DIY SONY VFET AMPLIFIER

Part 1 - Single-Ended Common Drain Mode

by Nelson Pass

Introduction

This article is the first half of the most recent in a series presenting DIY audio power amplifiers using Static Induction Transistors (SITs), aka VFETs. These are special field effect transistors with a characteristic similar to Triode tubes.

I recommend these articles for more detailed background:

2011 SIT Introduction

2012 SIT-1

2012 SIT-2

2012 SIT Nemesis

2013 Sony VFET 40 Year Commemorative Amplifier

2013 Sony VFETs Part 1

2014 Sony VFETs Part 2

2016 DIY Sony VFET

2018 SIT-3

Some of these projects are push-pull with complementary SITs operated in both Common Drain (CD) or Common Source (CS) modes. You will also see single-ended designs using just one SIT, also in either CD or CS modes. In CD the transistors are followers, where the output voltage is nearly the same as the input but with current gain. In CS they have both voltage and current gain.

VFETs have a lot of “personality”. Where regular transistors are dominantly controlled by voltage and current between the Gate and Source of a FET (or Base to Emitter current for Bipolars), with VFETs there is also a very significant influence of the voltage from Drain to Source, much like a Triode tube.

This allows for interesting effects, and also strongly guides the design approach. The VFET is a *prima donna* that enjoys Class A operation and is very particular about the load lines, but compensates with extraordinary sonic performance.

About 10 years ago the research head of Semi-South invited me to have a custom batch of state-of-the-art SITs made with the new SiC (Silicon Carbide) process, and while very expensive it turned out to be one a very good deal. These SIT-1 transistors were employed to good effect in three First Watt amplifiers, imaginatively named the SIT-1, 2 and 3.

Shortly after I starting working with the SIT-1's, a helpful diyAudio member alerted me to the existence of a supply of Sony VFETs sitting in Singapore. These were original parts used in amplifiers and receivers from the '70's and into the the '80's by Sony. I bought much of this stock (leaving a generous quantity for DIYers...) and created the “Sony VFET 40 Year Commemorative Amplifier”. It was a three-stage balanced complementary Common-Source design at 100 watts, and six channels were made, four of them gifted to Sony. This was followed by three DIY versions, two of them complementary push-pull followers (CD) and one a complementary push-pull CS.

I now have about 180 each left of the 2SK82 N channel and 2SJ28 P channel VFETs, and I have chosen to use them in a DIY Single-Ended Common Source version. One reason I picked this approach was that the performance of SITs in single-ended Class A shows off the qualities of the devices, but also allows construction of twice as many amplifiers.

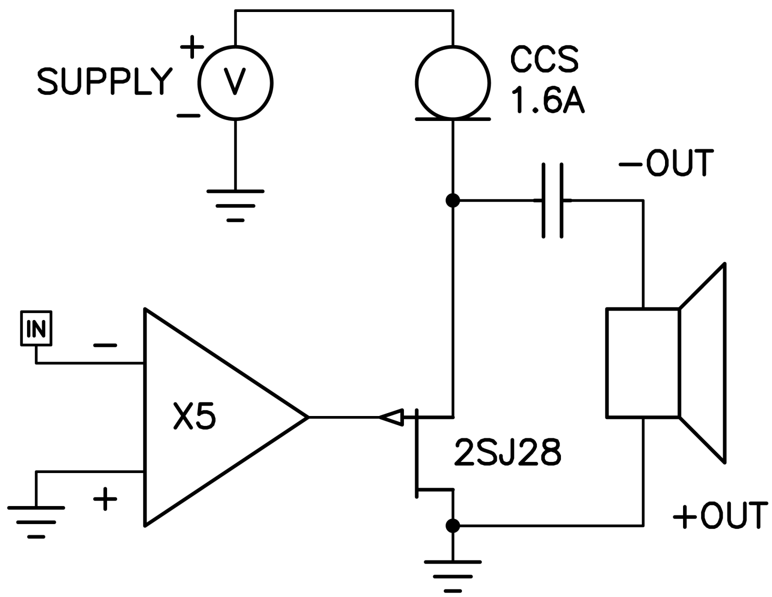
These will be released in two versions, identical in concept except for part polarities and will be available from the store at www.diyaudio.com. The first is for the P channel 2SJ28 described here. It will be followed by the N channel version with the 2SK82. Delivery of the first version as a complete kit is scheduled for April 2021.

After that we will be out of these parts, however I have made the design flexible, so that DIYers can play around with the circuit using different transistors, including the Sony 2SJ18 and 2SK60, other VFETs, and also Mosfets/Jfets of various flavors. For this we intend revised additional full and partial kits. These will not depend on transistor matching (although that is nice).

The amplifiers are followers and so will have a separate voltage gain front end, and there are at least five versions that will be available - the first one is mine, based on the Edcor transformer as used in the First Watt M2 amplifier, and four other original designs from Mark Johnson which will drop right in.

Basic Design

Ordinarily the operation of a single-ended follower is very straightforward – you bias it up with a current source and drive it with a voltage source, and you are done. Here is the simplified circuit of the first amplifier, the 2SJ28 version:

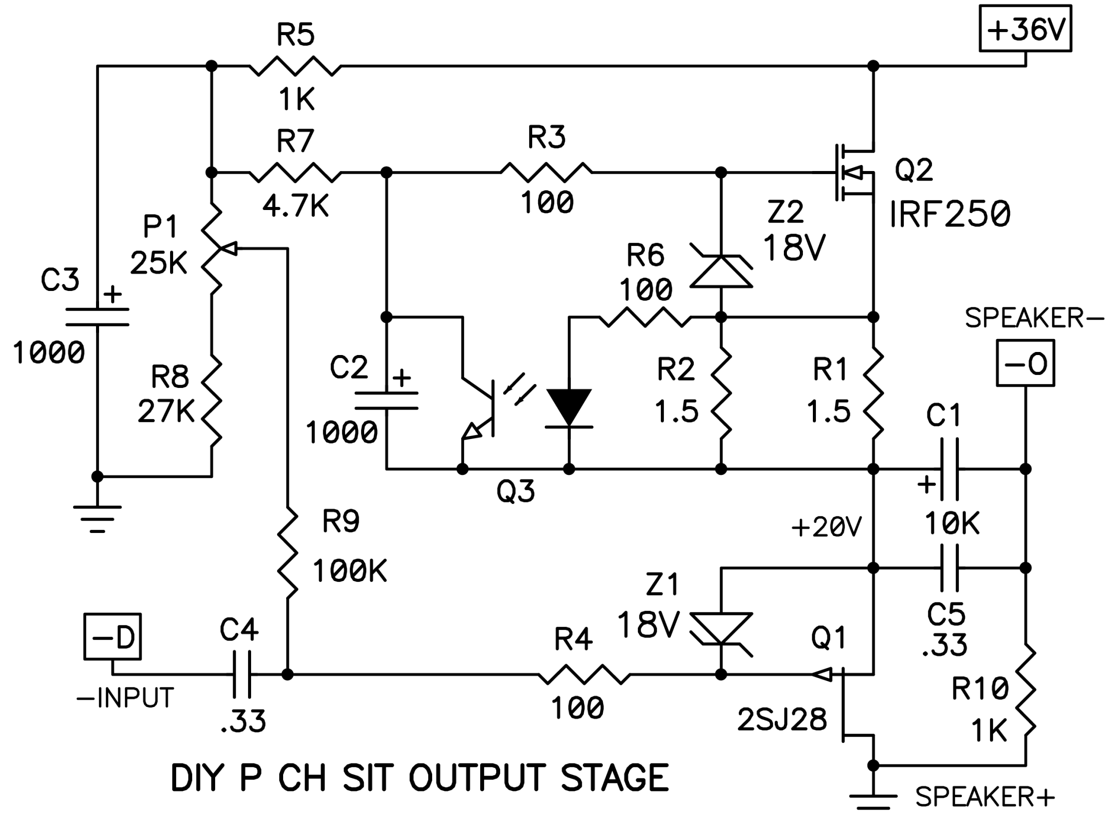


The 2SJ28 is operated as a follower (CD), with the Drain at ground and biased by a constant current source at 1.6 amps. The power comes from an external switching supply at +36 volts. The loudspeaker is driven by the Source pin of the VFET through a large capacitor. The Gate of the VFET is set at a DC voltage which puts the Source pin at +20 Volts DC, and is driven by AC signal from a separate circuit, seen here as the X5 block. In the base front end version, a Jfet buffer drives an Edcor transformer to create the X5 voltage gain. All the circuits are Class A, Common Drain, and without feedback loops.

You may note that we invert the polarity of the input and also the output polarity. This is done so that we can get the desired second harmonic characteristic of the amplifier and also preserve the absolute phase of the signal.

You may wonder why the Drain of the VFET is attached to ground. The reason is that the Drain impedance of the VFET is quite low compared to regular transistors, and any noise that appears on the Drain is going to make it to the output signal. Since Ground is the quietest spot in the circuit, it is logical to attach the Drain there. In the N channel version this is still true, although the supply voltage for the current source becomes negative instead of positive.

Here is the detailed output stage:



Q1 is the VFET gain device, Q2 is an N channel power Mosfet used for the constant current source, and Q3 is an opto-isolator wired to regulate the current through Q2. The Zener diodes are there to protect the Gate pins of Q1 and Q2 from high Gate-Source voltages which could damage them.

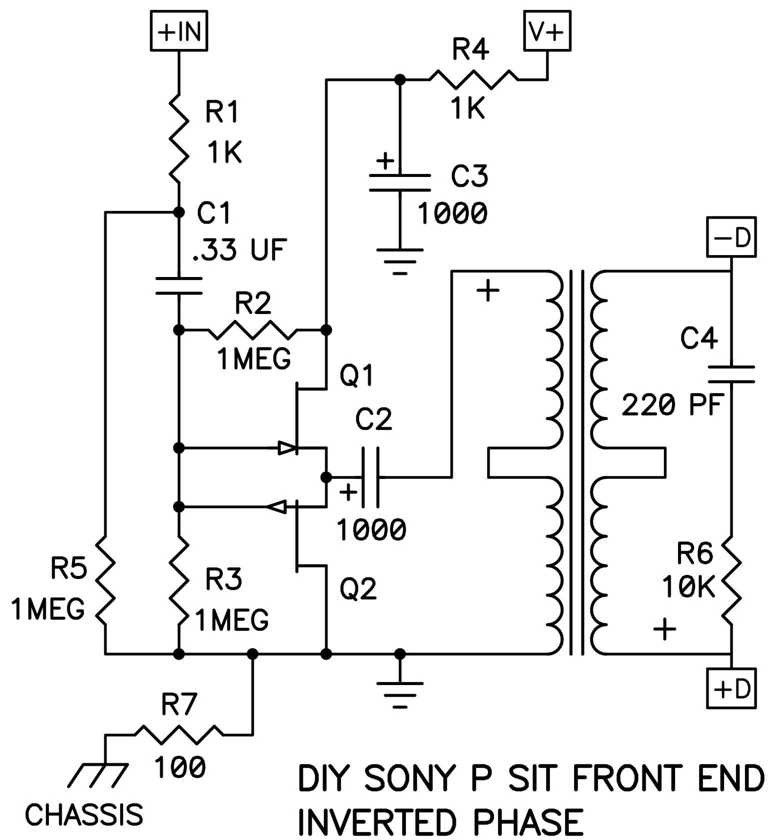
Input AC signal comes in at -D, which is coupled to the Gate of Q1 through C4 and R4. C4 blocks the DC difference between input and Gate, and R4 damps out parasitic oscillation that may develop at Q1. Gate DC value for Q1 is delivered through R9, which also sets the >100K input impedance of the stage.

This Gate DC value is set at 20 volts plus the Vgs value of the VFET, which ranges from 8 volts to 13 volts, and is adjusted by P1 to give +20 volts at the Source pin of the VFET.

The network consisting of R1, R2, R6, R7, C2 and Q3 sets the bias. Voltage sensed across R1 and R2 by the bias current turns on the LED of the opto-isolator which makes current flow through its NPN transistor portion, adjusting the bias voltage for Q2. As with R4, R3 is there to prevent parasitic oscillation.

The kits have the output stage partially assembled – Given irreplaceable VFETs I decided to personally mount the devices on the metal brackets with enough parts and test for torque, isolation, leakage, voltage bias and current bias.

There is no voltage gain to the circuit, and while you can operate it simply as a voltage buffer if your preamp has enough gain and voltage swing, there will also be 5 different front ends circuits available to deliver the voltage gain. Four of these are from Mark Johnson, and are recommended, as well as mine, described in this section.

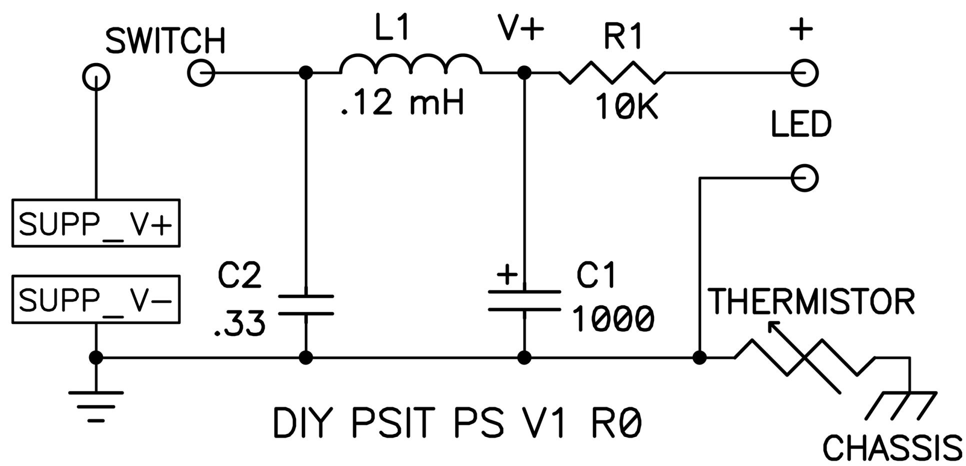


This circuit is mounted on a separate board from the output stage, and consists of a pair of complementary Jfet followers which drive the primary coil of the Edcor 600/15K step-up transformer. The Jfets are selected Toshiba 2SJ108 and 2SK370, the same chips as 2SJ74 and 2SK170 but in a smaller package, which provides for an input impedance to the amplifier of 330 Kohm and low distortion.

R1 prevents parasitic oscillation, and input biasing is provided by R2 and R3. R4 and C3 filter the supply and reduce the voltage to the limits of the Jfets, R5 bleeds DC to prevent thumps, C2 DC blocks the transformer primary, and R7 gives some reference to chassis ground.

The output coil of the transformer is floating, so +D and -D can be switched to reverse output polarity (which they are in this version) with one going to ground and the other driving the output stage.

Lastly, because the external switching supply generates some high frequency noise I have provided a supply filter:



The Meanwell supply chosen was the most quiet tested, and in the prototype circuit I did not see the switching noise at the output. Nevertheless I anticipated that it might be a cause for *audio nervosa*, so I worked this simple circuit up. Now I can't see the noise on the supply rail either. Nice to note that the channels draw a literally constant DC current – no modulation of the supply.

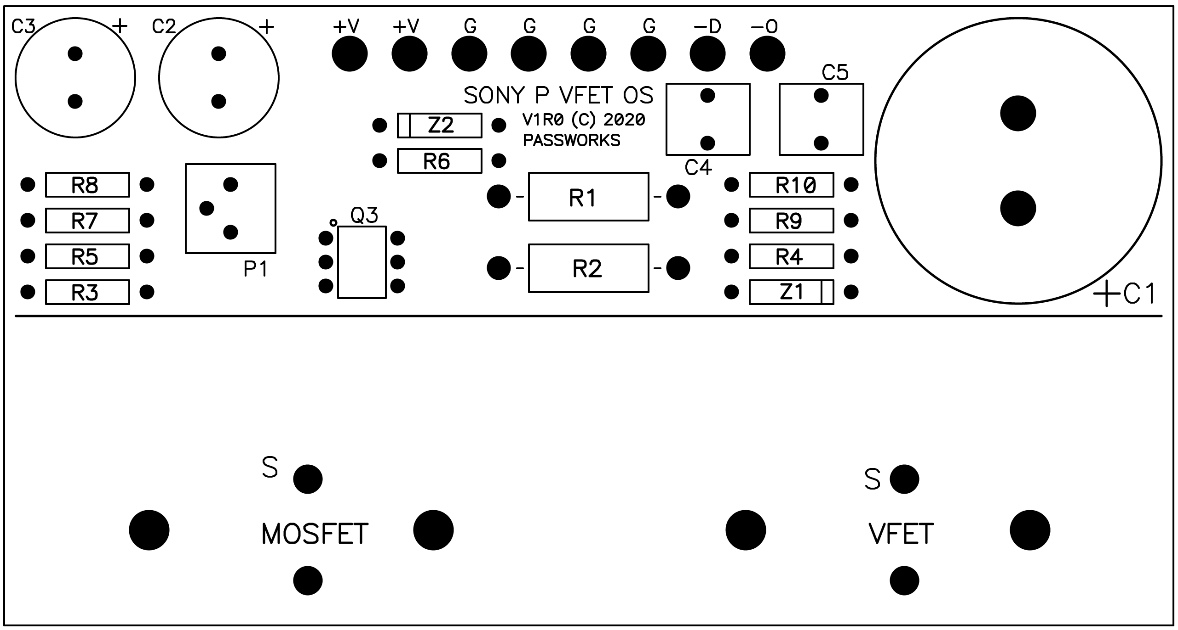
Not much to say here about the filter, a couple of capacitors and a commercial toroidal inductor. The pc board also has a convenient spot to wire the switch and the LED. Note that the chassis is wired directly to the wall outlet ground through the external power supply and this is attached to circuit ground through a power Thermistor which provides some protection against ground loops while also allowing a high current ground path for safety. Worth noting, some will want to use larger capacitors than shown, but keep in mind that the protection circuits of many switchers will not allow startup into huge capacitors.

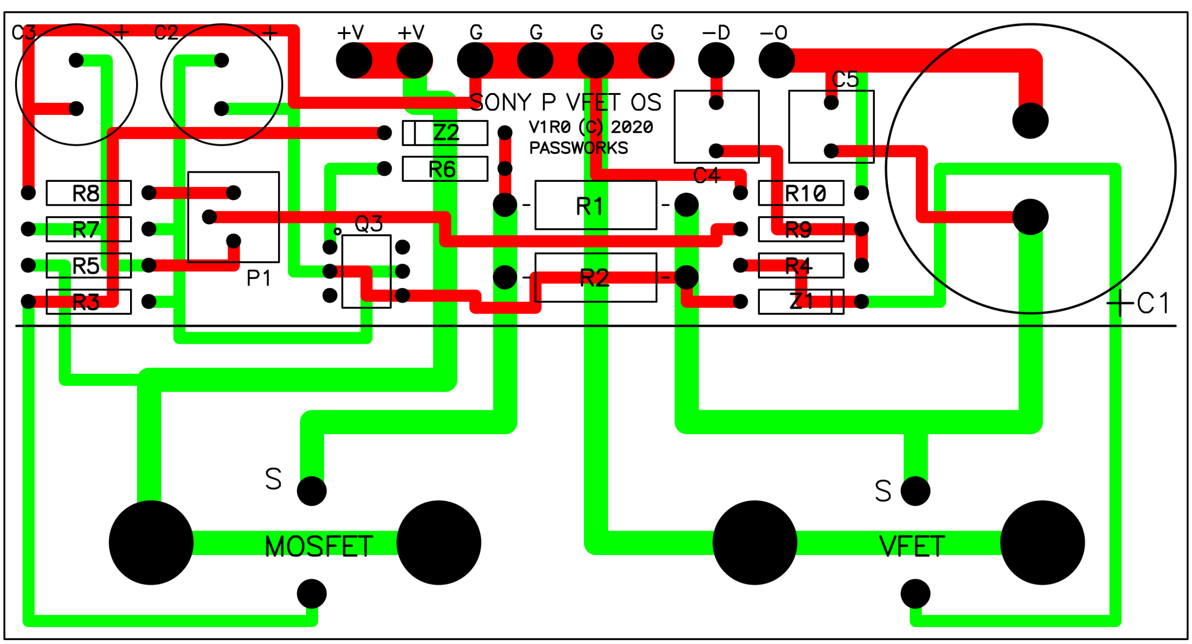
Assembly

DiyAudio member 6L6 (aka Jim Tiemann) has been doing pictorial build guides and providing support for the various projects in the Pass Labs forum for some time, and deserves accolades here for his efforts. Of course you will understand that he is rewarded by fame, first access to projects and the pleasure of informing me of my errors. He plans to similarly serve this project, and you will definitely want to view these.

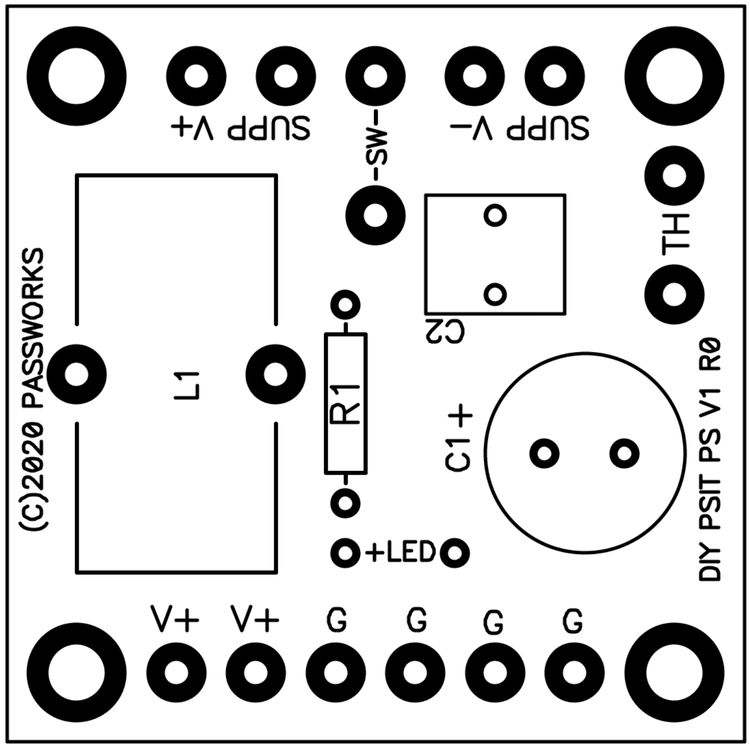
Here are black and white images of the top surfaces of the three circuit boards for this version and color images showing both layers of copper, the red being the top traces and the green the bottom traces . You will perhaps note that I try to make my pcb's look like my schematics where possible...

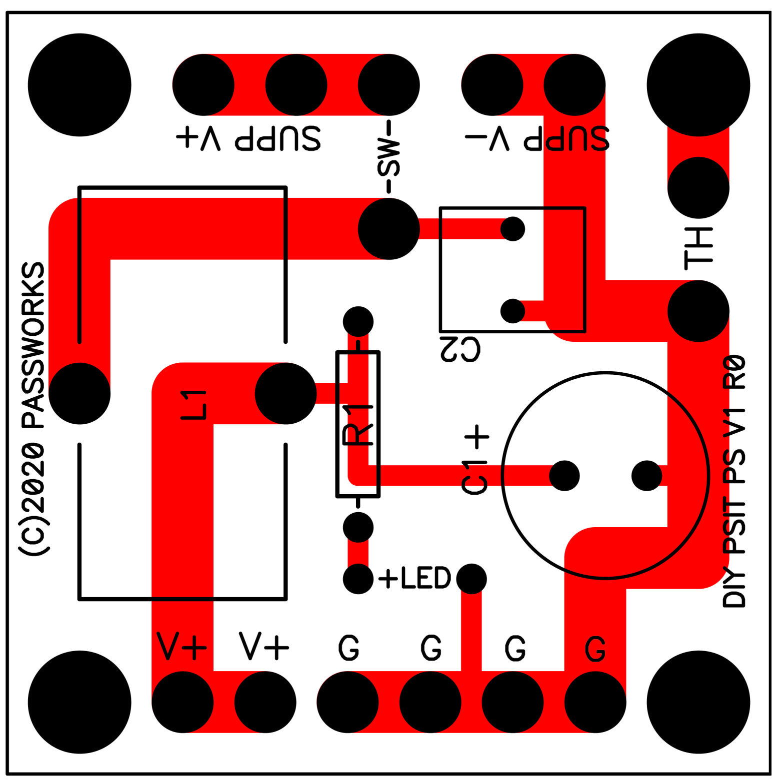
Here is the output stage for each channel. It is mounted on a bracket that fits the UMS *Universal Mounting Specification* of the heat sinks available from diyAudio.



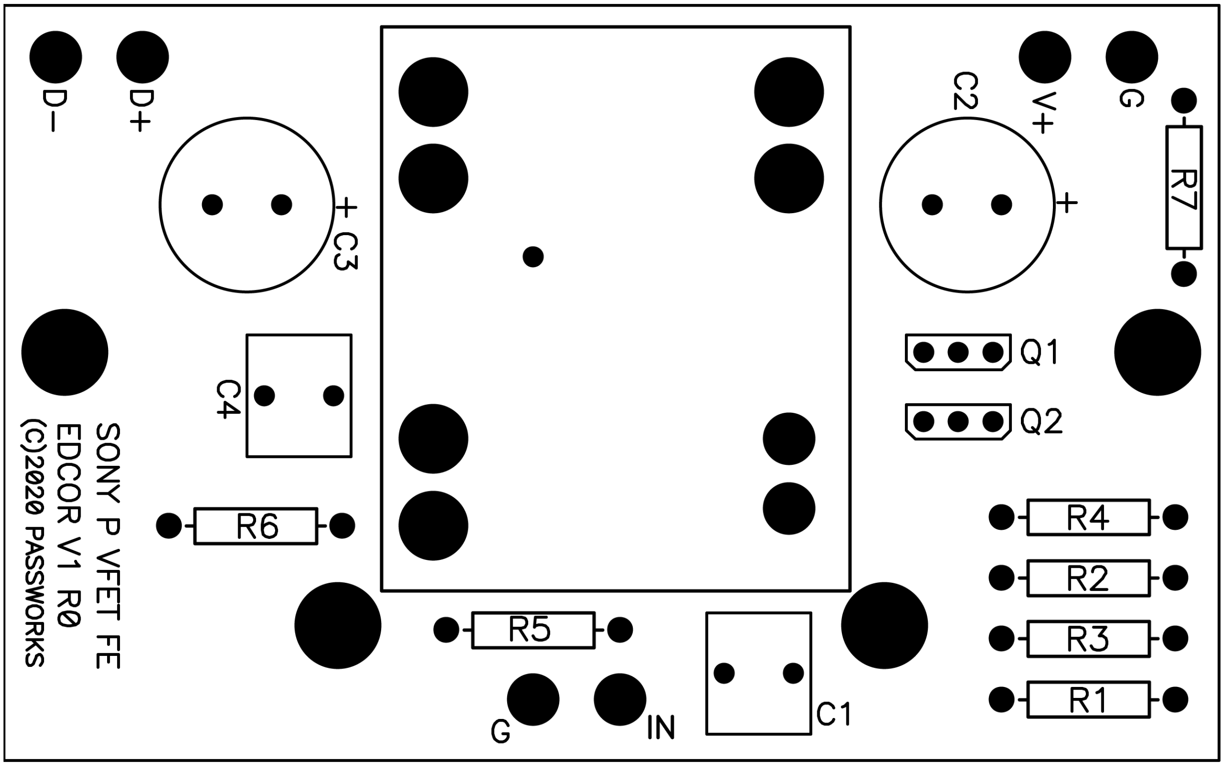


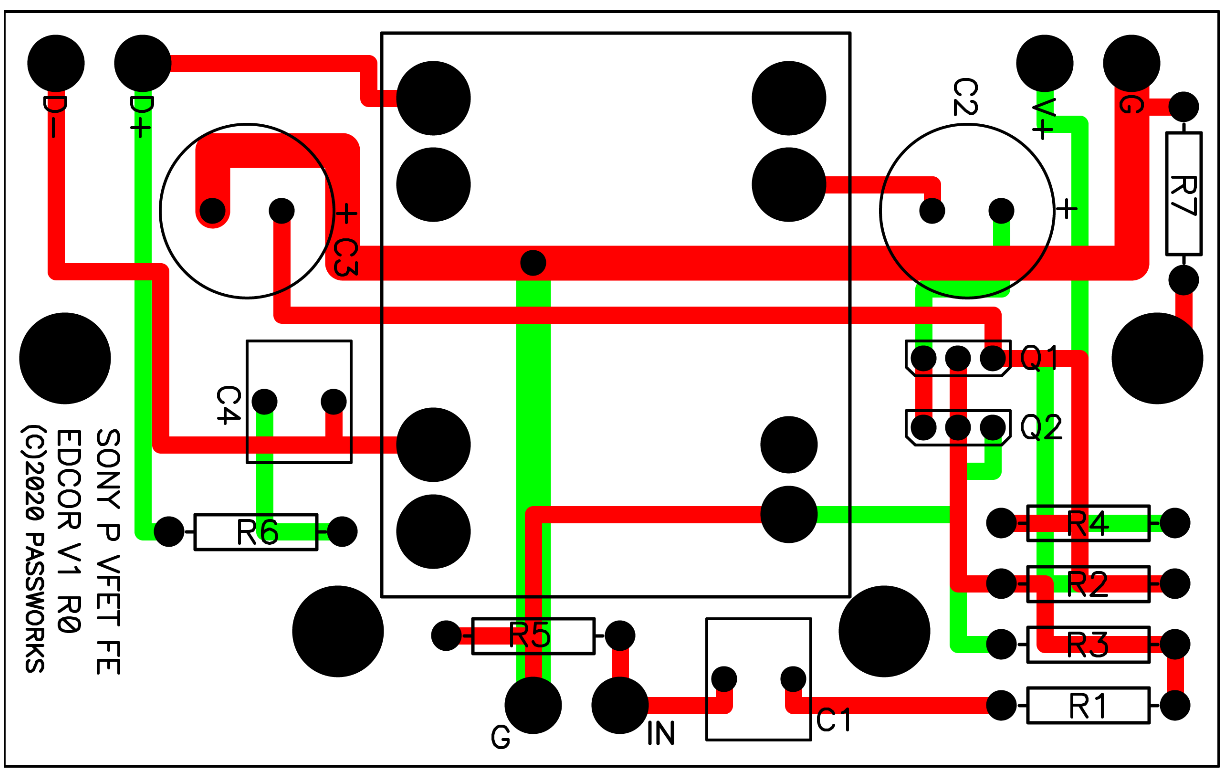
This is the pc board for the power supply filter:



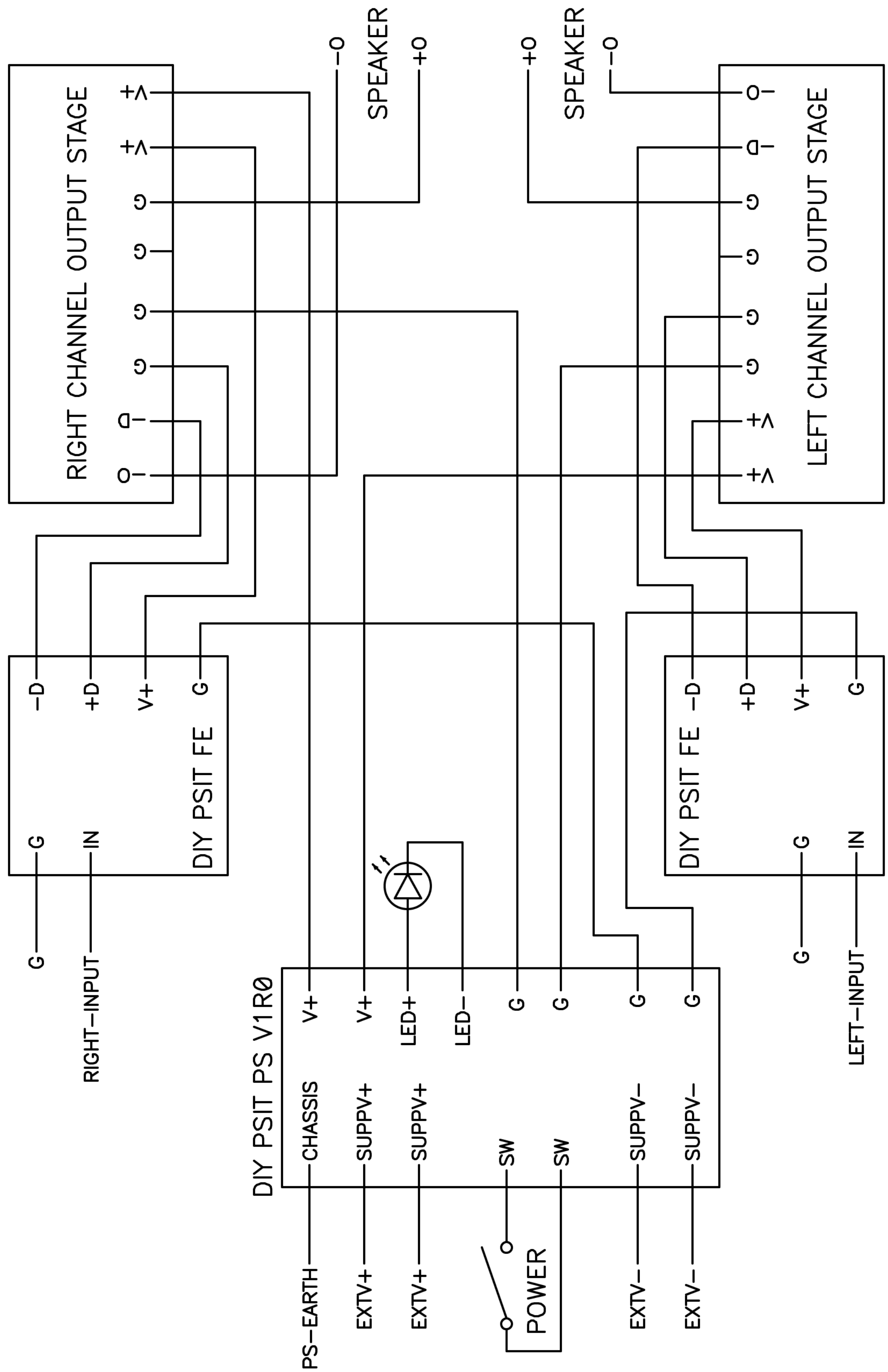


And here are the pc board images for the stock front end:

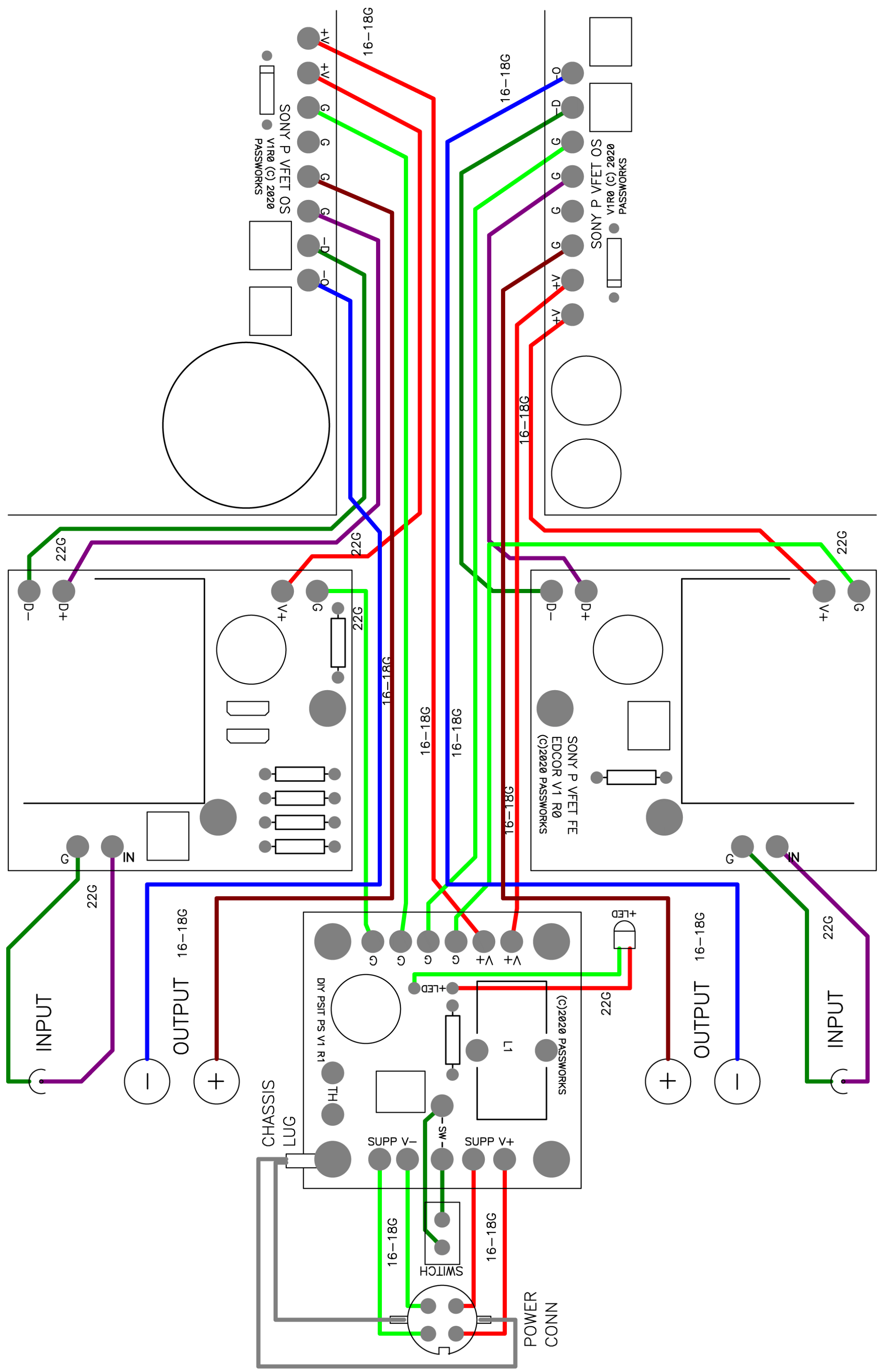




We have two wiring diagrams showing the wiring between components:



And again with some color:

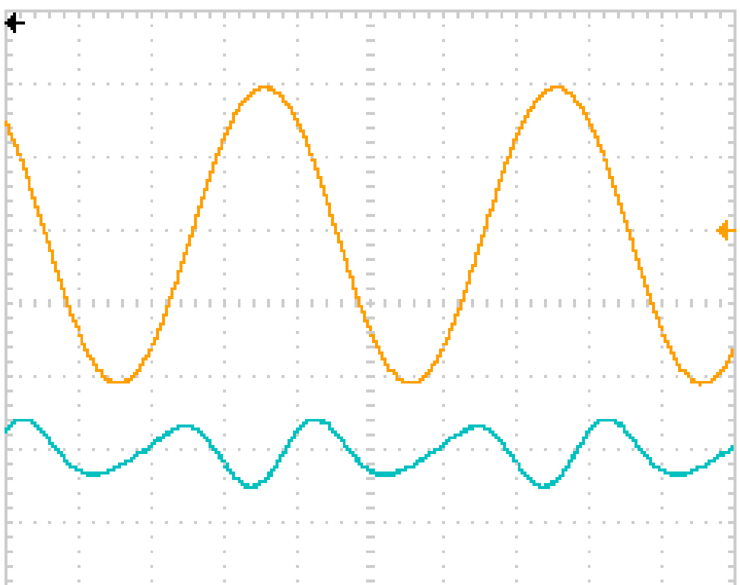


Performance

Each channel draws about 1.6 amps at 36 volts DC for about 57 watts dissipation. The channel is shipped adjusted, the only adjustment on the boards being the DC voltage for the Source pin of the VFET at 20 volts.

Nominal gain is about 10 dB, and output power is rated at 10 watts into 8 ohms and 5 watts into 4 ohms. Damping factor at 8 ohms is 6.

The distortion character is second harmonic. Here is the distortion waveform at 1 watt, 1kHz into 8 ohms:

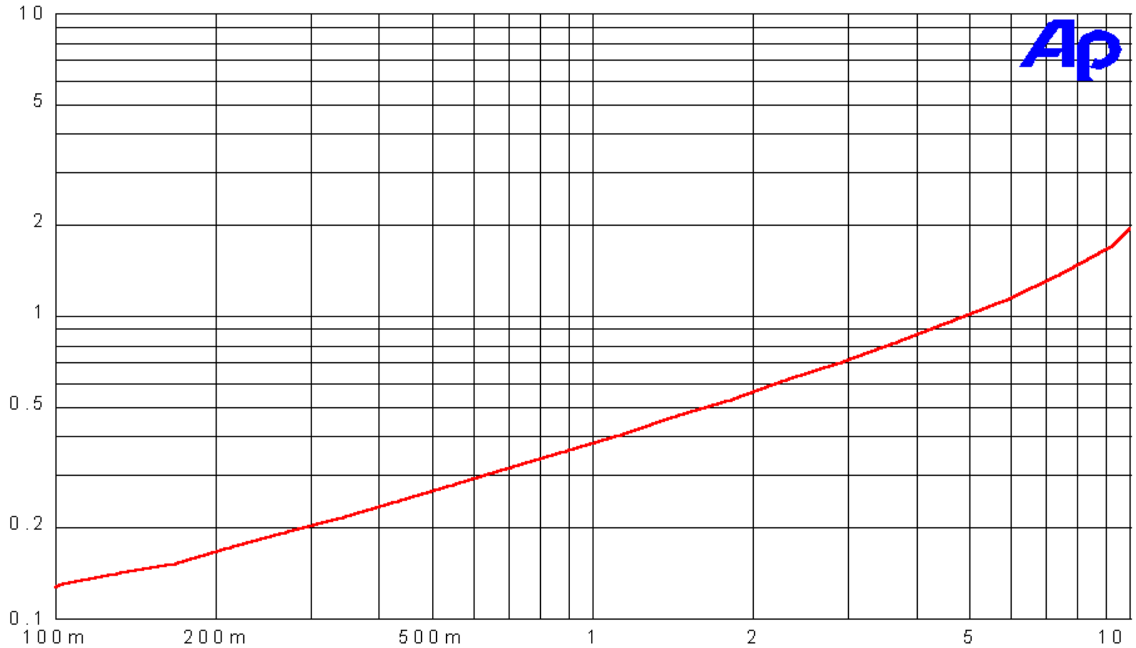


DISTORTION WAVEFORM

The fundamental wave is in orange, and the distortion waveform is in blue. We can see the dominant second harmonic, and for this circuit we would expect a "positive phase" alignment of this distortion, where the blue wave peaks positive for each peak of the fundamental. However, because we have become enamored of the "negative phase" second harmonic, where those peaks are negative as seen above, so we create this effect by reversing absolute polarity going into the output stage circuit and then reversing it again at the output by flipping the speaker polarity at the output terminals, keeping absolute polarity of the musical signal, and giving it the desired alignment of the distortion.

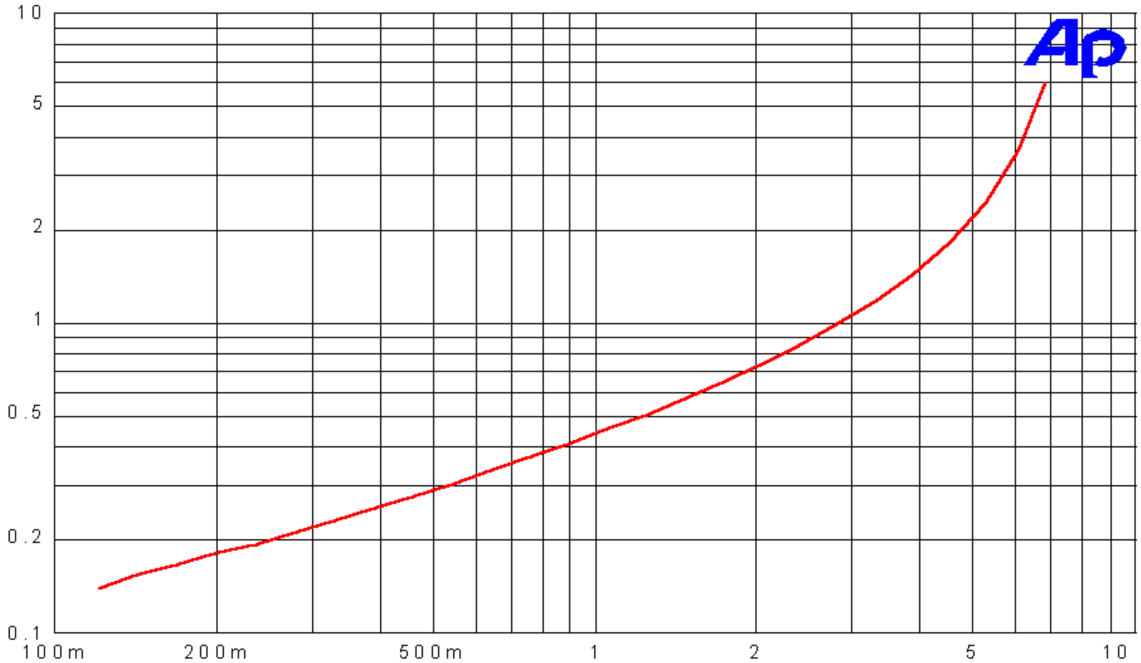
This would be a matter of taste, so you are free to not reverse these phases and enjoy a "positive phase" second harmonic if you like, or any other permutation.

Here is a graph of that distortion vs output watts into 8 ohms:



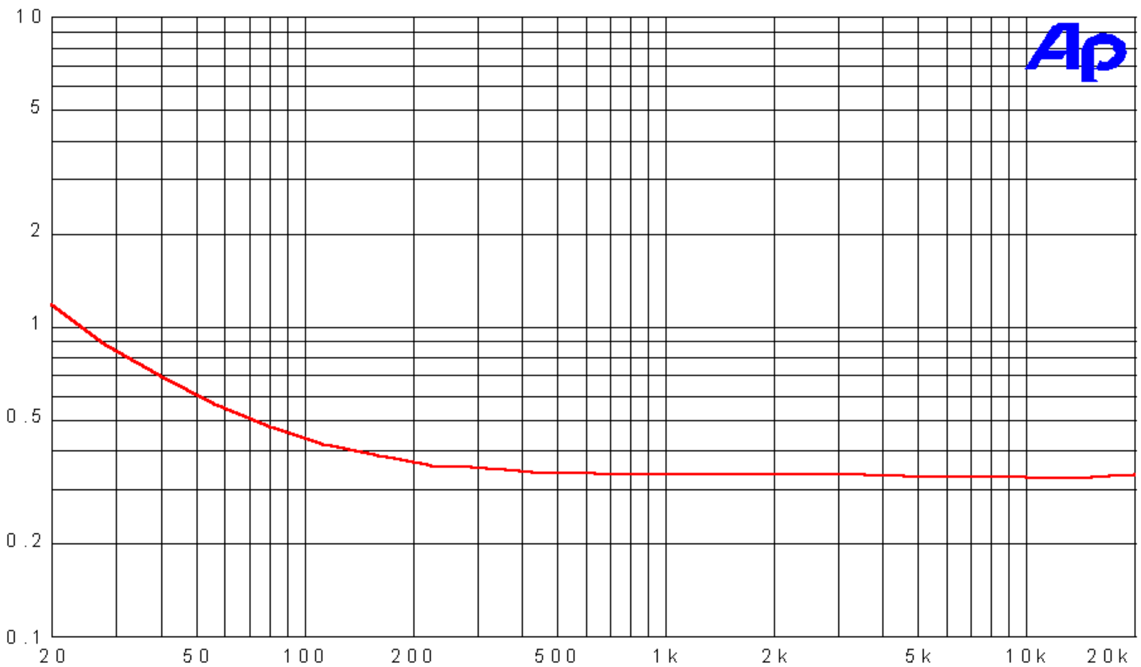
DISTORTION VS OUTPUT POWER 8 OHMS

And here is the distortion vs watts into 4 ohms:



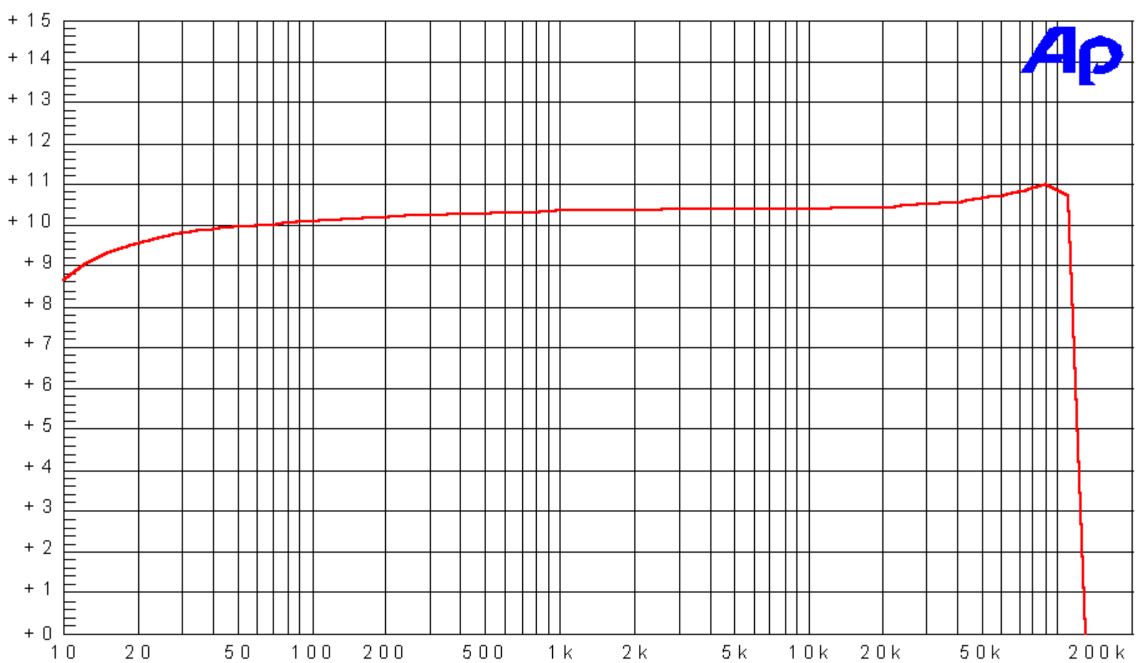
DISTORTION VS OUTPUT POWER 4 OHMS

Distortion vs frequency (showing transformer distortion at low frequencies):



DISTORTION VS FREQ 1 WATT 8 OHMS

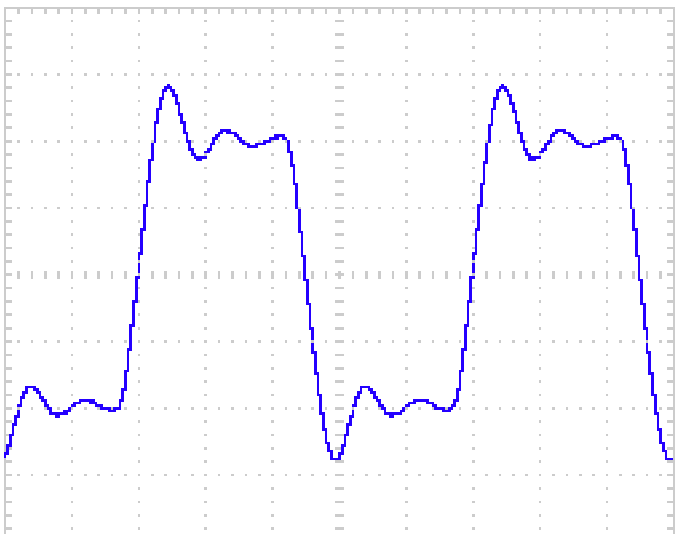
The frequency response curve at 1 watt into 8 ohms, mostly showing the bandwidth of the transformer:



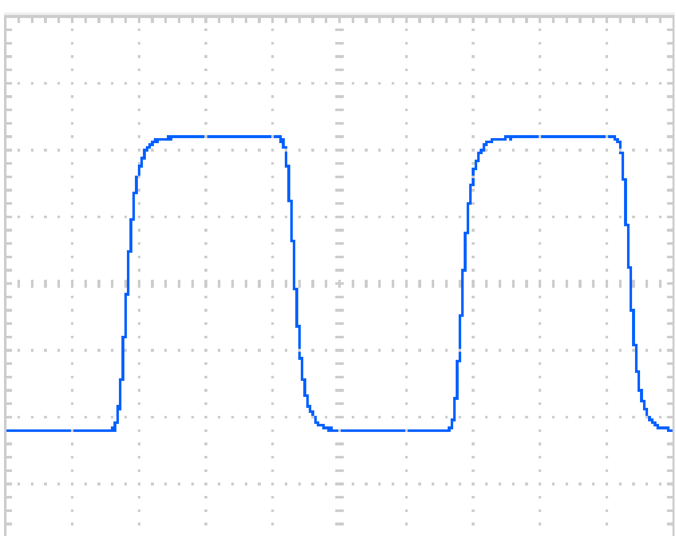
FREQUENCY RESPONSE

It's worth noting that although the amplifier has a fairly low output impedance, it has significant voltage loss as a follower. This is mostly the result of having a low Drain impedance – the gain of the VFET is a function of the Drain to Source voltage as well as the Drain to Source current, and this effect is largely independent of the load. This is why the net gain is only about 10 dB with the base front end. For the full 10 watt output you would want a source that can deliver about 3 volts rms, fortunately into a high impedance load (about 330 Kohm).

For the case of the Edcor 600/15K transformer, the response has a small resonant peak at about 100 kHz, as seen in this 20 kHz square wave:



Without the transformer the response of the output stage alone is better and without resonance. This is dependent on the source impedance, so your mileage may vary:



Here is the bill of materials for the P channel board kits:

SUB	REF #	QTY	DESCRIPTION	VENDOR	PART #
	THERE ARE TWO CHANNELS AND A POWER SUPPLY FILTER TOGETHER IN ONE SKU				
	NOTE - * AFTER PART # INDICATES ALREADY MOUNTED ON PC BOARD/BRACKET				
OS	DIY PSIT OS V1 R0	2	SONY P VFET OS		
OS	BRACKET*	2	CHANNEL BRACKET		
OS	MOSFET TO-3*	2	IRF250		
OS	VFET TO-3*	2	2SJ28		
OS	Q3*	2	OPTO ISOLATOR - LITE ON	DIGIKEY	160-1304-5-ND
OS	Z1*, Z2*	4	ZENER DIODE 18V	DIGIKEY	1N5248BFSTR-ND
OS	P1	2	TRIM POT 25K BOURNES	DIGIKEY	3386P-253LF-ND
OS	C1	2	CAPACITOR 10000 UF 50V	DIGIKEY	604-1050-ND
OS	C2, C3	4	CAPACITOR 1000 UF 50V	DIGIKEY	493-12786-3-ND
OS	C4, C5	4	CAPACITOR .33 UF PP	MOUSER	MKP2F03301M00JA00
OS	R1, R2*	4	RESISTOR 1.5 OHM 3W	DIGIKEY	A138414TB-ND
OS	R3*, R4, R6	6	RESISTOR 100 OHM .4W	DIGIKEY	PPC100YCT-ND
OS	R5*, R10	4	RESISTOR 1K OHM .4W	DIGIKEY	PPC1.00KYCT-ND
OS	R7*	2	RESISTOR 4.75K OHM .4W	DIGIKEY	PPC4.75KYCT-ND
OS	R8	2	RESISTOR 27K OHM .4W	DIGIKEY	PPC27.4KYCT-ND
OS	R9	2	RESISTOR 100K OHM .4W	DIGIKEY	PPC100KYCT-ND
OS	#6 SCREW*	8	#6-32 SCREW .5"L (TO-3 MOUNT)		
OS	#6 NUT*	8	#6-32 LOCKNUT (TO-3 MOUNT)		
OS	SPACER*	8	NYLON SPACER #6 HOLE .25"D X .25"L		
OS	#3 METRIC SCREW	8	CHANNEL MOUNT 12mm HEX		
OS	#3 METRIC WASHER	8	CHANNEL MOUNT		
OS	TO-3 INSULATOR	4	THERMALLY CONDUCTIVE INSULATOR		
PS	DIY PSIT PS V1 R0	1	PC BOARD		
PS	L1	1	INDUCTOR 120 uH	DIGIKEY	2200HT-121-V-RC-ND
PS	C1	1	CAPACITOR 1000 UF 50V	DIGIKEY	493-12786-3-ND
PS	C2	1	CAPACITOR .33UF POLYPROP WIMA	MOUSER	MKP2F033301M00JA
PS	R1	1	RESISTOR 10 KOHM .4W	DIGIKEY	
PS	TH	1	POWER THERMISTOR		
PS	LED	1	RED LED		
PS	SCREW	4	#6-32 SCREW .5"L		
PS	NUT	4	#6-32 LOCKNUT		
PS	SPACER	4	NYLON SPACER #6 HOLE .25"D X .25"L		
FE	DIY PSIT FE V1 R0	2	SONY P VFET FE		
FE	XFRMR	2	TRANSFORMER	EDCOR	PC600/15K
FE	Q1	2	LSK170 N CHANNEL JFET		
FE	Q2	2	LSJ74 P CHANNEL JFET		
FE	R1, R4	4	RESISTOR 1K OHM .4W		
FE	R2, R3, R5	6	RESISTOR 1 MEG OHM .4W		
FE	R6	2	RESISTOR 10K OHM .4W		
FE	R7	2	RESISTOR 100 OHM .4W		
FE	C1	2	CAPACITOR .33 UF PP	MOUSER	MKP2F03301M00JA00
FE	C2, C3	4	CAPACITOR 1000 UF 50V	DIGIKEY	493-12786-3-ND
FE	C4	2	CAPACITOR 220 PF PP	MOUSER	FKP20102201D00KSSD
FE	SPACER	8	NYLON SPACER #6 HOLE .25"D X .25"L		
FE	#3 METRIC SCREW	8	CHANNEL MOUNT 12mm HEX		

Conclusion

From a purely listening standpoint, this amplifier should be a lot of fun. The sound is rich enough in negative phase 2nd harmonic to give a nice illusion of depth without becoming a cartoon, and has the kind of characteristic associated with good single-ended tube amplifiers, although with slightly better numbers.

The amplifier is particularly happy into 8 ohm speakers with efficient drivers - I suggest 90 dB/watt or higher, although you are welcome to try any load you like – this amplifier is not easily damaged.

Those who build the kit will appreciate not only the sonic result, but also the finely crafted chassis that was designed for the occasion by the people at diyAudio. Every effort is being made to accommodate newcomers in this project, and I greatly recommend 6L6's build guides which will be found at www.diyaudio.com.

As well, Mark Johnson has designed four different front ends (all of them as good or better than presented here) for this amplifier, and they go right in without a fuss, and have been designed to work also with the additional versions of this project. If you have your own VFETs in a TO-3 package, there will be a basic version available, and after that we will support TO-247 power Fets.