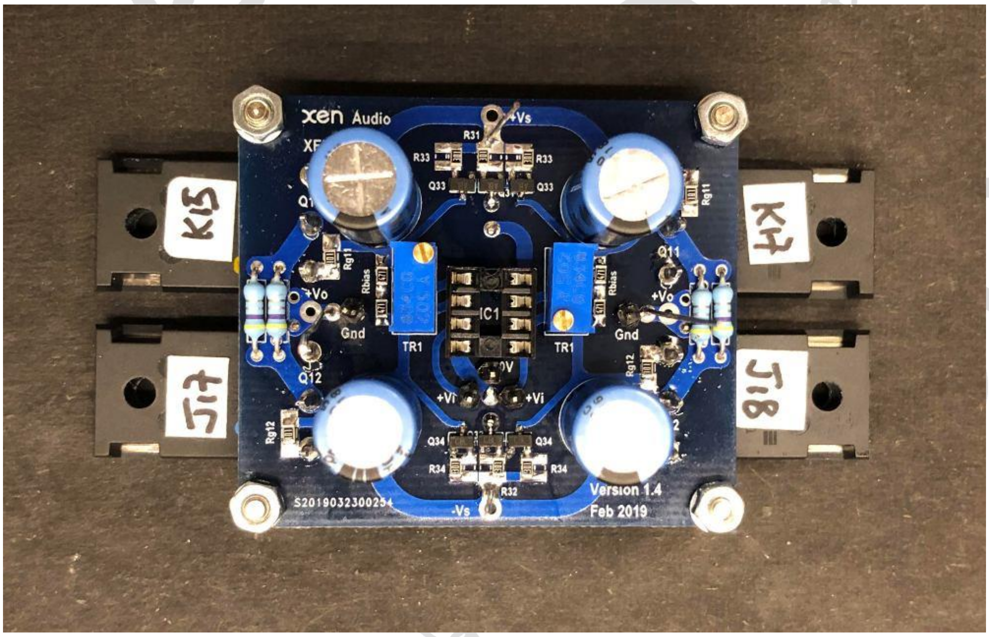
XELF Lateral MOSFET Buffer
XEN Audio
May 2019



Design Considerations

With the success of our discrete opamp [1], there was a big itch to test it in a circuit. Wayne's WHAMMY came to mind. Which raise the question, how would a MOSFET follower buffer from XEN look like ?

For headphone use, with or without an opamp to drive it in a NFB loop, 5 pairs of 2SK170V / 2SJ/$V would be a good solution. Total Class A output current can be up to 120mA, and output impedance in the order of 3 ohm. Input capacitance is high though, requiring a low impedance source. And of course, a very expensive solution with unobtainium JFETs.

And then we have the LH0033 Sziklai that was used in the ZGF Desktop [2] before. The LH0033 Sziklai is a really nice circuit, as it is very easy to drive and has real low output impedance. But the circuit is somewhat complicated.

There was a discussion a while ago about auto-bias circuits from Nelson and from JLH [3, 4]. Such circuits are convenient as one does not need to worry about thermal stability, as the circuit regulates that automatically. Apart from us being allergic from these in-circuit control loops, there is also the limitation that source resistors with a large-ish voltage across them (0.65V for JLH and 0.9V for Pass) are a necessity. Given a certain bias, this automatically determined the source resistor value, which can be higher than otherwise desired. This is especially true when the buffer is not used within an NFB loop. Also in the JLH solution, difference in Vbe of control devices will also lead to a small DC offset.

As there are no P-Channel depletion MOSFETs available commercially, one cannot implement a MOSFET version of the JFET “Beast” mentioned above. One can however implement an all-NFET “Feucht” follower, using devices such as IXTP01N100D. One can even implement quasi-push-pull using a White follower or a Taylor Current Source [5, 6]. But choice of devices is limited, and at least Idss matching and good thermal coupling is necessary. More importantly, Class A current is half that of a push-pull circuit with the same bias.

The most common push-pull solution with enhancement mode MOSFETs is the 4-resistor bias circuit.

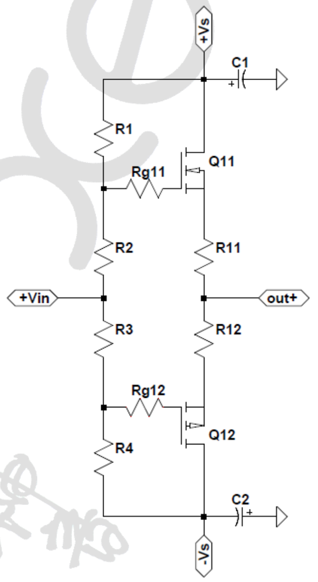


Fig. 1 4-Resistor-biased MOSFET Follower

Nothing wrong with this, as it cannot be much simpler. But it has rather poor PSRR, and the signal source is loaded by R1 // R4. R2 and R3 are used to adjust bias of the upper and lower MOSFET individually. So one adjustment affects the other, and a few iterations are required to get both bias and DC offset to the desired values.

The problem with R1 & R4 can be solved by replacing them with two identical current sources. The snack is them being identical, as difference in current will results in DC offsets. This problem in turn has also been solved by the self-tracking CCS used in the SL HPA and the XCEN [7, 8]. The price is 5 extra transistors. But it is a price worth paying for.

So we now end up with the following topology :

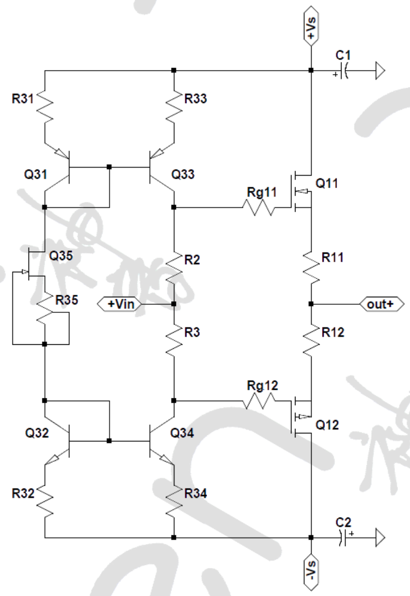


Fig. 2 CCS-biased MOSFET Follower

Nothing new ? Indeed. A search in the net revealed that this has been published by AMB in 2005, although it was not chosen for final implementation [9]. Note also how similar this circuit is to the UTHAiM with BJT current mirrors.

AMB suggested to adjust bias via the current source Q35 / R35. But DC offset can only be adjusted by R2 & R3. One might just as well leave R35 alone and adjust R2 / R3 instead. It would be nice of course if we can adjust bias and DC totally separately. So we came up with the following improvement :

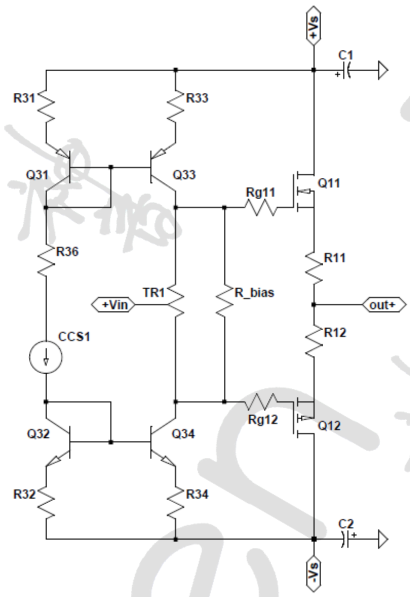


Fig. 3 The XELF Follower

Bias is only adjusted by changing the value of R_{bias}, and DC offset can be adjusted by TR1 without affecting bias. Of course one can replace TR1 with fixed resistors after trimming. For simplicity, a Semitec Current Regulating Diode (CRD) is chosen for CCS1. R36 is meant to drop the voltage across CCS1 by half to reduce its dissipation. You may consider it optional. Since we need to connect this two components in series before soldering onto the PCB at connection points CCS+ and CCS-, it is perhaps more convenient to do so on a small Vero board of about 5x22mm. The latter can be placed on the bottom side of the PCB with a clearance of say 2mm. Those skilled with soldering can of course skip the Vero, do it directly P2P and insulate afterwards with a small length of heat shrink.

How about thermal stability ? The best solution is intrinsic stability, i.e. operating the MOSFETs at zero or slightly negative tempco. This was one of the reasons behind using lateral power MOSFETs in the UTHAiM output stage. And the same still applies here. An added bonus is that you can use this to drive low-impedance load (small speakers) by just cranking up the bias (to say >1A).

Explicitly illustrated in the datasheets of the Exicon devices, the capacitances of the MOSFET remains constant over a large range of Vds. This is particularly not the case for vertical MOSFETS such as those from Fairchild or IR. A further advantage of lateral MOSFETs is their low bias voltage Vgs (< 1V), allowing them to swing much closer to the rails than vertical MOSFETs. While the bias voltage of bipolar devices is even a touch lower (~0.65V), their dynamic base currents are not negligible and they do load the opamp unnecessarily. Plus they suffer from thermal run-away.

For those who wants perfection, it is optional to trim the self-tracking current sources to make sure there is no DC current flowing from or into the signal source. One can simply do this by temporarily shorting both arms of TR1 with jumpers, then connecting +Vin to Gnd via a 10k resistor, and then adjusting R33 or R34 (dependent on offset polarity) until +Vin becomes zero.

Note that it is assumed the inputs are not floated and has some Gnd reference. This is automatically the case when they are connected to a 10k stereo pot for volume control. If none is used, it is advisable to solder on the PCB bottom side 2x 100k 0805 SMD resistors (Rip) between the input pins and the Gnd pin.

PCB Design

Since the original idea was to make a buffer to test our discrete opamp's with, the PCB was done with that in mind. But it can equally be used as stand-alone boards for a pair of buffers only. All one needs to do is to skip the opamp, the feedback resistor network, and the supply R-C's,. Then jumper pin 1 to pin 3, and pin 7 to pin 5. QED.

XELF Minimalistic

Of course we are fully aware that the biasing circuit for the MOSFET follower can be even simpler when used in combination with an IC opamp. One can skip the upper current source and replace that by the opamp output. The bottom CCS will then load the opamp output stage into Class A, and the OL gain of the opamp will take care of any DC offsets. One can easily build this P2P on a Vero board, but also on the XELF PCB if one has to.

We wanted the XELF to be used also as a stand-alone buffer with any frontend (e.g. AD844 in ZGF mode). And additional CCS at the output of our discrete opamp is of no additional benefit, but instead only add to dissipation of the output stage. The latter is already fully biased in Class A, different from most IC opamps. So we still advise you build the full circuit in Fig. 3.

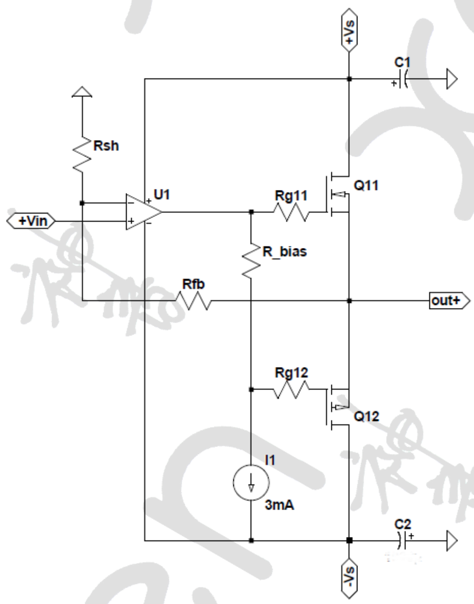
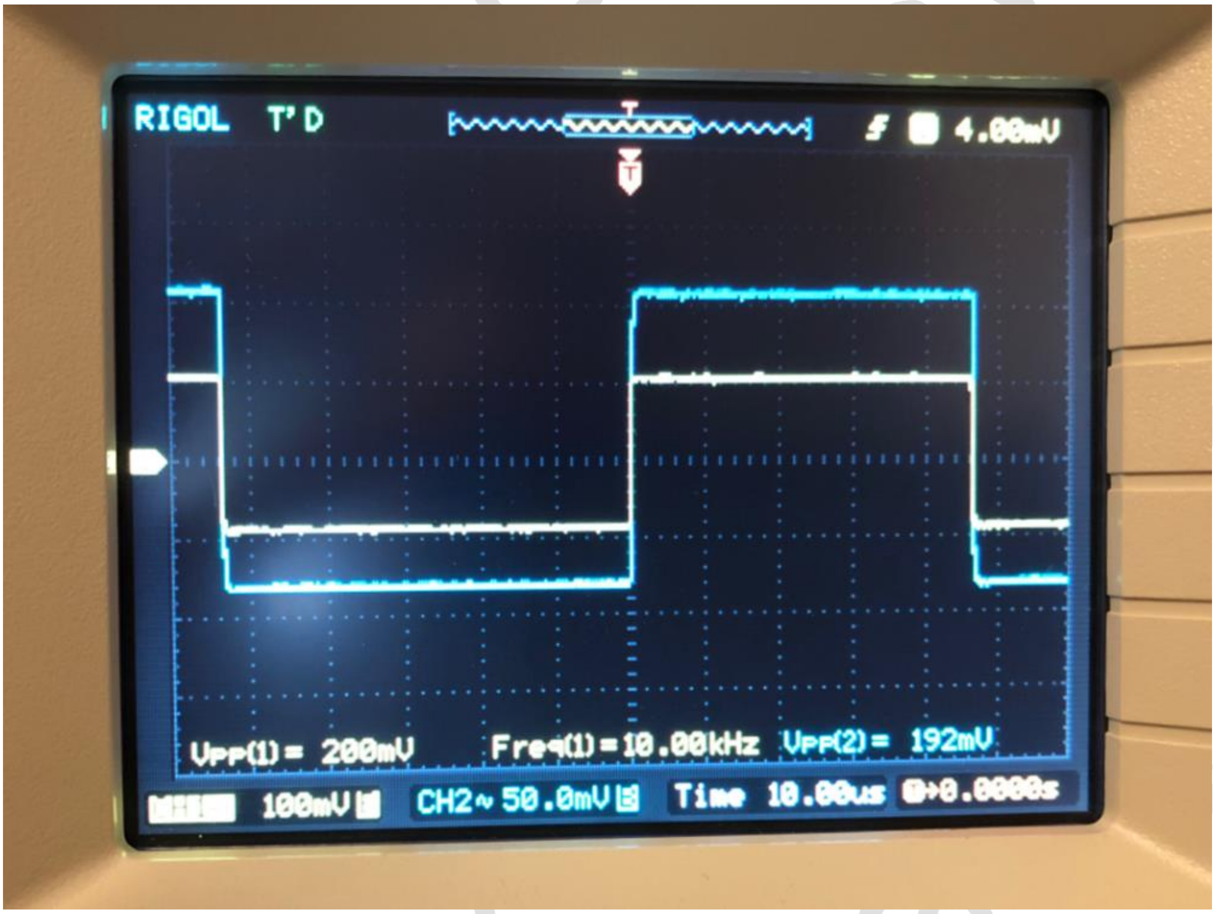


Fig. 4   The XELF Minimalistic

Measurements

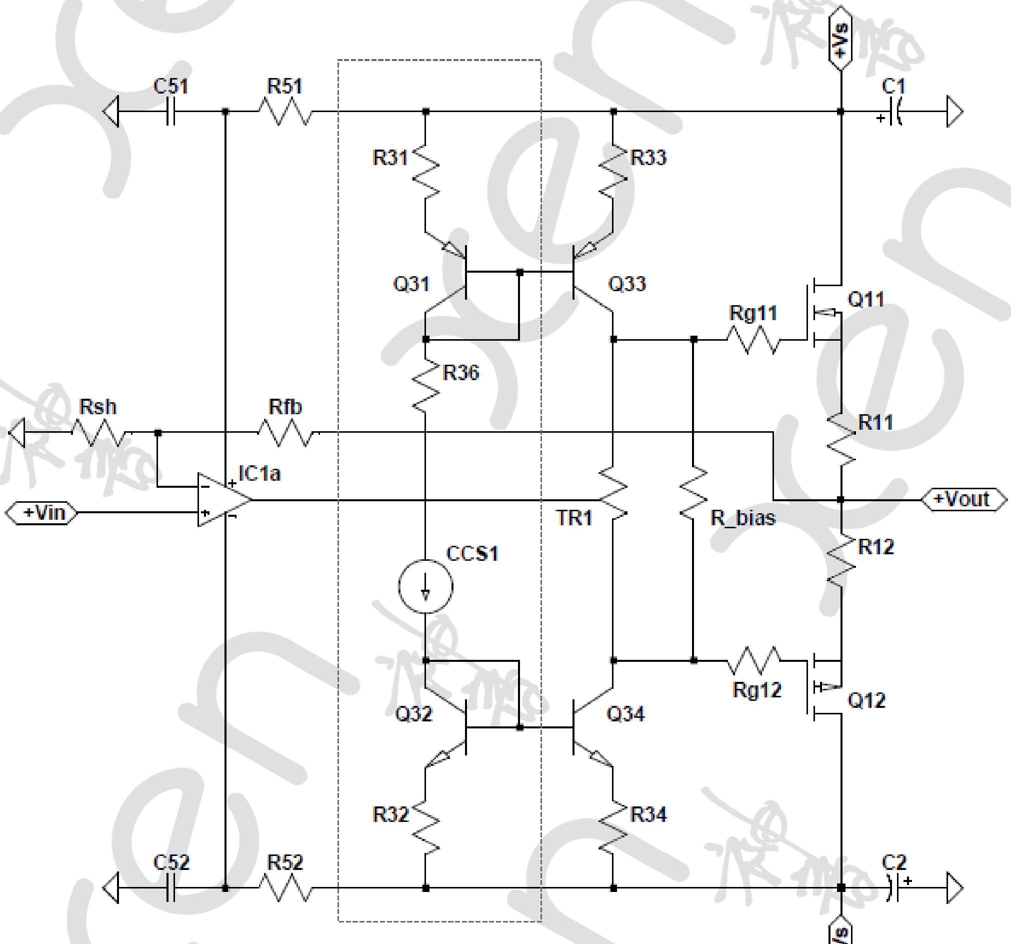
The Alpha test was undertaken by member Morde from the DIY Audio forum. After adjustments for bias (at 190mA) and DC offset, the drift was measured over an hour. The bias was stable to 5mA, and the DC offset to 4mV. That is the buffer on its own, without any opamps. Excellent values.

10kHz square wave is also textbook perfect. No surprise, as bandwidth is expect to be some 2MHz. And there is no visible difference between no load, 600R or 30R load. Zout is measured to be about 1.2R. All that without the opamp.



10kHz Square Wave Response into 30R

Appendix 1 XELF PCB Full Schematics



Common to both channels

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