 3.8mA

R1 70R
R2 35R
R3 18.8R

Q1 DC bias 9.75mA
Q2 DC bias 7.25mA
Q3 DC bias 2.5mA

Current modulation ratio $i_1 : i_2 : i_3 = 0.35 : 0.35 : 0.3$
Distortion @ 1V, 1k load 0.045% (entirely 2nd)

This is arguably even simpler than the Aleph current source, and does not employ any global negative feedback. In this particular example shown, the current contributions of all 3 FETs are about equal. Distortion is higher than the simplified Taylor follower, but it is almost entirely 2nd order. Thus, two of these, driven in differential mode, will offer equally excellent performance.

IV. Concluding Remarks

Nothing ground breaking, so why bother with the extra complexity (1 more active device and up to 4 additional resistors). Indeed, the two classic 2-JET configurations are hard to beat for most low-current applications. If you would, however, like to have a bit more current drive than 10mA, are thinking of using devices like LU1014s and DN2540s, then one or two of the circuits shown here should, in my humble opinion, deserve some serious considerations.