UDNeSS
XEN Audio
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UDNeSS stands for "Yo**u** **D**on't **N**eed **S**emi**s**outh's" 😉

For almost a decade people have been trying to figure out the schematics of Nelson Pass's First Watt J2 power amplifier. Some clones were even built, and recently the schematics made public. All of a sudden, there is a new rush for these power JFETs, jacking up ebay prices for >60% over one weekend.

Of course, the human nature is such that the more difficult to get, the more it becomes desirable. But this becomes treasure hunting rather than enjoying a hobby. So we took on the challenge to see if one can get close to the J2 without using any unobtanium parts.

The disclaimer first. We do not have the original J2 schematics. We have not seen or listened to a real one. And our information all comes from the public domain, like measurements by Stereophile, or publications from Nelson himself. So whatever we have to say here about the J2 is pure speculation without proof.

Having said that, we published a couple of Spice files, for discussion's sake, at the J2 thread. And Nelson was kind enough to suggest that they "look fine" [1]. So our analyses here is based on those schematics, which is of course not the real J2. So let's make life simple by calling the former SJJ, or Speculated J2.

But enough for disclaimers. The topology of the J2 is quite typical in simple opamps. You can find something very similar in the Pass "DIY Opamp" article [2], in the Borbely EB602 [3], or the First Watt Aleph J [4].

Especially in the Aleph J, the output device is loaded with the "Aleph" modulated current source (MCS), forming a single-ended push-pull circuit. In the J2, Nelson chose to use a mu-follower as MCS instead. This is also quite similar to the modulated current source published towards the end of the EB602 thread. While the latter uses the Vbe of a simple BJT to control the output stage bias, this is done in the J2 with the Vf of the LED in an opto-coupler.

Analysing the SJJ in detail, one can see that the open loop gain OLG is about 51dB with a 8 ohm load, giving ~30dB negative feedback (NFB) at 10x closed loop gain. The OLG is of course load dependent. You will lose another 6dB with a 4-ohm load, for example. The real nice part is that the -3dB bandwidth of the OLG is close to 20kHz. So the distortion level is constant over the entire audio band, as opposed to most modern audio opamps. In trying to emulate the same, these become the key design criteria.

The EB602-MCS can be looked at as a SJJ with reversed polarity for the supply rails, as well as active devices. This is advantages, as NJFETs are still easily available and one can avoid the other unobtanium – 2SJ109 or 2SJ74 matched pair for the input stage. But that would mean using P-channel FETs for the output devices. The SJJ performance owes a lot to the high transconductance of the SJEP120R100, but not the least also its almost zero tempco. While there are high-transconductance P-MOSFETs such as 2SJ618, these are also now unobtanium. On top of that, their very high tempco makes life somewhat difficult to maintain bias stability of the driver device. That in the modulated current source is stabilised automatically by the opto-coupler.

A good P-channel output device is the Renesas 2SJ162 lateral MOSFET, or its Exicon equivalents. This has a Vgs at (1.2A) bias not far from the Semisouth's. And it has a negative tempco at that current range, so that it is essentially self-stabilising. The problem is its low transconductance, about 1/6 of that of the Semisouth. Unless you use 6x matched laterals as a substitute. It will then become almost as expensive. One can recover the lost gain in the second stage by increasing that of the first stage, by replacing the drain resistor of the LTP with a current mirror. But the OLG characteristics now becomes more like an opamp again, with lots of NFB at low frequencies, but dropping continuously beyond the corner frequency, usually quite low at 10~100 Hz.

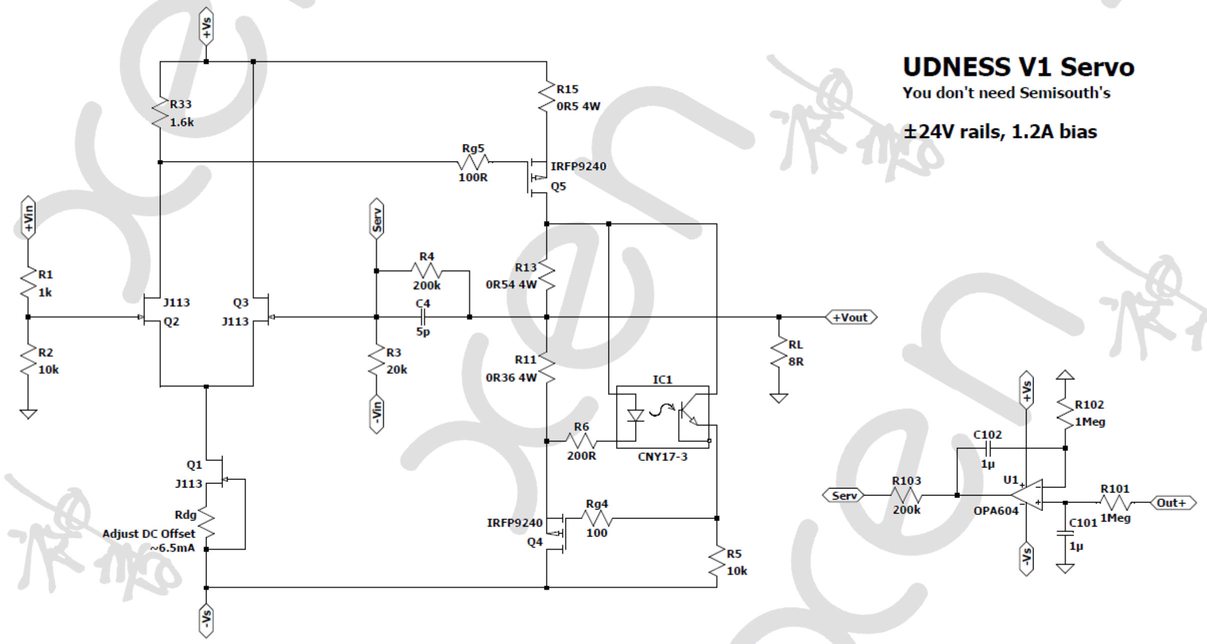
After a lot of considerations and simulations, we finally settled on the old faithful IRFP9240 instead. Its transconductance is not way off from the Semisouth, and this is largely recovered in the increased first-stage gain due to the 4x higher Vgs of the IRFP. Simulations also suggest that the J113, proposed recently by Nelson as a substitute for 2SK170, can be deployed adequately for the LTP. Thus, all the active devices are readily available at costs below 2 USD. Quite far from 400 USD for 4 (unmatched) SJEP120R100's. With these devices, we have been able to achieve pretty much the same performance in both open and closed loop as the SJJ in simulation. Even with slightly better phase margin (Appendices A & B).

What are then the drawbacks ? Firstly, the IRFP9240 also has a positive tempco. Not as bad as the 2SJ618, but still bad. There are a few known methods for taming that, but eventually we chose the simple solution of a DC servo. As already mentioned, the PMOS in the MCS is already stabilised by the optocoupler. We only need to servo to control the DC bias of the driver PMOS.

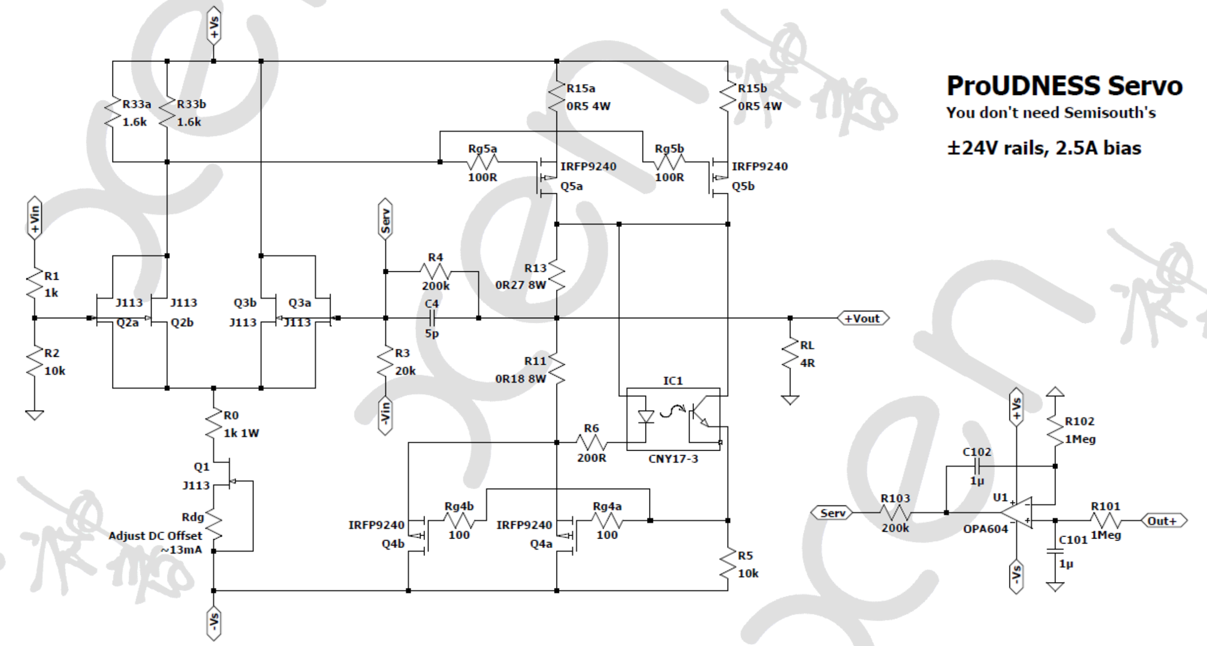
On top of that, both the J113 and the IRFP240 are noisier in comparison. But then they are still parts favoured by Nelson, so they cannot be so bad in power amp applications.

Since the devices are low cost now, we can use 2x in parallel everywhere, to improve its performance in driving low-impedance loads. This has been mentioned in the Stereophile review as the major weakness (if it can be so called) of the FW J2. Now you won't need another 400 USD to cure that. And the noise also goes down by 6dB. We took the liberty to call it ProUDNeSS. 😉

So is it now 90% of the performance at 10% of the cost? We don't have a FW J2, so we'll never known. Unobtaniums are exclusive, so there must be magic. But for the budget involved, I bet it will take a lot of beating.



Proposed Schematics for UDNESS with DC Servo

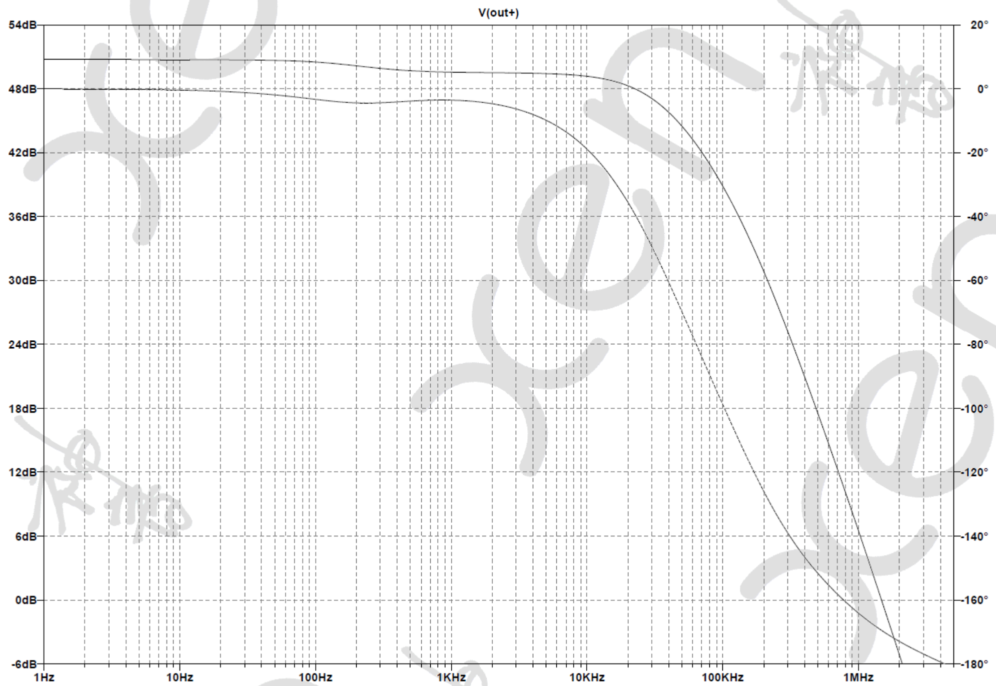


Proposed Schematics for ProUDNESS with DC Servo

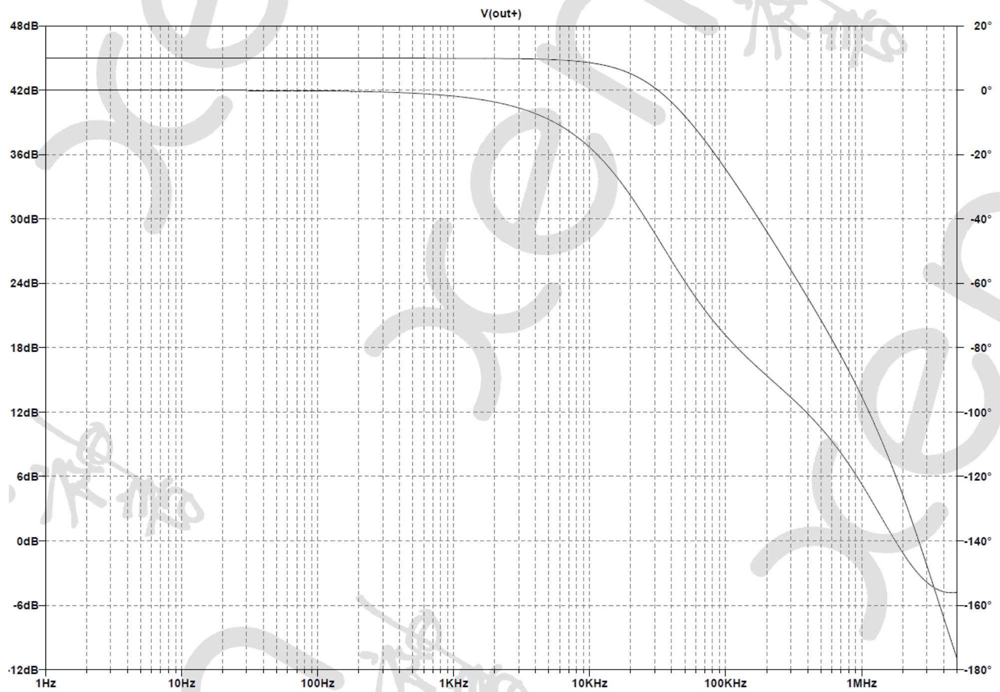
References

1. https://www.diyaudio.com/forums/pass-labs/151909-firstwatt-j2-26.html#post5892862 (post #1271)
2. https://www.passdiy.com/pdf/diyopamp.pdf
3. https://www.diyaudio.com/forums/headphone-systems/325163-borberly-eb602-200-revisited.html
4. https://www.diyaudio.com/forums/pass-labs/224881-aleph-universal-mounting-spec.html

Appendix A



Open Loop Frequency Response of the SJJ with 8-ohm Load
(Upper Curve -- Gain, Lower Curve -- Phase)



Open Loop Frequency Response of the UDNeSS with 8-ohm Load
(Upper Curve -- Gain, Lower Curve -- Phase)

Appendix B Simulated Distortion Spectrum at 1W

SJJ Output FFT

Input +/-0.2V, 1kHz 8 ohm Load

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	3.859e+00	1.000e+00	-0.42°	0.00°
2	2.000e+03	1.189e-03	3.082e-04	85.41°	85.83°
3	3.000e+03	9.784e-05	2.535e-05	14.85°	15.27°
4	4.000e+03	5.110e-06	1.324e-06	-91.09°	-90.67°
5	5.000e+03	1.448e-06	3.752e-07	-93.83°	-93.41°
6	6.000e+03	1.340e-06	3.471e-07	-73.14°	-72.72°
7	7.000e+03	1.445e-06	3.744e-07	-62.78°	-62.36°
8	8.000e+03	1.412e-06	3.658e-07	-58.74°	-58.32°
9	9.000e+03	1.303e-06	3.375e-07	-61.33°	-60.91°

Total Harmonic Distortion: 0.030923%(0.034573%)

UDNeSS Output FFT

Input +/-0.2V, 1kHz 8 ohm Load

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	3.770e+00	1.000e+00	-0.23°	0.00°
2	2.000e+03	1.003e-03	2.661e-04	-119.68°	-119.45°
3	3.000e+03	1.016e-04	2.696e-05	38.35°	38.58°
4	4.000e+03	6.777e-06	1.798e-06	26.00°	26.23°
5	5.000e+03	1.905e-06	5.054e-07	-92.58°	-92.35°
6	6.000e+03	1.222e-06	3.243e-07	-78.22°	-77.99°
7	7.000e+03	1.202e-06	3.189e-07	-71.25°	-71.03°
8	8.000e+03	1.206e-06	3.199e-07	-68.84°	-68.62°
9	9.000e+03	1.213e-06	3.218e-07	-66.08°	-65.85°

Total Harmonic Distortion: 0.026747%(0.031750%)

ProUDNeSS Output FFT

Input +/-0.14V, 1kHz 4 ohm Load

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	2.639e+00	1.000e+00	-0.29°	0.00°
2	2.000e+03	4.706e-04	1.783e-04	-116.34°	-116.05°
3	3.000e+03	3.575e-05	1.355e-05	40.90°	41.19°
4	4.000e+03	1.515e-06	5.740e-07	18.64°	18.94°
5	5.000e+03	6.295e-07	2.385e-07	-73.94°	-73.65°
6	6.000e+03	5.753e-07	2.180e-07	-61.67°	-61.38°
7	7.000e+03	5.839e-07	2.212e-07	-59.63°	-59.33°
8	8.000e+03	5.853e-07	2.218e-07	-55.43°	-55.14°
9	9.000e+03	6.274e-07	2.377e-07	-49.97°	-49.68°

Total Harmonic Distortion: 0.017881%(0.022929%)