F5X-P, an All-FET, Pure Class A Preamplifier (i)

XEN Audio
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Circuit Topology

With the success of the F5X Power Amplifier project, there has been a popular demand for a matching preamp. For the single ended F5, a number of such proposals already exist. And there were also suggestions of using the UGS for the balanced F5X.

In our opinion, however, it would be a pity to not have a matching preamplifier of at least the same speed and bandwidth as the F5X power amplifier, after take such trouble in making the latter fast. The most logic approach is of course to use the same basic circuit as the F5X. Indeed, why not.

A couple of months after we simulated the first circuits of such a mini-F5X, John Curl made public the schematics of his excellent JC-80 design, and the similarities in circuit topology are startling. Of course this is John's design some 30 years ago, and all credits go to him. The JC-80 uses an H-arrangement between the input stage JFET sources, very similar to the balanced F5 Turbo published by Nelson Pass a bit earlier. We also think this is as good as, if not better than the floating X as in the F5X power amplifier, and the PCB can also support the H-configuration, in addition to grounded and floating X. Everyone can then experiment for himself and pick the solution best suited to his likings.

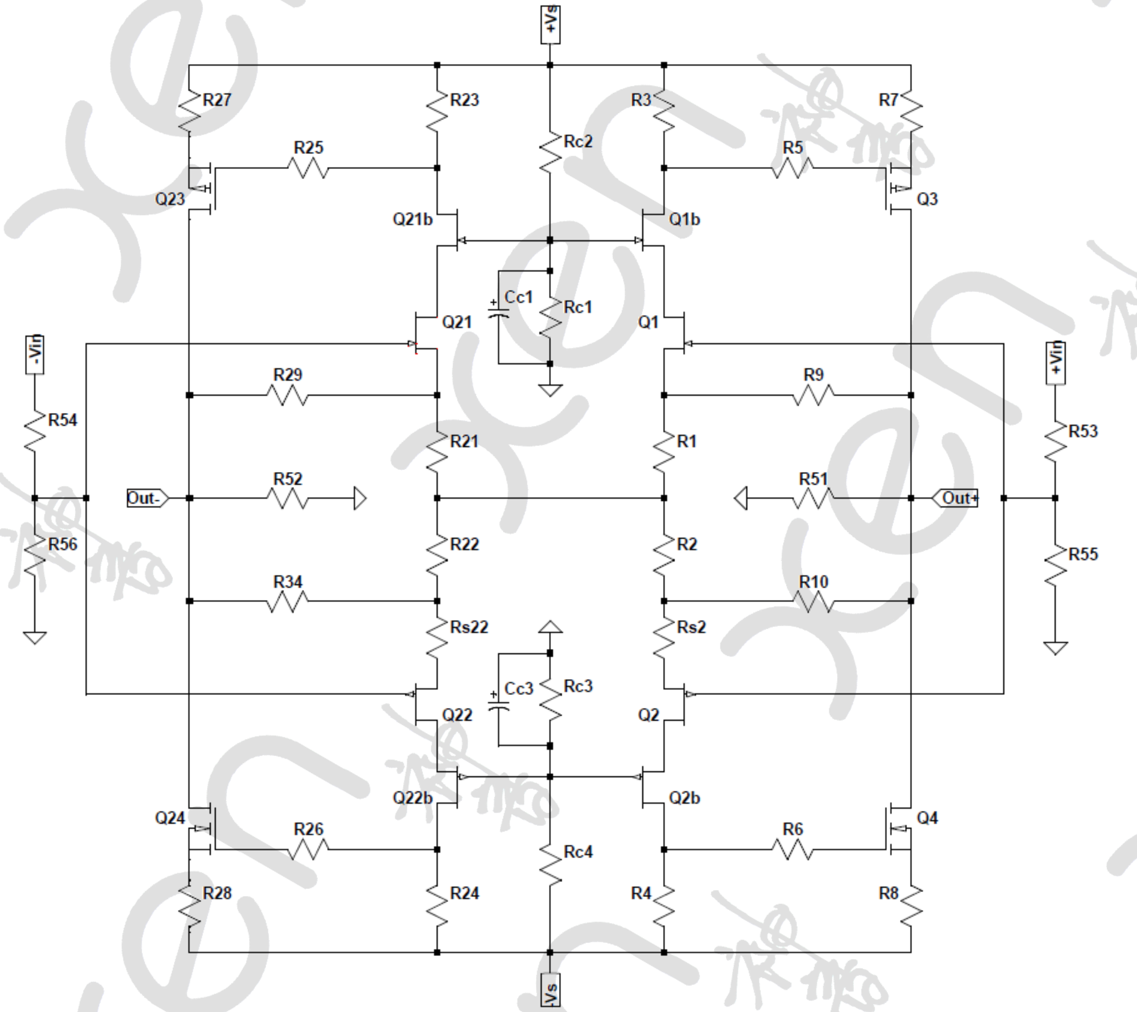
Again, as in the F5X power amplifier, the input stage can operate with or without cascode, and the PCB is also designed to support both. Having said that, simulations appear to suggest that there is no significant performance difference in both, so the final decision will again have to be made by listening tests.

The basic circuit is shown here with JFET cascodes. One can of course use low-noise bipolar devices (e.g. BC550C, BC560C) for the cascode devices instead, if the JFETs are too difficult to get. Component values are deliberately left out, as this is still work in progress and hence subjected to changes during the test phase.

As a first attempt, we believe it is possible to do away with any servos by good thermal coupling between the devices. Even if these were proven necessary, this can be added as a daughterboard to the main circuit PCB, thus not compromising the simple, symmetrical layout of the latter.

Some more target specifications :

Bandwidth	> 600kHz
Closed Loop Gain	approx. 20dB
Output impedance	approx. 10 ohm
Distortion (Balanced)	2^{nd} <80dB, 3^{rd} <90dB, 4^{th} <140dB at 4Vrms output (full swing for F5X)
	2^{nd} <100dB, 3^{rd} <120dB, 4^{th} <150dB at 0.35Vrms output (normal listening)



F5X Preamplifier Basic Circuit Topology

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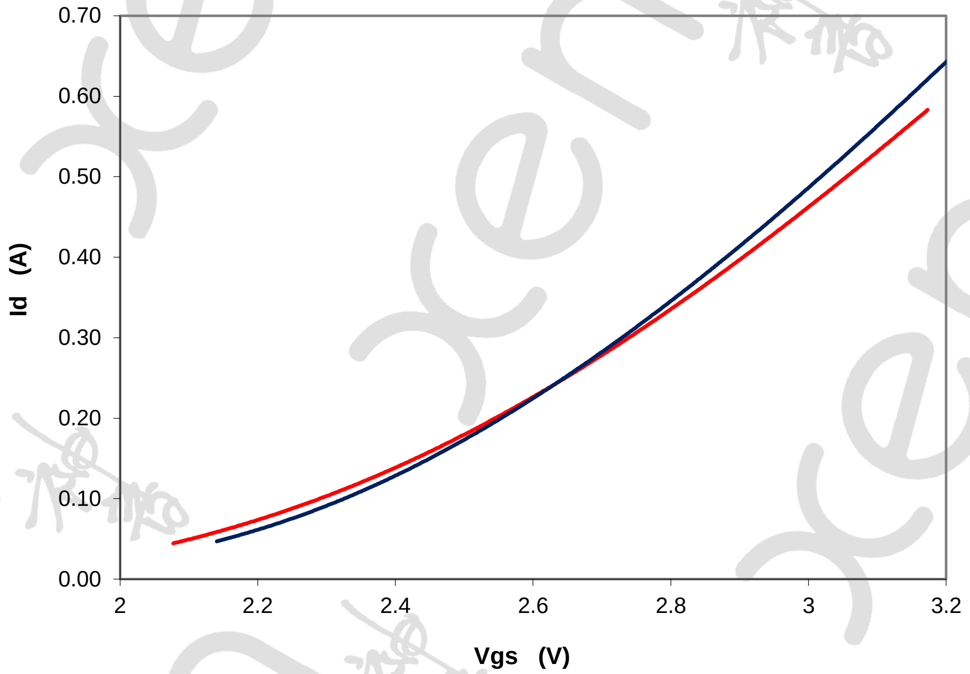
Active Devices

The first question that would be asked is undoubtedly, could we use some other JFETs like 2SK246BL/2SJ103BL instead of the unobtainium 2SK170BL/2SJ74BL for the input stage ?

The 2SK246 / 2SJ103 are no doubt easier to get. They are somewhat noisier, but have much lower capacitances and higher voltage capability. The major performance difference is, however, their low transconductance. This is particularly problematic when it is required to drive low impedance feedback networks to achieve a high bandwidth. As we shall show later, there are ways around to achieve our target bandwidth, at the expense of higher 2nd harmonics at each of the single ended output, as well as lack of current driving capability. One can of course argue that the 2nd harmonics would be much better in balanced mode, due to the even harmonic cancellation. But performance is still significantly better using 2SK170/2SJ74. So the latter will remain baseline for our project implementation, and we shall only publish simulated schematics at a later date using 2SK246/2SJ103, for the purpose of stimulating discussions.

For the second stage, there are a couple of popular TO220 devices that come into consideration. At first sight, the 2SK2013/2SJ313 complementary pair appears to be idea – low capacitances, relatively high transconductance, useable up to 500mA, and according to datasheet truly complementary. To be sure, we performed our own measurements of 5 random samples of each, at working temperature (say 40°C). The results are illustrated as follows :



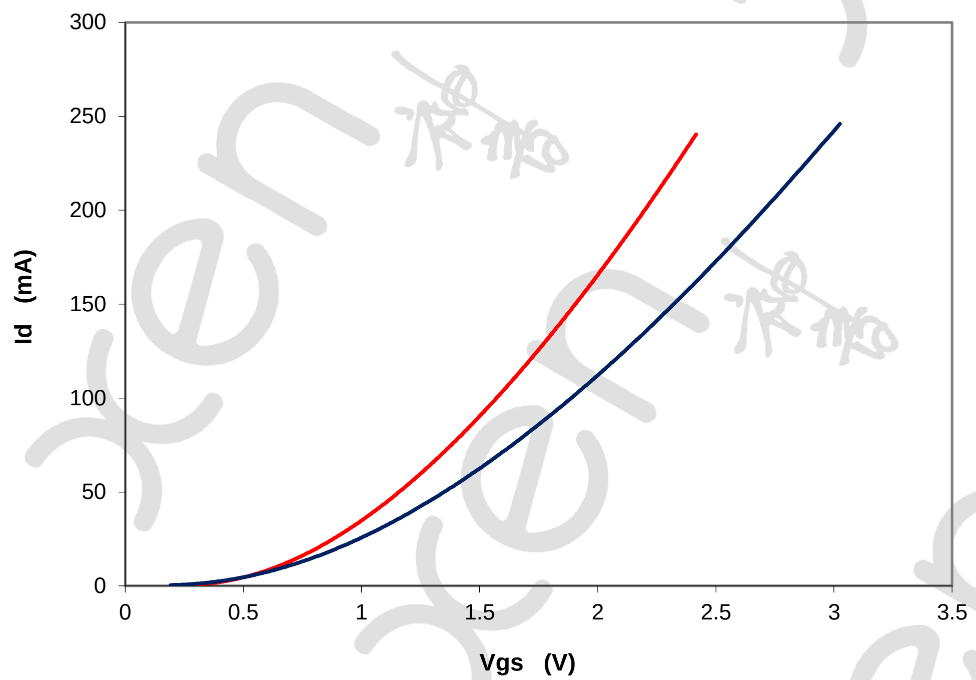
Id vs. Vgs for 2SK2013 / 2SJ313
(2SK2013 in red; 2SJ313 in blue)

As one can see, at least under operating conditions, they are not quite as complementary as the datasheet suggested. Also, they showed quite large variations between devices, both in Vgs and in transconductance, making matching difficult. On top of that Toshiba has already announced end of line for these (and other) audio devices, so they are increasing difficult to get.

As an alternative, we took a serious look at the 2SK214/2SJ77 from Renesas (Hitachi spin-off). They appear to be still active products. Charles Hansen of Ayre has commented that they have much lower capacitances, but more importantly, much lower non-linearities with their capacitances than comparable vertical FETs, even though their transconductances are also relatively low. In addition, they have a slightly negative tempco at Class A bias, thus enhancing their bias stability.

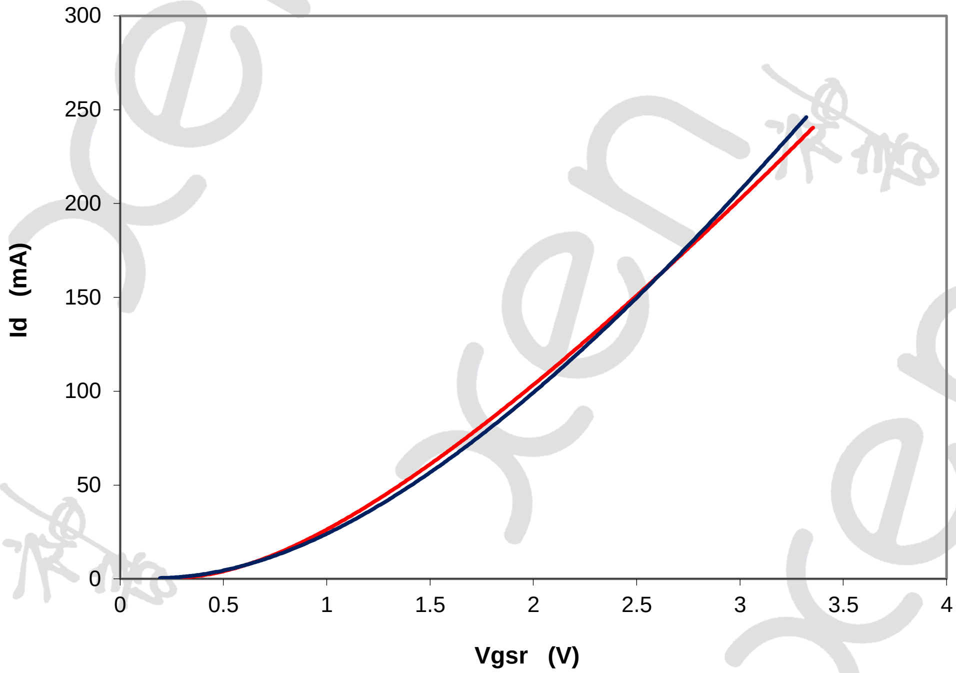
So in the baseline design, we have taken the decision to use them instead of the Toshiba devices. We do want to maintain the capability to drive a low-impedance feedback loop, without sacrificing bandwidth and distortion. After numerous iterations of optimisation, we believe we have reached a good solution. The loop feedback is a healthy 26dB, which we consider sufficient for a (largely) resistive load. Bandwidth (-3dB) is well over 1MHz, and all other major specifications can be reached.

As with the Toshiba devices, the Renesas FETs are also not truly complementary. Thus , measures have to be taken in circuitry design to take care of this to keep even harmonics low. Their measured characteristics at working temperature are shown below :



Id vs. Vgs for 2SK214 / 2SJ77
(2SK214 in red; 2SJ77 in blue)

Once we know the characteristics under working conditions, we can apply the source resistor compensation. For example, if we use a 3.9R source resistor for the 2SK214, and a 1.2R source resistor for the 2SJ77, we can get them to match very closely :



Id vs. Vgs for 2SK214 / 2SJ77 with R source Compensation
(2SK214 in red; 2SJ77 in blue)

As opposed to the Toshiba devices, the Renesas lateral FETs showed much less variations between devices from the same batch.

The default design is based on a 1st stage bias of around 6.5mA, and a 2nd stage bias of around 80mA. The exact value is not so critical, and can vary from say 3mA to 8mA for the first stage, and from 70mA to 120mA without noticeable difference in performance. In general, a lower front end bias together with a higher 2nd stage bias results in more negative feedback and hence lower distortion and lower output impedance.