NOTES ON *A Solid-State Single-Ended Power Amplifier* by Ed Simon
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This is definitely a minimalist design with just five transistors per channel and two of them are current sources. I was very intrigued by this design so I built one very nearly as described by Mr. Simon. Then I made some changes. These notes document those changes and the reasons I made them. So my final version is, of course, a different amplifier although the topology is much the same as the original. More importantly, it sounds very good.

My first change was to the power supply. The useful output power is just a bit over 1 watt RMS into 8 ohms per channel as the negative peaks start to clip at about -4.5 volts. So powering this amp from a ±21 volt DC power supply does nothing other than increase the dissipation in all the transistors. A power supply of ±10 to ±11 volts delivers the same output power and the amp runs much cooler. This was very important to me as I needed to rack mount it. When you have a power amp "farm," rack mounting is the only solution. One watt RMS may not seem like much power but with a pair of high efficiency speakers (such as the TDL® TSMD-2s) it fills the room with more sound power than is comfortable for me to listen to.

Another change was designing a circuit board with headers (and mating plugs) for making the connections on and off the board. Although the circuit is the same, I redrew the circuit diagram to show the headers and the power supply changes. With Q4 and Q5 on a circuit board, there is a problem with getting the heat out. Of course, the lower supply voltages help but Q4 and Q5 still get rather hot. The accompanying photos are worth a lot of words but some explanation is still needed. The finned radiators (see parts list) on the rear panel (simon2.jpg) are very efficient so the problem is conducting the heat to them.

Copper (and silver) have a thermal conductivity of about unity. Aluminum (depending on the alloy) is about 0.5 and brass (again, depending on the alloy ratio) is about 0.25. So copper is the clear winner. Photo simon4.jpg shows a copper bar 1/4 inch thick by 1 inch wide by 3 inches long. It is tapped 4-40 in two places to mount Q4 and Q5. What is not shown clearly in this photo are the two copper rods that connect the bar to the finned aluminum radiator. They are 5/8 inch in diameter and about ½ inch long. The exact length isn't critical, they just need to be the same to withing a few thousandths of an inch. They are drilled with a 9/64 inch hole (at their centers) to pass a 6-32 machine screw which bolts through the finned radiator, the copper rod and the copper bar. Moreover, the drilled rods are soldered to the copper bar using a brass 6-32 machine screw to temporarily hold them together. I used a brass screw here because there a slight possibility of soldering the screw to the rod or bar and brass is easier to drill out than steel. Use some paste solder flux between the rod and bar and heat with a propane torch to get a good solder joint. I punched 3/4 inch diameter holes in the rear panel so the copper rods would bolt directly to the radiators and I used thermal grease (the white stuff) between the ends of the rods and the backs of the radiators. Q4 and Q5 are attached to the copper bar with 4-40 x 3/8 machine screws, nylon shoulder washers and TO-220 silicon rubber insulators coated on both side with thermal grease. (The silicon rubber insulators have a lower thermal resistance than mica.) The idea is to get the thermal conductivity from Q4 and Q5 to the radiators as high as possible. This scheme works quite well as the copper bars go into thermal equilibrium at about 120 degrees F (about 49 C) after 30 minutes of operation.

As Mr. Simon points out on page 28, "... I used a TIP42C, which isn't a great audio transistor, but it's cheap." In my final design, I changed Q4 to a 2N6488 and Q5 to a 2N6491. These are a complimentary pair originally developed by RCA in the 1970s for audio amps. I've used them in the past and, in fact, the ones I used in this amp are 30 years old. Both types are still in manufacture (of course, not by RCA) and they are fairly inexpensive (about two dollars each). I hope the new ones perform as well as the old RCA stock. Also, IRF510s work as well as IRF610s for Q1 and Q2: I tried both. Q1 and Q2 are mounted on the same heat sink (see parts list). Yes, they do get a bit warm but the heat sink is primarily to keep them at the same temperature. Use nylon shoulder washers and silicon rubber insulators because the mounting tabs (drains) are at different voltages. I also used a heat dissipater on Q3 to keep it a little cooler (see parts list). Insulators aren't needed because the dissipater isn't in contact with any other part of the circuit.

Even in a low-power amp I like to use a High Quality Ground (HQG) where all the commons interconnect. In this amp, you can see it in photos simon3.jpg and simon4.jpg. It's a copper bar 3/16 inch thick by 1 inch wide and 3 inches long. The power transformer secondary center-tap connects here as does the common from the off-board filter caps. There is also a wire from AC mains ground (which connects to the rear panel) and ONE common wire from each circuit board. The circuit board is designed for insulated signal input connectors on the rear panel so there is a 3-pin header on the circuit boards for signal input. The third pin of each plug goes to the HQG.

I wrote a SPICE model for this amp primarily to look at the effects of changing the power supply voltages. However, it's also useful for looking at clipping levels and the frequency response (which is quite wide). I've included this model along with all the necessary library files. It should run in any SPICE that's PSPICE compatible. Unfortunately, the current SPICE models are not sufficiently detailed to show any operational difference between the TIP and 2N transistors at Q4 and Q5. However, I can hear the difference.

As Mr. Simon mentions, Q1 and Q2 should be matched to minimize the DC offset voltage at the output. A simple way to do this is with the circuit in ***matching.pdf***. Buy at least ten and preferably twenty of the IRF510s or IRF610s so you can find some closely matched pairs. (They are rather inexpensive.)

Although most components are the same as in the original article, I've included a parts list for completeness and to note the few changes. I used 22 AWG stranded, Teflon insulated wire for all the wiring. Number 22 is largest size that comfortably fits the Molex KK-series connectors.

R1, R10	100K	1%, 1/4 w metal film	
R2	100	1%, 1/4 w metal film	
R3, R11	10K	1%, 1/4 w metal film	
R4	47	1%, 1/4 w metal film	
R5, R8	1000	5%, 1 w metal oxide	Parts Express 003-1K
R6	12	5%, 1/2 w metal oxide	Parts Express 002-12
R7, R9	1R5	5%, 1 w metal oxide	Parts Express 003-1.5
R12	0R47	5%, 1 w metal oxide	Parts Express 003-.47
R20, R21	1200	5%, 1 W metal oxide	Parts Express 003-1.2K

C1, C5	4.7 uF	5%, 50 V polyester film	DigiKey EF1475 (Panasonic)
C2, C4	100 uF	25 V tantalum electrolytic	
C3, C6, C7, C10, C11	100 nF	5%, 50 V polyester film	DigiKey P4525 (Panasonic)
C8, C9	4700 uF	35 V radial electrolytic	Mouser XRL35V4700 (Xicon)
C20, C21	2900 uF	40 V electrolytic	Mouser 75-36DX292G040AA2A
	(See the Change below for an update on C20 and C21.)		
		Capacitor mtng brackets	Mouser 539-VR3
BR20	400 V, 8 A	bridge rectifier	
D1 – D4	1N4148		
D5, D6	1N4004		
Q1, Q2	IRF510 or IRF610		
Q3	TIP41		
Q4	2N6488		Parts Express or others
Q5	2N6491		Parts Express or others
H1	3-pin header, 0.1 inch spacing		Molex KK-series (Jameco has best price)
H2, H2	2-pin header, 0.1 inch spacing		
P1	3-pin shell with terminal pins		Molex KK-series
P2, P3	2-pin shell with terminal pins		
	Heat dissipater for Q1 & Q2		DigiKey 294-1117 (IERC)
	Heat dissipater for Q3		Jameco 42622 or equal
	Nylon shoulder washers and silicon rubber insulators for above		
	Rear panel heat radiators		Electronic Goldmine G2209
T1, T2	12 or 12.6 VAC, 2A		Mouser 41FG020 or equal
S1	SPST, 15A toggle switch		Mouser 642-631NH2
	2 RU rack enclosure		Sescom 2RU7

A CHANGE

Summertime in southern New Mexico is warm so the air conditioning runs most of the time. Not much background noise, but a little. On one cooler and cloudy day recently, the A/C was off and I noticed a slight hum from the main speakers coming from the Simon amp. So I took it out of the rack and measured 120 Hz at 40 mV pk-pk on the left channel and about 44 mV pk-pk on the right. Of course, it’s not audible when the music starts but still, a purist might object.

So I replaced C20 and C21 with 35,000 uF at 16 V caps (Mouser 598-DCMC16V353). The hum went down to 10 mV pk-pk (left) and 15 mV pk-pk (right). I can still hear a bit of hum if I put my ear very close to the right side speaker but it's now inaudible from the listening position.

These caps are the same physical size as the 2900 uF units so the replacement went easily. The new caps are in the Cornell Dubilier DCMC-series. Not only do they pack a large capacitance in a small package but they can handle high ripple current too. In this case, up to 6.1 A at 105 C.

A fundamental problem with single-ended amps is they have virtually no power supply ripple rejection (PSRR). Balanced amps, because they are balanced, usually have quite a high PSRR so smaller value filter caps work well.

SOURCES

If you can find the copper rod and bar locally, that's fine. If not, you can order it from:

Small Parts, Inc.
PO Box 4650
Miami Lakes, FL 33014
800-220-4242
www.smallparts.com (No minimum order)

Electronic Goldmine
PO Box 5408
Scottsdale, AZ 85261
800-445-0697
www.goldmine-elec.com

Jameco Electronics
1355 Shoreway Rd
Belmont, CA 94002
800-831-4242
www.jameco.com

Parts Express
725 Pleasant Valley Dr
Springboro, OH 45066
800-338-0531
www.parts-express.com

Sescom, Inc.
608 Main St
Wellsville, KS 66092
800-634-3457
www.sescom.com