Sony VFETs in Push-Pull Class A

Part 2: Common Drain Mode

by Nelson Pass

This article is the second of a series presenting “Do-It-Yourself” audio power amplifiers using Static Induction Transistors (SITs), also known as VFETs. These are unusual transistors with a characteristic similarity to Triode tubes.

Rather than recapitulate much of what I have already written about these devices, I refer you to previous articles linked below. I recommend looking at these for background material.

2011 SIT Introduction

2012 SIT Nemesis

2013 Sony VFET 40 Year Commemorative Amplifier

2014 Sony VFETs Part 1

2011 SIT-1 Owner's Manual

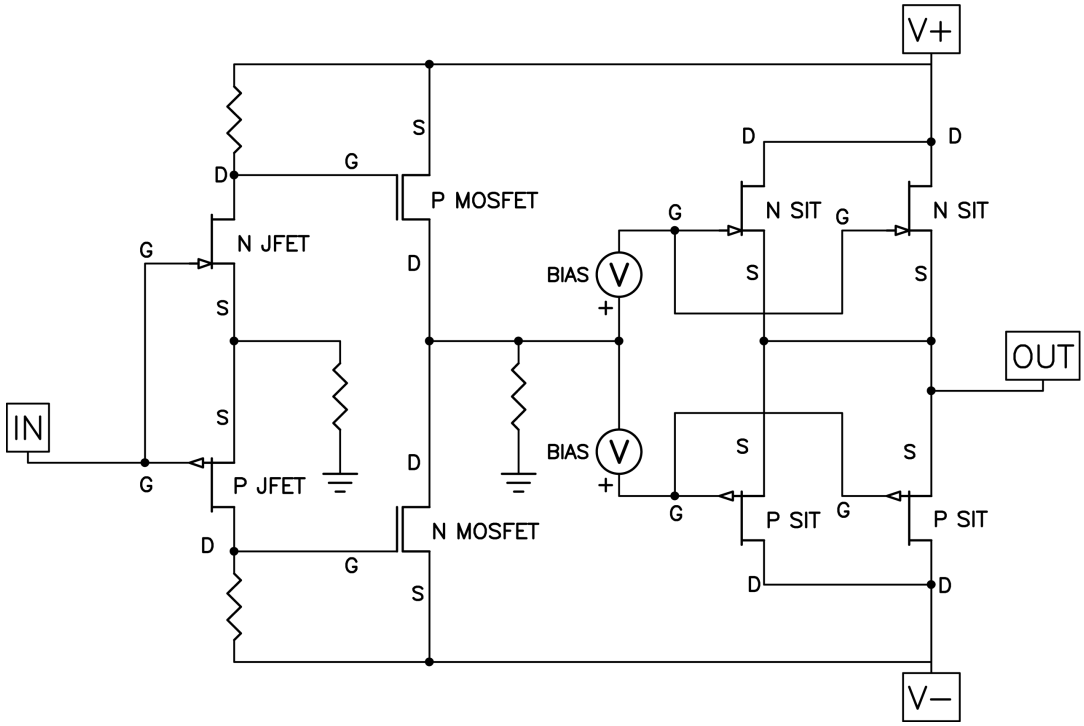
2011 SIT-2 Owner's Manual

The most recent of these, Part 1, is a simple DIY amplifier having just three components – two transistors and a transformer. It is very simple to build, although it requires four regulated power supplies. It operates in *Common-Source* mode, in which the gain transistors develop both voltage and current gain. Part 2 shows VFETs operating in *Common-Drain*, or follower mode.

This amplifier is more complex than Part 1, and has many more components. It can be regarded as the smaller brother of the *Sony 40 Year Commemorative Amp* with fewer parts and less power, however we will be adding a couple of interesting wrinkles, including local *Cascode feedback,* operation with and without global feedback, and also a modulated supply regulation scheme.

It is designed as a DIY project, and as of this writing you can still obtain the VFETs from CircuitDIY.com in Singapore, but probably not for too much longer.

Here is a simplified diagram of the circuit:



If you have absorbed the contents of the previous articles, you probably have a good picture of what is going on. To make it a little easier, I have identified the generic part types, and also the pin names: Drain, Source and Gate. You can see the input and output points, and also the two voltage sources used create the DC Gate voltages that set the output transistors to the desired bias current.

When we talk about bias we are referring to the voltage and/or current that set the operating point from which they can amplify without a lot of distortion.

Proper bias conditions are crucial to low distortion.

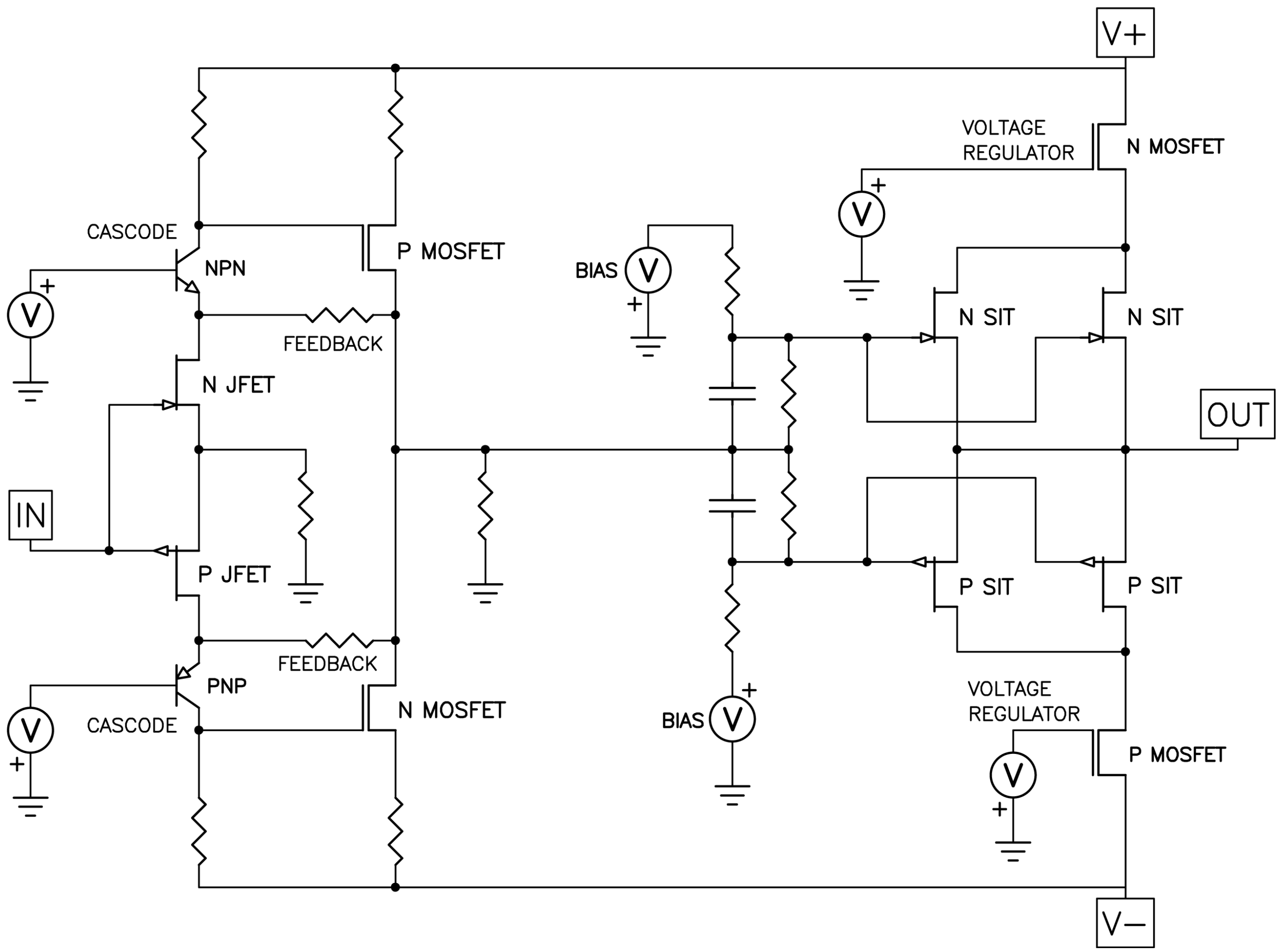
Coming from the left, the input drives the Gates of a complementary pair of JFET signal transistors in *Common Source* mode. These two devices are *depletion* type Fets which will “self-bias” to a current of 8 milliamps or so.

The current through the input Fets develops voltage at their Drains to create the signals that drive the second stage, which is a complementary pair of MOSFETs in *Common-Source* mode also, with their Drains tied together at a point where the entire voltage gain of the amplifier can be seen. This point drives the Gate pins of complementary VFETs in Common-Drain (follower) mode, and they provide the current gain which drives the loudspeaker.

The output bias circuits supply negative DC voltage to the N type VFETs and positive to the P types. VFETs are also *depletion* mode parts, where current likes to flow with 0 volts input, and the bias circuit is like using a brake pedal. Most MOSFET parts are *enhancement* mode parts, and have to be encouraged to conduct; the bias circuit in their case is more like an accelerator pedal.

If the transistors involved were more perfect, then we could just stop there. But of course they are not, and as with most other amplifiers, lots of circuitry is employed trying to overcome the flaws of the gain devices.

Here is a slightly more complex version of the circuit:



On the left side, the voltage gain stage, we can see new elements. We have *degenerating* resistors in series with the Source pins of the MOSFETS to lower the gain and stabilize the bias current against temperature drift. We have also introduced *Cascode* transistors for the input JFET devices and biased them with some constant voltage sources, and we have also introduced local *Cascode feedback* to linearize the gain and lower the output impedance of the front end.

Cascoding is a very useful technique which shields the gain devices from the consequences of the voltages that appear on their Drain pins. In this case it limits the Drain-Source DC voltage seen by the JFETs and their heat dissipation, and also reduces the gain modulation caused by AC and DC variations seen by the input devices.

You can read more about Cascoding here: [1978 Cascode Amplifiers]

Cascoding also gives us a simple means of applying local feedback to the second stage by providing a convenient *summing junction* from the Drains of the MOSFETs to the Emitters of the Cascode transistors. I named this *"Cascode feedback"*, and first employed it in the Xs amplifiers from Pass Labs.

It is most useful for applying modest amounts of local Drain-Gate feedback without degrading the power supply rejection (PSRR) of the stage. This is a simple case, where the front end starts out with a gain of about 26 dB, and after the application of *Cascode feedback* we see get 16 dB, for a feedback factor of about 10 dB. Being modest and very local, it is also very stable.

There are numerous variations and lots of little tricks, and besides lowering the output impedance of the front end, it is convenient and effective for reducing and tweaking the specific distortion character of the circuit, as the positive and negative halves of the circuit can be adjusted independently.

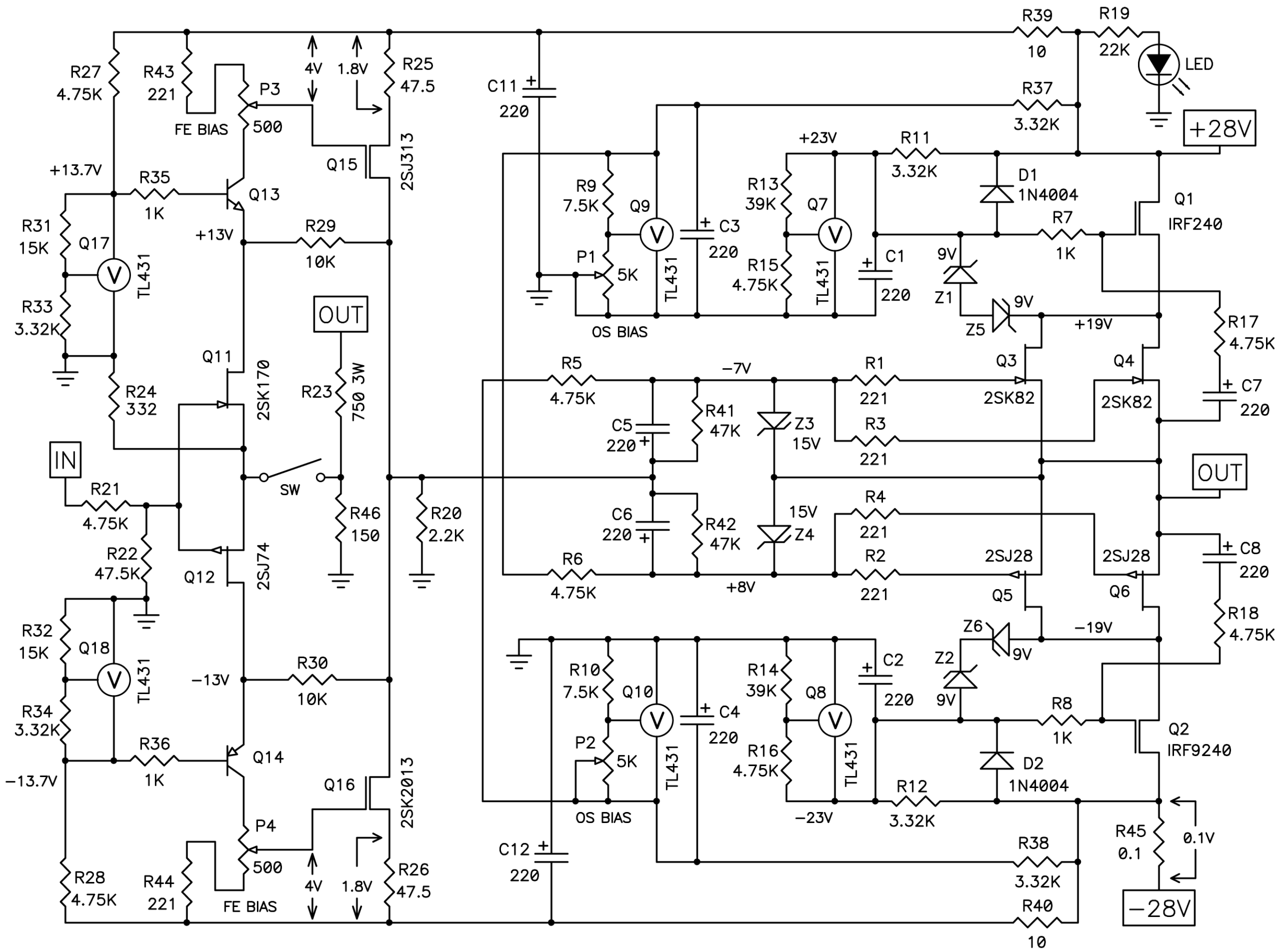
So far we have only seen arrangements where all the feedback (such as it is) is local to individual elements of the amplifier, mostly the ratios of the various resistors in the front end. Later we will see arrangements for global feedback.

On the right hand side of the drawing we will see more details about the output stage. More specific bias circuitry shows that the bias voltage is actually referenced to ground, and the Gates of the VFETs are coupled to the voltage gain stage through parallel RC circuits.

Of more interest, the output stage has acquired power voltage regulators, which keep the voltage seen on the Drains of the VFETs at known quiet DC value. The reason for this is simple; the VFETs have a low Drain impedance. That means that any power supply variation or noise will go through the Drain to Source channel to the output. We don't need any of that, and if we had it we would be forced to employ negative feedback to correct it.

The power supply regulators are simply constant voltage sources driving big power Mosfets as followers. Very simple, works like glue.

OK, gird your grid for the big one:



If this looks intimidating, remember that its simply a detailed look at the sub-circuits we have seen already, each of them relatively simple.

Let's look at them individually:

The input transistors Q11 and Q12 are the Toshiba JFETs 2SK170 and 2SJ74, no longer made, but can be substituted by LSK/LSJ versions from Linear Systems without problems. These are matched for Idss values of about 8 mA, Idss being the current that flows when the Gate and Source voltage are equal. The Sources of the input devices do not have *degenerative* resistance between each other, so they will run at this current.

The input Gates look at the signal through a 4.75K resistor, which provides some input radio frequency filtering when loaded by the input capacitance of the JFETs, and also some protection from high voltage input transients.

The current through the JFETs and the Bipolar *Cascode* transistors develops about 4 volts across R43 + P3 on the positive side, and R44 + P4 on the negative side. Potentiometers P3 and P4 are adjusted so that the nominal voltages across R25 and R26 is 1.8 volts DC and the Drain output voltage of Q15 and Q16 is near 0 volts. The 1.8 volt figure makes for about 1 watt dissipation in these transistors, and so they need a decent little heat sink.

Q15 and Q16 develop the full voltage gain of the amplifier. You will notice R20 which is a load to ground from the Drains of Q15 and Q16. R5, R6, R29 and R30 provide some additional AC loading to ground, and all told, the output front end sees slightly less than 1K to ground. These help set the gain of the front end along with R24, R25 and R26 and also R43/P3 with R44/P4.

Now we want to take a look at all the regulators. I have sprinkled TL431's around the circuit like the “happy little trees” in a Bob Ross painting.

On the front end, we see TL431 shunt regulators which have an internal 2.5 volt reference. In the example of Q17, the regulated voltage will be 2.5 * (R33+R31) / R33. In this case the math comes out 2.5*(3320+15000)/3320 = 13.79 volts. The TL431 doesn't invent the electricity to do this - it receives power through R27, and requires a milliamp or so to work. In this case 4.7 Kohms for R27 gives it about 3 mA, which is plenty.

And so it goes with all the other regulators, although their resistor ratios and output voltages will be different. You will see that some of them have capacitors in parallel. In the case of Q7 and Q8 we want them to come up to voltage slowly because we want other stuff like the front end to be working by the time significant voltage is available to the output transistors. For Q9 and Q10 the capacitor avoids the regulator introducing any distortion into the signal path.

Q1 and Q2 are just big fat power MOSFETs which follow the voltage sourced by Q7 and Q8 respectively. As previously mentioned, the VFETs are sensitive to power supply variations. Fortunately these MOSFETs are relatively insensitive to power supply noise and variations, having a very “Pentode” characteristic in which the current through the transistor is much less dependent on the voltage from the Source to Drain pins. Actually Q1 and Q2 *Cascode* the output VFETs.

You will see some diodes and Zener diodes in the output stage. D1 and D2 are there to bleed off C1 and C2 on shut down. Without them a quick shut-down / turn-on cycle of the power supply might cause excessive current through the VFETs. Rare as VFETs are now, we don't probably want that.

Similarly there are Zener Diodes sprinkled around to protect the Gates of the power transistors from damage. Half-Watt Zeners at the nominal voltages called out will be just fine. I have run the amplifiers extensively without any of these diodes without problems, but I would not expect all amplifier users to observe the ordinary precautions. You can use your own judgment on this.

There is one other detail in the output stage regulation; R17/C7 and R18/C8 which bootstrap the *Cascode* power transistors with about a one-sixth version of the output waveform so as to get a little more voltage swing at maximum and bring the output VFETs a little closer to the “sweet spot” of their load line curve.

The VFETs themselves have Gate resistors to avoid parasitic oscillation.

Almost forgot - there are two basic operating modes for this amplifier, and you can try them both if you like.

If you set R24 at 332 ohms and leave R23/R46 out, the amplifier will have no global feedback (only local) and deliver gain of about 16 dB. If you switch in R23 and R46, it will still have 16 dB of gain, but about 3 times the damping factor and one-third the distortion, corresponding to about 10 dB of global feedback. You can operate the switch while the amplifier is running. These gain resistor values are nominal; you are free to vary them within reason.

Construction Notes:

You will not see schematics for the power supply here. I used an ordinary First Watt type supply design, documented elsewhere, with 22 VAC transformer secondaries to provide +/-28 volts DC. 24 or 25 VAC will work fine, running a little hotter. The minimum recommended for this amplifier is +/-27 volts, but it will run OK with a little lower supply if you adjust the values of R13 through R16 for lower voltage. If the voltage is too low for good regulation, it will run fine but the bias will drop a bit.

You will note R45 which is a 0.1 ohm current sense resistor. When you are setting this amplifier up, you will want to monitor the current draw of the amplifier by measuring the DC voltage across this resistor. At 1 amp, the voltage will be 0.1 volts. When you are adjusting the amplifier, your eyes will not want to stray far from the voltmeter watching this value. Don't have a voltmeter? *Get one.*

Depending mostly on heat sinking, you will probably be running this amplifier between 1 and 1.5 amps bias current. Here I will document the performance with 1 amp bias. Ordinarily you would expect such a push-pull amplifier to leave

Class A at about 2 amps (32 watts peak), but as we have not used ballast resistors on the Sources of the output transistors they will enjoy a larger envelope for Class A operation. Later you will see a scope photo of the current draw, where the minimum current is about 100 mA at a 40 watt peak into 4 ohms, which indicates a Class A envelope of about 3 amps.

I used a First Watt chassis (you know, the ugly one), and it runs about 45 deg C. on the sinks with a 1 Amp bias. 1.5 Amps will get you to 55+ degrees, and you can try that if you want. I didn't find a large difference in performance between the two, but I already know that most DIYers deal in excess, so have at it.

I matched the VFETs for a Vgs within 0.1 volts at 0.5 amp current at 20 volts, and 0.2V Vgs is good enough. Some of you won't have good matches or only enough VFETs for 1 pair per channel, but you can build the amplifier and it will work fine, with somewhat less power and higher distortion. I tested that with 1 amp bias current, and it did just under 20 watts into 8 ohms.

The input JFETs are selected for Idss to within a milliamp or so at 8 mA. The Toshiba 2SJ313 and 2SK2013 give a consistent 2.2 Volts Gate-Source in this circuit, and the IR parts will come in around 4 volts Vgs.

There is nothing unusual regarding the construction of this amplifier. All the usual cautions and advice about building power amplifiers apply.

If you have questions which are not answered here I advise you to ask them directly or post them in the Pass Labs sandbox at www.diyaudio.com where you will find the residents friendly and helpful. That is my browser's home page, and I see it before I read emails in the morning.

Of course the best way to fire up the amplifier first time is with a Variac™ which adjusts the AC power up nice and slow while you watch the behavior. In particular you will observe the current draw across R45, keeping it below .1V DC and the DC offset voltage at the output near 0 volts. Also, you want to observe the voltage drop across R25 and R26 to make sure that too much current isn't going through the front end.

I initially set all the potentiometers to the midpoint, which is reasonably close. You can observe and adjust the front end alone before applying power to the output stage. To do this, you omit R11 and R12 so that the output stage gets no power. Then you can supply DC voltage to the front-end and bias systems to set them up first. Watch the DC voltages across R25, R26 and R20 and also the voltages on the Gates of the VFETs.

P3 and P4 should be adjusted until there is 1.8 volts across both R25 and R26 while the DC offset at R20 should be close to 0V. You have to tweak these pots iteratively to get this right, but it's not difficult.

P1 and P2 should be set to so that the DC values on the Gates of the VFETs are similar to those figures used to match them. Typical will be something like -8V on the Gates of Q3 and Q4 and +8V on Q5 and Q6. Set this a little higher initially as a precaution and increase the bias by decreasing the voltages later.

If you set the front end up first, then it should be pretty easy to enable the output stage by placing R11 and R12 in place, shutting off the power and letting it bleed down first, and then restoring power.

At this point you can start checking all the test points (R45, R25, R26, R20, and the output DC) and all the other voltages called out in the schematic. These values will drift a bit as the circuit warms up, so you will get to play with them iteratively, as they affect each other. I advise adjustments in half way steps.

All 4 pots will affect the DC offset at the output, but after the front end is adjusted to 0 V at R20 you *carefully* use P1 and P2 to set both current and offset on the output stage.

It takes a little while, but you have lots of time while the circuit warms up anyway. If you can get all the DC voltages right, it will probably play music.

Performance

The amplifier delivers 20 watts into 8 ohms and 40 watts into 4 ohms. You will notice from the curves that the distortion at various wattages is very similar between 8 and 4 ohms.

This amplifier is pretty happy with lower impedances.

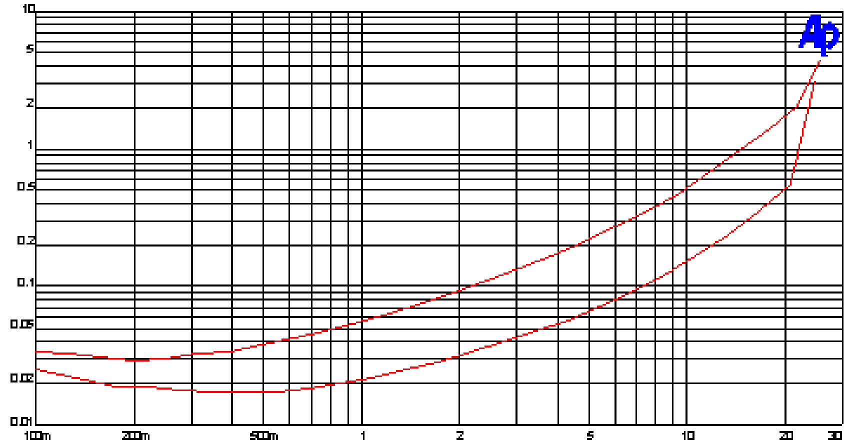
The response is down to unity at DC, and extends to 100 Khz at the top end.

Without feedback, the 8 ohm damping factor is about 18, and with global feedback it's about 65.

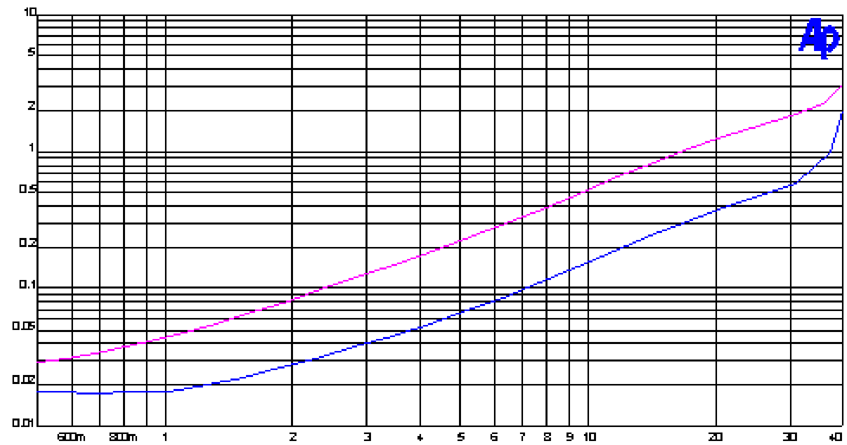
No thumps.

With good layout and no ground loops, you can expect about 50 microvolts of output noise.

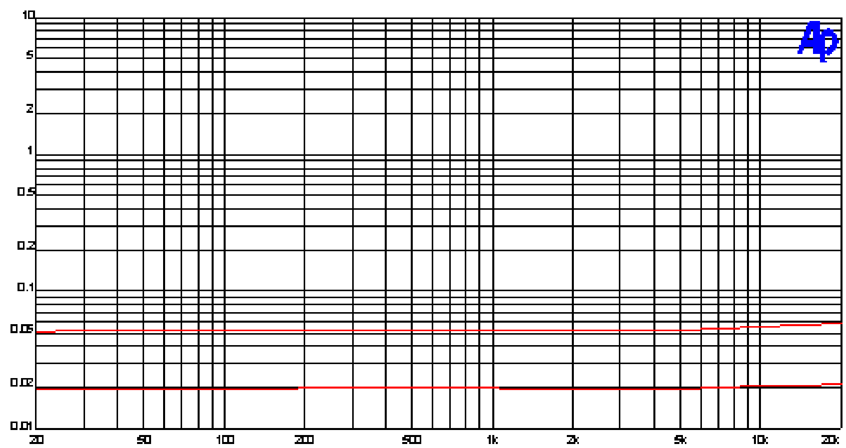
Here are the pictures worth a thousand words:



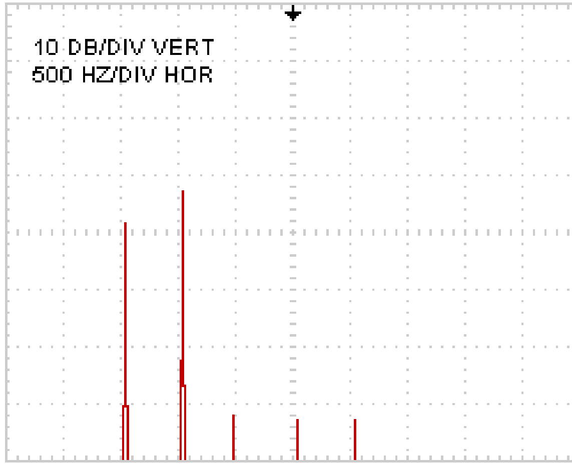
Harmonic distortion vs power at 500 Hz, 8 ohms, w/ and w/o feedback



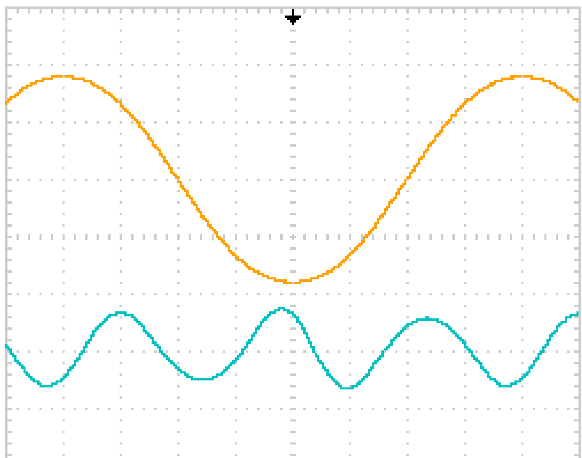
Harmonic distortion vs power at 500 Hz, 4 ohms, w/ and w/o feedback



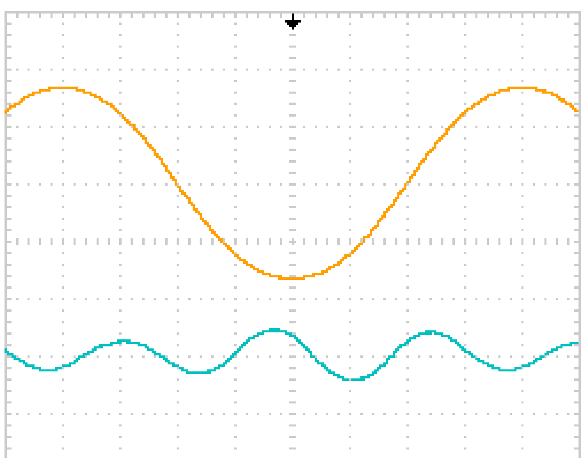
Harmonic distortion vs frequency at 1 watt, 8 ohms, w/ and w/o feedback



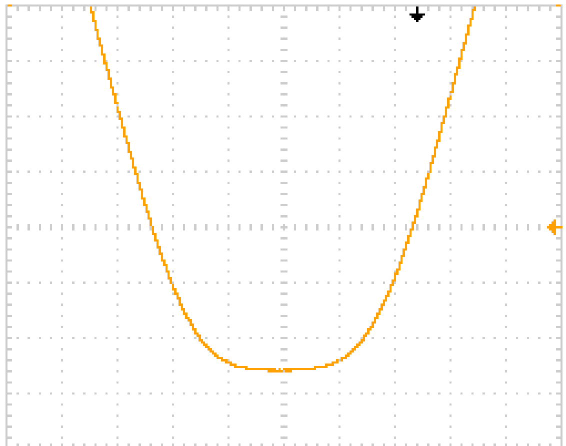
0.04% harmonic distortion spectrum at 500 Hz, 1 watt, 4 ohms, w/o feedback



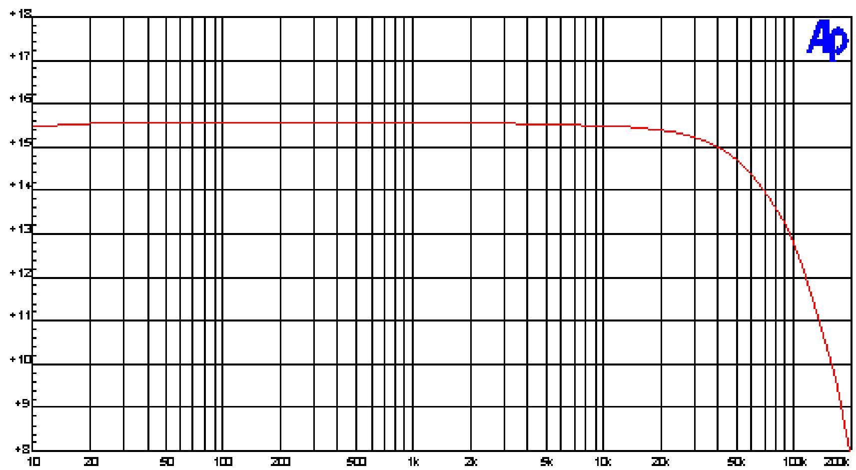
1.7% harmonic distortion waveform at 20 watts, 500 Hz, 8 ohms, w/o feedback



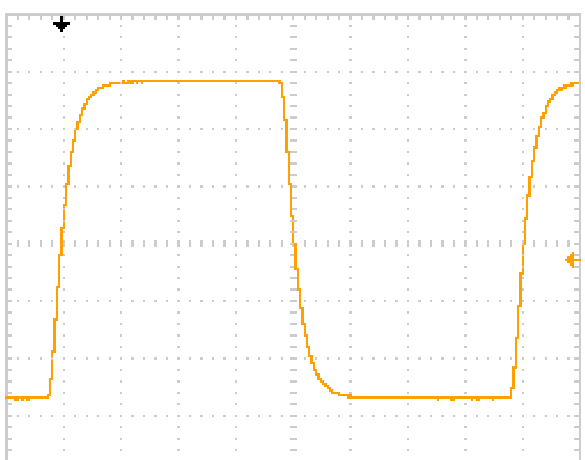
2% harmonic distortion waveform at 35 watts, 500 Hz, 4 ohms, w/o feedback



Current through positive output stage while the negative output stage delivers 3 Amps peak (40 watts peak @ 4 ohms). The minimum current is 0.1 Amps

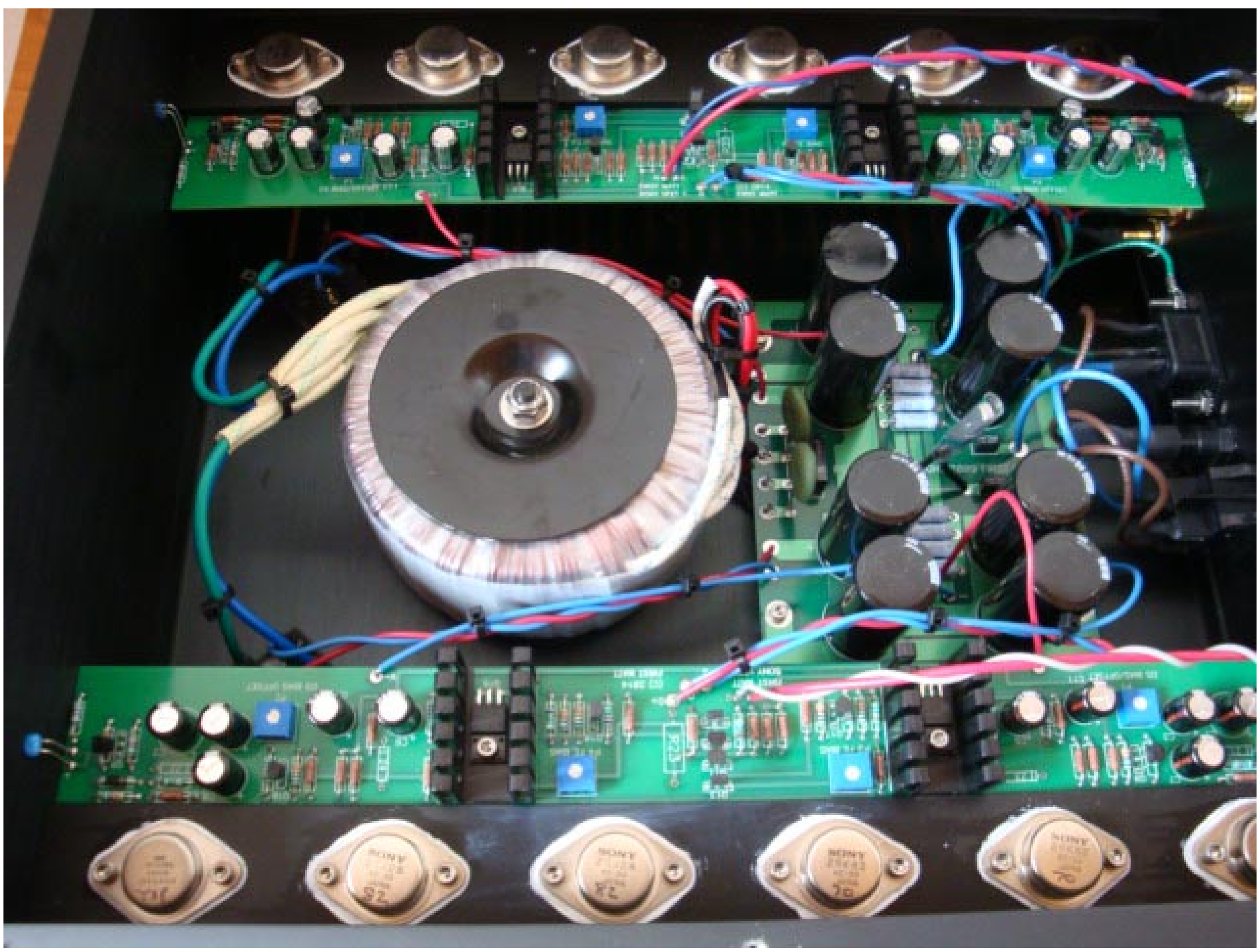


Frequency response of the amplifier, -3 dB down just above 100 Khz



50 Khz square wave at 2 watts into 4 ohms.

And the money shots:



Some people insist that an amplifier should have no sound of its own. I don't agree particularly; every amplifier is different, it's only a question of how much you can hear. In any case, I enjoy the differences – that's what entertains me.

When I first began working with VFETs / SITs the Triode character of the parts encouraged me to start with single-ended Class A designs, an approach which promised to best play to their strengths. This remains true, I think.

But the big Sony VFET amp project showed that they have something to bring to the table with push-pull topologies as well. They are surprisingly dynamic sounding (perhaps due to their mostly third harmonic nature) but like the single-ended versions, they deliver subtle detail while remaining what I would call "sweet", that is to say warm and extended at the top end. The single-ended pieces can easily be made to have greater apparent depth, but the push-pull approach gives a little more clarity. Both reveal musical details with ease.

If you like a more neutral character to your sound, just kick in the feedback and these effects will be come more subtle. I would say that it's just a matter of taste.

Here's the amp playing into my newly unpacked Cathedrals.