FETs Eddy Mic/DI Pre-amp

The FETs Eddy is a discrete FET-based mic preamp project designed to be paired with the transformers of your choice for balancing the signal and run on an inexpensive 48V power supply for both the preamp and the phantom power. The specified bill of materials will provide a big signal with some FET distortion at higher gains and plenty of output. It's intended to be used with a switching jack as a DI eith guitar or bass as well.

This build document is a bit more complex than what I normally make for a couple reasons: First, unlike your average guitar pedal, this involves high currents and higher voltages. Second, there are a couple variants, and I wanted to be clear about the pros and cons of each. There are also a couple add-ons for the project if you want a more complex preamp.

IMPORTANT: Q1 and Q3 are technically backwards on the layout for the spec'ed transistors! My Eagle part was incorrect. The drain/collector is toward the top of the PCB. This will be fixed in future layouts.

Bill of Materials (stock FET build)

If you want to substitute a part, make sure it will work with the 48V supply!

Mouser NEARLY COMPLETE BOM. What's missing: An appropriate FET or Germanium transistor if you are building those versions (add a 2n2270 to just build all-silicon), the external trimpot (which Mouser doesn't have), standoffs, transformers, power supply, DC jack, and case. You can edit the cart to remove any power supply parts you don't need. If you are building the "alt gain pot" version, you will need some more resistors. You might also want to order extra 6k8 resistors so you can get a close match for the phantom power resistors.

Component	Qty	Source
Combo input jack	1	Mouser. (This is a switched jack.) Or regular XLR jack (no DI).
Output jack	1	Mouser (more). Smallbear has a clone for less. You can also use a TRS jack or both. (I prefer both.)
Screws for XLRs	4	Mouser.

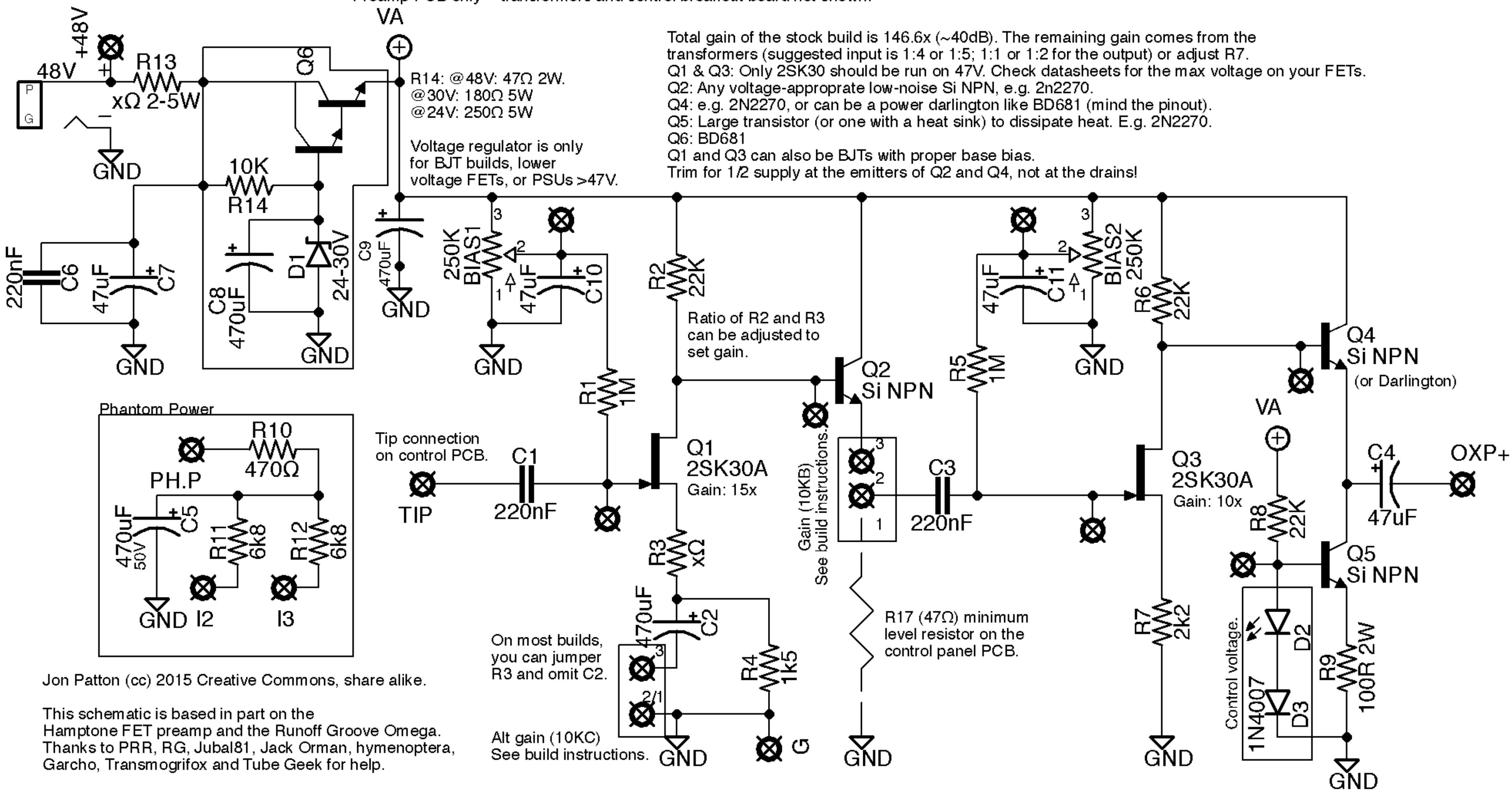
DPDT toggle	1	Smallbear. Mouser. Phase (polarity) switch. Get 2 if you're doing a switched pad.
SPDT toggle	1	Smallbear. Mouser. Phantom power switch.
2n2270	2 or 3	Mouser. For Q2 and Q5, option for Q4 (see notes).
2SK30	2	Smallbear - GR bucket / Smallbear - (usually) Y bucket, see notes
BD681	1 or 2	Mouser. For voltage regulator (if needed), option for Q4 (see notes).
Zener	1	For voltage regulator (if needed). 24V (drops to ~23V). 25V (this will regulate almost exactly to 24V). 30V. 47V.
10K 1/4W	1	For voltage regulator (if needed).
1,000µF	1	Power supply filtering for entire box.
470µF 50V	3-4	Mouser or this one. You can use a smaller cap (lower voltage rating) if you are regulating down to a lower voltage (e.g. for germanium). 35V 8mm if you prefer.
47µF 50V	4	Mouser. The 63V is the same size (and actually cheaper, for some reason), and the 100µF might also fit.
220nF	3	Mouser.
100pF	1	Optional for RF rejection across the input transformer secondaries. (Not show in schematic.)
6k8 1/4W	2	For phantom power. Match these closely (0.1%).
470Ω	1	For phantom power.
1k5 1/4W	1	Gain stage 1 for 14.6x gain.
2k2 or 1k5 1/4W	1	Gain stage 2. 2k2 for 10x gain (for higher-ratio transformers) or 1k5 for 14.66x gain (for lower-ratio transformers).
22K 1/4W	3 or 4	Only 3 are needed if you are building the alt gain pot version.
11K 1/4W	1	Optional for alt gain pot configuration.
1M 1/4W	2	
100Ω 2W	1	Mouser. Or 1W (Tayda) is also safe. See output section notes.

50Ω 2W	1-2	Mouser. 1W (Tayda) is also safe. See power filtering notes.
Jumper(s)	2	Used in place of unneeded part(s).
LED	2	One should be green for the control voltage. The other is just the phantom indicator.
1N400x	1	For the control voltage. (See notes.)
1N5817	1	Polarity protection for the entire box.
10KA 9mm PCB-mount	1	Gain pot. Smallbear: continuously variable or with detents. Closest thing at Mouser. Tayda. Note the Alt Gain pot is 10KC.
External trimpot	1	Simple variable input pad. 250KA (see notes). Smallbear. (Or 9mm PCB-mount.) Not needed if you're using the switched pad.
250K multi-turn	2	Bourns 3296. Mouser. Tayda (200K is fine). 2262 will also fit.
1:4+ input	1	Jensen (1:4.8 was my favorite), Cinemag, VTB2381, etc. See notes.
1:1 or 1:2 output	1	Tons of choices. Edcor XSM; Carnhill VTB2281 (my favorite for the germanium build); Jensen, Cinemag, etc. See notes.
48V DC supply wall wart	1	This one's good (more than enough amperage). This one worked, too in testing, but some whistling appeared after I finished the project. There's no whistling when it's powering a different preamp, and it didn't appear during any early testing, but some mistakes I made while prototyping could conceivably have damaged the supply. Either should be safe to use with this project.
DC jack, 2.1mm	1	The recommended supplies are both center positive, so a non-isolated jack is okay.
Standoffs	4	Mouser has lots but make sure they're small enough -- you don't want to bump against components. If you get the kind with its own threads on one side, you will probably also need some feet for the bottom of the case, because the threads will poke out through the bottom. I actually just use sticky standoffs or double sided tape.
2-56 Screws	4 or 8	Either 4 or 8 depending on the type of standoff you got.
2-56 nut	4	Only needed you got the self-thread type.

Heat sink	1	Optional for Q4. This one fits a 2n2270.
Enclosure	1	Of course you need a box. I used a Hammond 1444-22 for the prototype pair, but it’s not actually rack-sized. You can get a single rack unit at a very reasonable price from Circuit Specialists. Not immediately obvious: Make sure your enclosure is large enough for your transformers. You may need to mount some output transformers on the side of the enclosure if you’re using a 1RU.

FETs Eddy

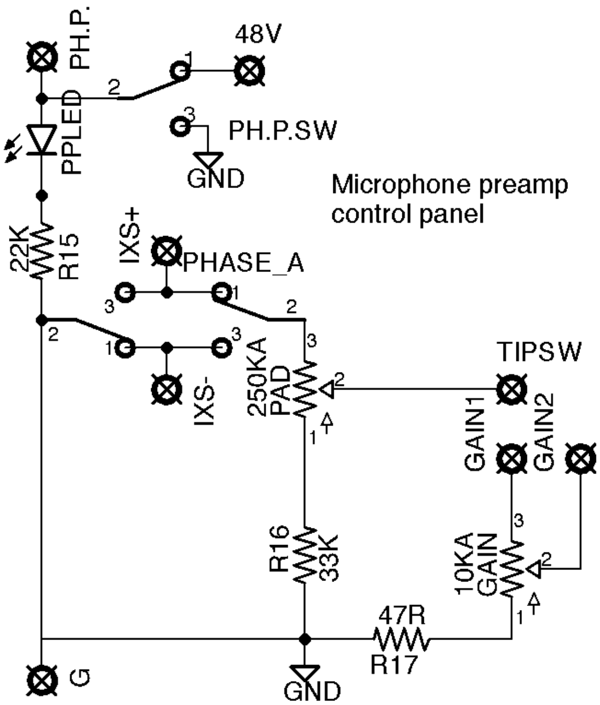
Preamp PCB only -- transformers and control breakout board not shown.

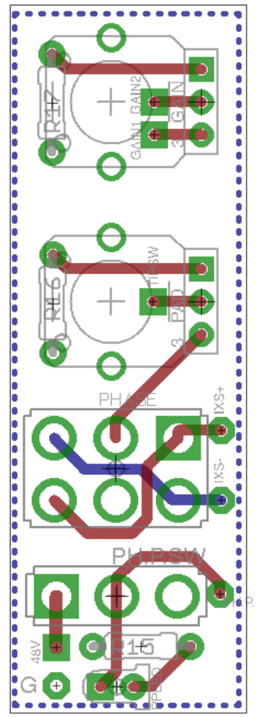


Total gain of the stock build is 146.6x (~40dB). The remaining gain comes from the transformers (suggested input is 1:4 or 1:5; 1:1 or 1:2 for the output) or adjust R7.
Q1 & Q3: Only 2SK30 should be run on 47V. Check datasheets for the max voltage on your FETs.
Q2: Any voltage-appropriate low-noise Si NPN, e.g. 2n2270.
Q4: e.g. 2N2270, or can be a power darlington like BD681 (mind the pinout).
Q5: Large transistor (or one with a heat sink) to dissipate heat. E.g. 2N2270.
Q6: BD681
Q1 and Q3 can also be BJTs with proper base bias.
Trim for 1/2 supply at the emitters of Q2 and Q4, not at the drains!

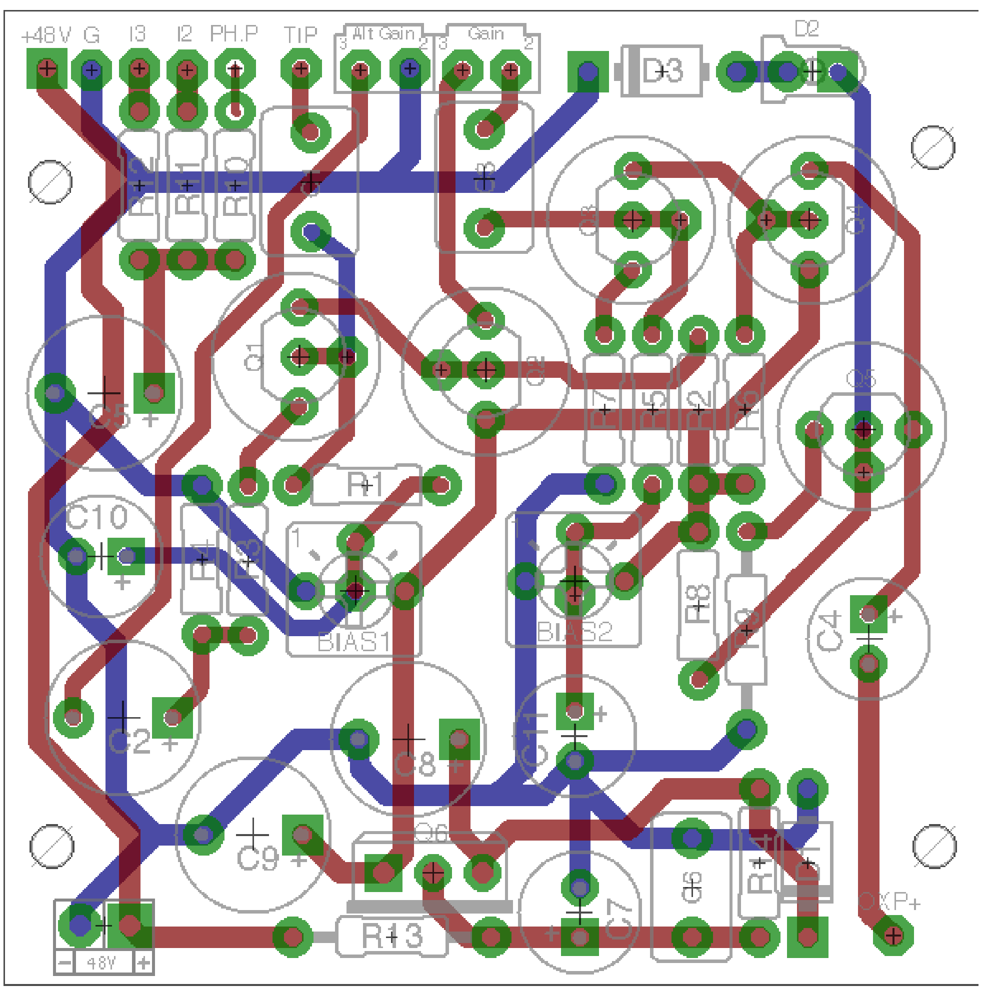
This schematic is based in part on the Hamptone FET preamp and the Runoff Groove Omega.

Thanks to PRR, RG, Jubal81, Jack Orman, hymenoptera, Garcho, Transmogrifox and Tube Geek for help.





18.35x54.91mm



50x50mm

What's Involved in This Project

1. Preamp board. This is the main PCB. It comprises a gain stage with high input impedance, a buffer for the volume pot, followed by a second fixed gain stage, and a high-current output buffer designed to drive a 600Ω:600Ω output transformer. The first gain stage is designed to accept an instrument like a passive electric guitar signal directly or a microphone via an input transformer.
2. Control panel. The control panel PCB holds the controls for the preamp: The volume control, phantom switch and LED, pad potentiometer (intended to be a 250K 9mm external trim), and phase (polarity) switch. This is purely to facilitate wiring.
3. Add-on PCBs: I intend to design an optional EQ section, which can be spliced in between the gain stages. Details when I work that out.
4. Transformer balanced. Although the added cost is substantial compared to other methods, this eliminates the need for extremely close matches of transistors for input stages or the use of op amps. I also just wanted to use transformers, because they add some color and the end result is a more interesting option on my shelf. Besides, the Edcor output transformer isn't really THAT much more expensive than a 2604 op amp plus the PCB space and parts to use it for an output stage, which is one of your only choices for running the entire preamp on 48V. There are many options for the transformers, so the project can be realized in many different ways.

Cautions (AKA Is This What I'm Looking for in a Preamp?)

1. This is not an ultra-low-noise, squeaky clean preamp. I've done what I can to minimize problems, but this circuit's topology, like others in its lineage, was designed to clip the FETs at least a little. Some distortion is not just to be expected but built into the stock build (the pad can clean things up a little). I have included some alternate ways to build the circuit, including using BJTs instead of FETs, so take a look at the mods section BEFORE you commit components to the board if this isn't what you're after.
2. Gain is fixed in both stages in the stock build, and depending on your transformer selection and gain ratios, there might not be enough of it for ribbon microphones and very-low-output dynamics like the SM7B on quiet sources. Adjustments to the gain are somewhat easy, though.
3. Finally, the gain pots in my prototype builds, no matter how they were wired, crackled sometimes. Normally I wouldn't consider this acceptable, but you probably won't be twisting the gain control during a take, right? Although this shouldn't happen with the variable gain wiring (which ought to have no DC across it), the real world is occasionally uncooperative due to capacitor leakage. I could have avoided this in the voltage divider

(stock) version by adding a large capacitor between the Q2 emitter and the gain control, but there were already three capacitors in the signal path. Adding another was a compromise I simply didn't want to make.

Stock Build Wiring & Setup Instructions

This includes the wiring for the input and output transformers, phase (polarity) switch, phantom power, and the instrument (¼") input (which bypasses the input transformer, pad pot, and phase switch).

1. It's important that you use a single chassis ground point. This is called "star grounding." I used one of the XLR chassis connections (usually right next to pin 1) that was next to my power supply jack. Connect the following to it:
    a. The - pin of the primary leads of the output transformer (you can ground the secondary center tap but it doesn't matter);
    b. The preamp and control panel PCB ground wires;
    c. Pin 1 of the input jack and, if you're using a combo/switched jack, the ring, sleeve, ring switch, and sleeve switch pins;
    d. Pin 1 of the output jack and the sleeve pin of the TRS output (if you're using a second jack or a combo jack);
    e. The ground connection of your DC power jack (the sleeve if you use the recommended supply); and
    f. The - side of the big power filtering cap for the whole box if you're using it (and you should be) -- see below.
2. Wire the connection for the XLR pin 2 to the + lug of the transformer and pin 3 to its - lug. (On the Edcor transformers, these are lugs 1 and 4. Don't do anything with the center taps.)
3. Connect the secondary leads of the input transformer to the ISX+ and ISX- pads on the control panel PCB.
4. Wire the TipSw pad on the control panel to the Tip Switch of your combo XLR switched jack, and then wire the tip connection to the input of the preamp PCB. If you are skipping the DI, connect TipSW to the input transformer's secondary + instead.
5. Connect the OPX+ pad on the preamp PCB to the output transformer's + primary.
6. Connect the output transformer secondaries to lugs 3 (+) and 2 (-) of your output jack. If you're using a TRS jack or a combo jack for the output, these will are the tip (+) and ring (-) connections; if you're using a combo jack, you can just use some jumpers right on the jack.
7. Wire the Ph.P. (phantom power) pads on the preamp and control panel PCBs together.
8. Connect I2 and I3 get connected to the input XLR pins 2 and 3.

9. Connect the appropriate gain pads to the PCB. If you're using the control panel PCB (and you should), you don't need to run a wire for lug 1 of the gain pot -- it will be connected to ground already.
10. <u>Before you plug in the power supply, if you are using a FET for Q1 and/or Q2, set the bias trimmer all the way to ground.</u> After power-up, adjust the bias trimmers such that the emitters of *Q2 and Q4* are at half of the measured Va voltage. This will ensure that the output of each stage is symmetrical. You can bias Q1 differently for some different color, however. (I bias it a little high.) It will take a second to settle after each adjustment, so take your time.
11. There are extra 48V and Ground pads along the top of the PCB for convenience. You can use these to run power and ground to the control panel.

Power supply filtering for the whole box

Because the PCB project was intended to go in a box with multiple channels, you will need to include some additional power filtering and, if you choose, polarity protection before connecting the power connections to the PCB. Adding these two components -- which can be done on perfboard, veroboard, or simply point-to-point -- will help lower noise from the power supply for all channels and will also add a little protection to some components during startup.

1. I use a 1N5817/18/19 for polarity protection because of the minimal voltage drop. Connect its anode to the tip lug of your DC jack.
2. Connect the cathode to the + lead of a 1000µF 63V capacitor. Wire the - lead of that capacitor to your star ground.
3. The positive lead of the filter capacitor is now your power supply connection. This is what's wired to all +48V PCB pads.

Input and Output Transformers

The input transformer should be at least 1:4, and can be as high as 1:10 (a ratio usually reserved for tubes). What you pick will have several implications for the rest of the build, so here's a brief rundown:

Ratio	The good	The bad
1:4 or 1:5 Input	• Less likely to clip the first gain stage FET except with high level microphone signals. Of course, this might be a bug, not a feature! • The secondary impedance doesn't need to be as high to avoid loading the microphone. A smaller input	• Less "free" voltage gain. • Less likely to clip the first gain stage FET except with high level microphone signals. Of course, this might be a feature, not a bug!

	trimmer (as low as 25K for a 1:4) can improve noise performance and lose less high end when trimmed. This is also beneficial with the BJT build, because the input impedance goes down as the gain goes up. ● Lower ratios tend to have a more linear frequency response and aren't as easily saturated.	
1:8 or 1:10 Input	● Lots of extra free voltage gain. A 1:10 with the stock build, for instance, will give you 63 decibels right out of the gate with less noise than if you added that much extra gain via the transistors. ● More likely to clip the first FET. Of course, this might be a bug, not a feature! ● 1:10 transformers also tend to have a different color -- unless the core is physically large, they are more likely to distort than lower ratios, and their bandwidth is often more constricted. If you're building multiple channels, you might consider a higher ratio transformer just to make one of the channels sound different.	● More likely to clip the first FET. Of course, this might be a feature, not a bug! ● Requires higher input impedance. The input impedance in the stock build is high enough to handle it. However, the BJT build would be likely to have trouble with it at higher gains, loading the microphone and affecting the high frequencies. ● Seem to be a little more difficult to find than lower ratios.
1:1 output	● Should experience no impedance problems with loads as low as 600R. ● No additional noise concerns. ● Very easy to find. I see them constantly used for very good prices. ● Low noise.	● No additional free voltage gain.
1:2 output	● Additional free voltage gain added to an already large signal for a better signal:noise ratio.	● Doubles the output impedance (not usually a problem on 10K modern interfaces). ● Output increase can cause

		issues with some lower-headroom interfaces. ● More likely to cause distortion in the output transformer. ● Can sometimes add a little extra hum to the signal because output transformers aren’t shielded like input transformers.
2+:1 output	● This will give you current gain instead of voltage gain. If you have especially low impedance requirements, or want to lower the current requirements of the output stage (for power supply reasons), or need to lower the output, this is worth considering. ● A higher ratio would allow you to use a much lower current output stage, or even omit the output buffer entirely if you don’t care about the significant gain loss.	● Significant gain loss needs to be made up with additional gain in the active components, which can increase noise.

I ended up using 1:4.8 input (Jensen 13k6) and 1:2 output (Carnhill 2281) transformers for the prototypes, even though the project was originally designed around 1:4 and 1:1 ratios. I do plan to make a couple channels with those ratios as well. There are tons of high-quality output transformers that will work.

For the truly adventurous, it’s possible to rewire the Edcor 1:1 (600:600) to 1:2 (150:600). To do this, you have to very carefully desolder the center tap wires on the primary. Measure the resistance to one of the outside lugs from one of the wires, and note which wire connects to which outside lug. Then get a small metal tab and insert it into the open spot on the plastic shell. Resolder the wires where appropriate. Now you can wire the primary in parallel if you wish or in series if you prefer, or I suppose make it switchable for a +6 setting.

Output Stage Notes

Since the output stage was (a) a cause of some serious trouble for me and (b) important for driving the transformer load, I wanted to put a few notes here about it.

1. I’ve incorporated a control voltage for this stage at the immensely helpful suggestion of Jack Orman and PRR on DIYStompboxes. The output current in milliamps will be

roughly the total forward voltages of D2 and D3 times the value of R9 divided by 10. (R8 plays a small role, I think by dividing against R9.) 20mA will drive a 600Ω load very, very well (assuming a 1:1 output transformer), though the original Hamptone circuit on which this is largely based was (probably) shooting for something around 25mA. Your average green LED alone (2V Fv) will get you ~20mA. An LED plus a 1n400x will get you to ~25mA. I ended up using both just so I didn't wonder if I had enough output drive, and it turned out to be good enough for driving a 150Ω load (parallel wiring on a Carnhill VTB2281 into a 600R load). Don't omit these parts or you WILL fry things.

2. Q5 will generate a LOT of heat due to the high current of this stage. You need to use a physically large transistor -- not just something high-voltage -- so that it will be able to dissipate the heat. Something in a TO-92 package isn't likely to survive, which is why I've suggested the 2N2270, a TO-18 metal can transistor that's pretty easy to find (and it sounds quite good to my ear if you decide to use it in one of the gain stages!). You could also use something with a heat sink. R9 will also get fairly hot, which is why it's specified as a higher wattage. Don't use a quarter watt resistor there -- it *will* burn out.
3. If you put in Q4 or Q5 incorrectly -- backwards, wrong pinout, etc. -- you will destroy things, especially R9 and probably the control voltage LED. Be very careful about the pinout of these two transistors. The emitter of Q4 is toward the top of the PCB, and the emitter of Q5 is on the left. Triple check the datasheet before you solder.
4. Q4 was specified as a Darlington in the original Hamptone. I originally expected this one to generate a lot of heat as well, but I've found that it doesn't even get warm. I ended up using the same transistor in my own build -- a BD681 -- because I had them for the voltage regulator, but this is a bit of a pain since the pinout is ECB, so you have to bend two of the (quite thick) pins. This spot doesn't appear to be too picky about what you put in it, and it's probably more convenient to just use your favorite low-noise transistor in this spot. Just verify the pinout (and the maximum voltage) before soldering. The pinout is CBE left-to-right.

Build Variants

Stock FET Build

The stock FET build uses 2x 2SK30A for the gain stages and a BJT transistor buffer with a voltage divider (volume control) for the "gain" pot. Total gain is 146.6x without the transformers. It uses the standard bill of materials.

What's this one good for? I like it on bass and electric guitar, direct or miced, because it tends to sound gigantic, and second in a chain after another preamp to intentionally clip. I'll also reach for it when I *know* I will want to suppress the transients of a louder source -- partly why I like it so much on bass. Even though I've called this the "stock" build, it's actually not my favorite for general use, as it's much more heavily colored than the BJT versions.

For the stock build, jumper R3 and omit C2. These components are not needed.

Suggested build (i.e., how I would build it) -- 48V version with DI

Resistors		R14	Omit	C10	47µF
R1	1M	R15	22K	C11	47µF
R2	22K	R16	33K	**Potentiometers**	
R3	Jumper	R17	47Ω	Gain	10KA
R4	1k5	**Capacitors (all >=50V)**		Pad	250KA
R5	1M	C1	220nF	Bias1, Bias2	250K multi-turn
R6	22K	C2	omit	**Semiconductors**	
R7	2k2	C3	220nF	Q1 & Q3	2SK30 Y
R8	22K	C4	47µF	Q2, Q4, Q5	2N2270
R9	100Ω 2W	C5	470µF	Q6	Jumper
R10	470Ω	C6	220nF	D2	Green LED
R11	6k8 0.1%	C7	Omit	D3	1N4001
R12	6k8 0.1%	C8	Omit	INPUT XFO	1:4.8 Jensen
R13	50Ω 2W	C9	470µF	OUTPUT XFO	1:2 (or 1:1) Edcor

24V Version (safer for lower-voltage FETs)

Resistors		R14	10K	C10	47µF
R1	1M	R15	22K	C11	47µF
R2	22K	R16	33K	**Potentiometers**	
R3	Jumper	R17	47Ω	Gain	10KA
R4	1k5	**Capacitors***		Pad	250KA
R5	1M	C1	220nF	Bias1, Bias2	250K multi-turn
R6	22K	C2	omit	**Semiconductors**	

R7	2k2	C3	220nF	Q1 & Q3	2N5457**
R8	22K	C4	47µF	Q2, Q4, Q5	2N2270
R9	100Ω 2W	C5	470µF 50V+	Q6	BD681G
R10	470Ω	C6	220nF 50V+	D1	25V Zener 5W
R11	6k8 0.1%	C7	47µF 50V+	D2	Green LED
R12	6k8 0.1%	C8	470µF	D3	1N4001
R13	50Ω 2W	C9	470µF	INPUT XFO	1:4.8 Jensen
				OUTPUT XFO	1:2 (or 1:1) Edcor

*25+ except where noted. **Twist the leads!

Pros:

1. Distortion from the FETs is softer and more pleasant than many other types of transistors.
2. Fewer components than the 5-BJT build.
3. Very high input impedance.
4. Excellent bandwidth.

Cons:

1. Current draw is a little higher than the BJT versions.
2. Cost is higher -- the specified 2SK30s (to run the pre on 48V) are $1 each and not easy to find everywhere.
3. The biasing is a little touchy.
4. Noise is slightly higher than some other builds.
5. Lowest total headroom of all versions, due to the quirk of FETs that they will distort when the signal size on their input exceeds a certain voltage. With a 2SK30, that's about 1.2V-1.6V. Accordingly, you may have to pick your gains to accommodate either low output mics (which means more idle noise and lower headroom) or high output mics (which means less gain).

Stock BTJ Build

The 5-BJT build uses all five transistor slots on the PCB for gain staging similar to (or identical to) the FET build. It's a little cheaper to build. When built to run on voltages lower than the full 48V, you can also build this version to use NPN germanium transistors.

What's this one good for? I didn't actually box up the prototype of this version up as I preferred the 4-BJT version. However, the usages are similar (see the notes below), with the added bonus of being able to control the output volume instead of simply the gain. If you're running this version on 48V, you may not even need the pad -- the headroom is very high.

Make the following substitutions: Use a low-noise BJT that can handle 48V in Q1 and Q3. (2N2270 or 2N4401 are both great choices.) Jumper R4 and omit C2. These components are not needed on this build.

Suggested build (i.e., how I would build it) -- 48V version with DI

Resistors		R14	Omit	C10	47µF
R1	1M	R15	22K	C11	47µF
R2	22K	R16	33K	**Potentiometers**	
R3	Jumper	R17	47Ω	Gain	10KA
R4	1k5	**Capacitors (all >=50V)**		Pad	250KA
R5	1M	C1	220nF	Bias1, Bias2	250K multi-turn
R6	22K	C2	omit	**Semiconductors**	
R7	1k5	C3	220nF	Q1-Q5*	2N2270
R8	22K	C4	47µF	Q6	Jumper
R9	100Ω 2W	C5	470µF	D2	Green LED
R10	470Ω	C6	220nF	D3	1N4001
R11	6k8 0.1%	C7	Omit	INPUT XFO	1:4.8 Jensen
R12	6k8 0.1%	C8	Omit	OUTPUT XFO	1:2 (or 1:1) Edcor
R13	50Ω 2W	C9	470µF		

*2N4401 is a good low-noise sub for all but Q4.

Pros:

1. Higher headroom, gain, and output available than in the FET build.
2. Low current requirements for the gain stages.
3. Good bandwidth.
4. A little easier to bias.
5. Lower input impedance --- the DI will not be as quite as sparkly.

Cons:

1. Does not clip as gracefully as the FET build.
2. Too much output for most (all?) interfaces when run on 48V if you want to push the pre to clipping. For this reason, I highly recommend building this version to run on 24V.

Alt Gain Build --- 4-BJT build (Si or Si/Ge hybrid)

The 4-BJT build uses the negative feedback gain control on the first stage rather than the voltage divider between stages. Consequently, the buffer for the volume pot is no longer necessary, saving some parts. Like the 5-BJT build, if you use the voltage regulator, you can also build this version to use NPN germanium transistors. The 4-transistor version, with a germanium in Q1, was my favorite variation.

What's this one good for? Anything where you want a big dynamic range, and very slightly softened (but not *clipped*) high-frequency transients. Out of the preamps on my shelf, the germanium 4-BJT build of this is my favorite on acoustic instruments (guitar, mandolin, and banjo) and clean electric guitar and often my first choice for vocals. It's also good when you want the bass to stand out.

For the 4-BJT build omit Q2, and wire the "Alt Gain" pads to the control panel PCB's connections for Gain 3&2 with a 10KC pot. Use a 10K for R7, lowering the gain of stage 2 to ~2x. Use an 11K for R2, 10K for R4, and 150R for R3. Jumper C4. Gain of the first stage is now variable from just over 1x to up to 73x (be sure your transistor can supply this), with the total gain factor being ~160. There are other ratios you could use to change the gain staging, but these are the values I used.

Suggested build (i.e., how I would build it) -- 48V version with DI

Resistors		R14	Omit	C10	47μF
R1	1M	R15	22K	C11	47μF
R2	11K	R16	33K	**Potentiometers**	
R3	150Ω	R17	Omit	Alt Gain	10KC
R4	10K	**Capacitors (all >=50V)**		Pad	250KA
R5	1M	C1	220nF	Bias1, Bias2	250K multi-turn
R6	22K	C2	omit	**Semiconductors**	
R7	10K	C3	220nF	Q1, Q3-Q5*	2N2270
R8	22K	C4	47μF	Q2	Omit

R9	100Ω 2W	C5	470µF	Q6	Jumper
R10	470Ω	C6	220nF	D2	Green LED
R11	6k8 0.1%	C7	Omit	D3	1N4001
R12	6k8 0.1%	C8	Omit	INPUT XFO	1:4.8 Jensen
R13	50Ω 2W	C9	470µF	OUTPUT XFO	1:2 (or 1:1) Edcor

*2N4401 is a good low-noise sub for all but Q4 & Q5. Seriously, don't use one in Q4 or Q5.

24V Germanium version

Resistors		R14	10K	C11	
R1	1M	R15	22K	**Potentiometers**	
R2	11K	R16	33K	Alt Gain	10KC
R3	150Ω	R17	Omit	Pad	250KA
R4	10K	**Capacitors***		Bias1, Bias2	250K multi-turn
R5	1M	C1	220nF	**Semiconductors**	
R6	22K	C2	470µF	Q1	2N1306**
R7	10K	C3	220nF	Q2	Omit
R8	22K	C4	47µF	Q3-Q5***	2N2270
R9	100Ω 2W	C5	470µF 50V+	Q6	BD681G
R10	470Ω	C6	220nF 50V+	D1	25V Zener 5W
R11	6k8 0.1%	C7	47µF 50V+	D2	Green LED
R12	6k8 0.1%	C8	470µF	D3	1N4001
R13	50Ω 2W	C9	470µF	INPUT XFO	1:4.8 Jensen
		C10	47µF	OUTPUT XFO	1:2 Carnhill

*25V+ except where noted. **Suggested because its C-E voltage is definitely high enough! ***2N4401 is a good low-noise sub for all but Q4 & Q5.

Pros:

1. Fewer parts needed.
2. Lower noise with lower-gain settings because the gain is not fixed.

3. Most possible headroom and dynamic range.
4. Easy to get extra gain. (Just use a lower value for R7.)

Cons:

1. Less clipping from the transistor(s), except with high output microphones and instruments.
2. Less bandwidth. Because most of the gain is coming from a single device, the Miller effect becomes much more of a concern. You always trade bandwidth for gain.
3. Lowest input impedance. Again, because most of the gain is coming from the input device, the input impedance will necessarily be lower. You may not want to use this for going direct with a single-coil guitar, for instance.
4. Too much output for most (all?) interfaces when run on 48V if you want to push the pre to clipping. For this reason, I highly recommend building this version to run on 24V.

Quick note: In my germanium build, the Bias1 trimmer had to be set fully to 9V to bias Q1 close to half supply. It sounded very good, so I decided not to fret about that.

Something Close to the Hamptone FET preamp from Tape Op

The board is set up for building a slight variant of the Hamptone FET preamp, on which this design is primarily based, with some changes (some of which I consider improvements): Q2 replaces the unnecessarily high current draw of an extra two-transistor output stage; the output capacitor has been increased in size and uses a (much easier to find and fit) 47µF electrolytic; and the output stage uses a control voltage to set the output current instead of relying on the gain of the transistors used, which frequently resulted in destroyed components. (Ask me how I know!)

Make the following substitutions from the stock build: Use the “GR” gain bucket for the 2SK30s (this is close enough to the 2N5457), or you can twist the leads on a pair of 2N5457s. Jumper the Alt Gain pads. Use a 1.8K resistor for R4, 50R for R3, and 560R for R7. (This last value is different from the original but bumps the gain up.) Include C2. Install the voltage regulator components for 24V-30V. (Some people report improvements running on 30V, but keep in mind that the output level at that voltage may clip your interface.) The original suggested a 1:10 input transformer.

It’s a dirty, dirty boy.

Voltage Regulator

Although the FET version preamp is intended to be run on 48V, there are several reasons you may want to consider including the voltage regulator to bring down the voltage:

1. Greater choice of transistors. At 24V, you can safely use any FET in your parts drawer or even some germanium transistors for the BJT build. At 30V, there are a host of great choices. I still think that the 2SK30 is the best choice for the gain stages due to its exceptionally low capacitance and nice clipping.
2. More power filtering. You can use larger value filter resistors to cut down on power supply noise if needed.
3. To manage output. If you want to build a version with more clipping, you're going to want a lower supply voltage to help facilitate that.

Adding an Output Level Control?

While this project is hardly intended as a distortion box, the lack of an output control makes it basically impossible to use it as one if you're recording into a digital interface -- you'll clip the converters pretty easily. Unless you're using FETs in both stages, you aren't getting much if any distortion at all without cranking the gain. My solution was simply to build two channels and chain them, and use the volume control on the second to set the final output level. But if you only build one channel, that's not going to work. So I thought I'd add a note of a couple ways to implement an output control.

The simplest and cheapest method is to use a 1KA or 5KA pot hooked up like a normal volume control at the output of the main PCB. If you use the 1KA, use a 100µF for the output capacitor (C4) and you will be fine for everything except the lowest subs. You would then connect the wiper to the output transformer.

Another way would be to use a balanced attenuator pot after the transformer. These are 3-gang pots that typically have 600 or 500 Ohms on the two outside gangs, and either 600R or 1K in the center. It provides a constant load on both sides and works fairly well. These are often used as input pots. Unfortunately, they're often expensive and can be tricky to wire

The third way (one which also offers the absolute best control and repeatable settings) is to use a 2-pole 12-position rotary attenuator at the output. This works essentially the same way as the pad, but it's broken up into discrete settings. I recommend reading this to work out the details on your own.

EQ Add-On

Work in progress. The EQ will be passive and designed to go between the gain pot and Q3.

Potential Compressor Add-On.

The "alt gain" pads provide an opportunity to add a feedback compression circuit like the Bearhug. Unfortunately, while the actual implementation turned out to be fairly easy, I ran into two serious snags: (a) developing a proper metering system that can be matched to the exact behavior of the audio path proved exceedingly complicated, and analog compression without metering is probably not super useful for most people; and (b) there is sometimes some crackling when the compression kicks in in some builds, perhaps due to leakage across the electrolytic capacitor, but rare though it might be it's not acceptable to me. Accordingly, I've decided to shelve this idea for now at least until I can identify a proper meter driver.

How It Works

Keep in mind that I am just a guy with a breadboard, ears, and a dream, not an electronics wizard. This is the best explanation I can offer for how the circuit works. All things considered, I find transformer-balanced circuits to be a little easier to grasp than some other solutions.

XLR and Instrument Input Section

The microphone input is stepped up through the input transformer; the amount depends on your input transformer ratio. The pad follows. We can either match the impedance for the best possible noise performance (which would lose 6dB), or bridge it for the best possible gain performance. I chose to bridge the input impedance of the microphone, which is the more modern way of doing things. This means using an impedance that's ten times the actual impedance, for minimal gain loss.

If every microphone had a 150Ω termination this would be easy. The transformer turns that into 3.5K. Ten times that is 35K and the nearest pot value that's ten times that high is 50K. But a 600Ω mic would require a 138K pot, and a 1KΩ termination like on the Sennheiser e609 I have sitting in front of me requires 230K. Some ribbon mics with very thin foil may have higher requirements. So I went with a 250K pot, with a minimum resistance enough to make the pad's lowest setting -18dB. Feel free to change things around. Another thing worth considering is that if you have special impedance requirements for a microphone (for instance, an SM57 sounds far better with a lower input impedance), it's probably easier to simply put a pot in a box between the pre and the microphone and dial it in, or to add a pot to the front panel to reduce the impedance on the primary side. The other reason to use a high value for the pot is that it divides in parallel with the 1M gate resistor on Q1; and, if you use a BJT in that setting, when the gain goes up, the input impedance drops, in which case, the 250K could look a lot smaller to a mic that needs the extra gain. If you use a smaller pot, remember that you need to change R16's value as well. A voltage divider calculator is here.

There's a bit of hiss with the pad, but very little of it with a condenser microphone and no hiss at all with my tube mic (a D251 build) in any pad position. A dynamic isn't likely to require padding[1], so there are very few situations where the hiss will be a relevant concern. The pad also can add shades to the tonality because, as a large resistive divider, it does shave off some treble. However, I recognize that the extra noise is a problem for some people, so I made and shared on Osh Park an alternate switched pad version of the control panel. The wiring is a bit different.

I've suggested a switched jack for the DI, one that disconnects the tip from the secondary when something is plugged in. The FET input is more than high enough for a passive guitar or bass. A piezo pickup might want a buffer. My guitar going direct actually sounds pretty good. A bass also sounds good. Also, just a thought: The instruments could go through the DI and still

[1] And if it does, you probably don't want to be in the area of whatever it is you're recording.

have an ~1M input impedance if you make the gate resistor 22M. This would let you use a cheaper jack, but would only work with a FET build, would increase hum, and the extra gain really really isn't needed for any guitar I'm aware of.

Preamp gain stages

The signal enters at a 220nF capacitor to remove any DC from the input. A 1M resistor appears at the gate of the FET (or base for a BJT[2]) and is referenced to a bias trimpot that pans between the supply voltage (~48V in the stock build, or e.g. ~24V with the voltage regulator) and ground. When the trimpot is turned up toward the supply voltage, the voltage at the drain (or collector) will fall, allowing us to set the drain voltage without altering our gain ratio. A large capacitor filters out noise at the bias node. This is sometimes called "noiseless biasing." A multiturn trim is best here because the range for a FET to be dialed in will be really small, and below half a volt.

The ratio between two resistors set the voltage gain in the stock build: R3/R2. With the suggested 1k5 and 22K, we'll get 14.66x gain. You could make fine adjustments to the amount of gain of the whole box by including R3, but I simply used a jumper for that resistor because I had enough gain for my purposes. You could also include R3 at some small value (e.g. 50Ω and and bypass R4 with C2 to get a really big gain factor. This is what the original Hamptone FET preamp did. All the usual tradeoffs of getting lots of gain apply in that case: less bandwidth, more miller capacitance, more noise, no clean headroom ...

The drain is DC-coupled to the base of Q2, which is a simple unity gain buffer. We might lose 0.1x gain here with a lower gain transistor, but that's peanuts. DC coupling is useful because it saves a capacitor and a biasing resistor, which ensures that all frequencies pass. In the stock build, the emitter of Q2 is connected to ground via the "gain" pot, which is a voltage divider between ground and the emitter output. When it's turned all the way up, no signal is attenuated to ground except a trivial amount lost by the output impedance of the transistor (which is rarely more than a couple hundred ohms) divided against the value of the volume pot. The 10K value of the pot keeps a good amount of current flowing.

I've suggested using the gate bias of Q1 to set the emitter of Q2 at half of the voltage supply. This means that the buffer will have a symmetrical output, even though the FET might bias asymmetrically. This is fine in my book -- my favorite FET circuits use ⅔ biasing.

You could, if you wanted, use the FETzer valve resistors values for gain stage 1. The output is, if I recall correctly, about 33dB on 48V. That's … kind of a lot, and that's without the input transformer or the second gain stage. You would use an 18K for R2 and a 390R for R3. I'd make the 390R a half-watt at least if you decide to go that route, because the current requirements will be quite a bit higher. In that case, you would adjust the drain of Q1 to 31V and

[2] I will refer to the FET pins from here on out, but everything I write will apply to either type of transistor.

ignore the voltage on the emitter of Q2. Chances are decent that you could simply ground the gate and get very very close to ⅔ supply.

The second gain stage repeats gain stage 1, except that the gain is a little lower, 10x.

The voltage divider in between the stages in the stock version attenuates to -26dB on the lowest setting. This isn't a lot on its own, but it's enough that the absolute maximum output of the previous stage (assuming a 48V supply) will be knocked down to just 0.225V, and it's 3dB less gain that what's added by the previous stage. Together with the pad, this gives a total of 42dB of control over the signal strength going into the second gain stage.

Why did I pick these gain factors (14.66x for the gain in stage 1 and 10x for stage 2 of the stock build), aside from the convenience of standard values? A 2SK30 will clip with about 1.2V-1.6V on its gate (this is the Vp) according to Runoff Groove's testing. My (perhaps incorrect) assessment is that this is the maximum negative swing of a wave before the FET enters cutoff and so that's the biggest the input signal at the FET will get. The exact voltage varies quite a bit because FETs are delicate little snow flakes, but 1.4V is about the center of the bell curve. A 1.4V signal at 14.66x voltage gain ends up at ~20V. And since our supply voltage is 48V (probably less, actually), we know that regardless of the signal size going *into* Q1, we can't possibly get a signal larger than 48V.

If the 10KA gain control set at 0 at 10,000/47R, this means that the signal size could be attenuated from 48V down to 0.225V before hitting the second FET; even if the first FET was overdriven, and even if the first stage were using every ounce of the 48V supply (e.g. if a BJT is used), the resulting output signal (2.25V) would be around +4dBU[3]. Initially I had some trouble with my interface (a Focusrite Scarlett) clipping -- it turned out that the converter headroom was a little lower than the published specs and far below that of the analog circuitry. After some experimentation, I found I could get away with a signal of ~9V into the rear line ins (the front line ins had more headroom). I ended up wiring my output transformer as 1:2 for some extra free gain, so a 47R was the largest minimum resistance I could get away with in the most stressful situation I was able to come up with: A tube mic with the pad off being hit with a signal just below the overmodulation threshold of the microphone itself. I know some better converters (like Apogee, RME, Universal Audio, etc.) can take a larger signal than my Scarlett, and the extra output could be useful for a compressor or EQ or for burning a track into real tape.

One other quick note about the voltage divider control: It's not decoupled from the buffer. Doing so would have required a large capacitor, and unless I wanted to use the gigantic 10µF film capacitor of the original (1µF isn't enough to retain full bass), this meant a second electrolytic capacitor in the audio path. The drawback is that the pot can develop DC across it, and this means that it crackles.

I'm "okay" with this (pun very much intended). To me the benefit of avoiding that capacitor outweighs the unlikely scenario that I need to adjust the gain *during* a take because I

[3] It's actually +4.4dBU. If you want +4dBU, a 39R will do that almost exactly.

forgot to set it to a safe level beforehand -- nevermind the lack of a free hand to do so if I'm recording myself.

Output Buffer and Transformer

The output stage is a high-current buffer. The top transistor is the load, and the lower transistor is responsible for driving that load. Some diodes on the base of Q5 provide a control voltage that helps set the current through the transistor. In the original Hamptone circuit, the hFE of the transistors was likely lower than most modern parts, and without it current gain is absurdly large. Large enough to set fire to a substantial number of parts. The emitter resistor of Q1 appears to be partly responsible for the output impedance and current. Unfortunately I can't really describe this section better, because I don't fully understand it except it worked. You can read the thread about it (and watch me get very frustrated) here. There are also more notes about it above.

The output cap is 47µF. Yes, it's electrolytic, but it's going to be a low ESR electrolytic, right? A gigantic 10µF capacitor like what was in the FETboy/Hamptone might conceivably sound *slightly* "better," but there's plenty of precedent in classic circuits (like Neve preamps) for using an electrolytic. And a 10µF film capacitor is half the size of the PCB as it exists. Again, not worth it to me.

All that's left at that point is to balance the output. A transformer handles this perfectly and simply and sounds good, so that's what I decided to use. The primary is connected to the PCB output and ground, and then the secondary is connected to the XLR.

Acknowledgments: I am hugely indebted to many people in that thread (Garcho, Transmogrifox, Tubegeek, Hymenoptera, PRR, and Jack Orman) for helping me with the problems in this part of the preamp and helping me correct some misunderstandings in the application of Ohm's law. I literally could not have finished this project without them. Also, thanks to Jubal81 (Jason Lilly) for suggesting gate biasing and fixed gain staging for the FETs, which really made it a better project overall. Hamptone for sharing the original FET preamp on which this was partially based in TapeOp magazine. Runoff Groove for the Omega, which inspired the first gain stage.