Ship Of Theseus: compatible, interchangeable amp modules

by Mark Johnson [rev 2022 March 02]

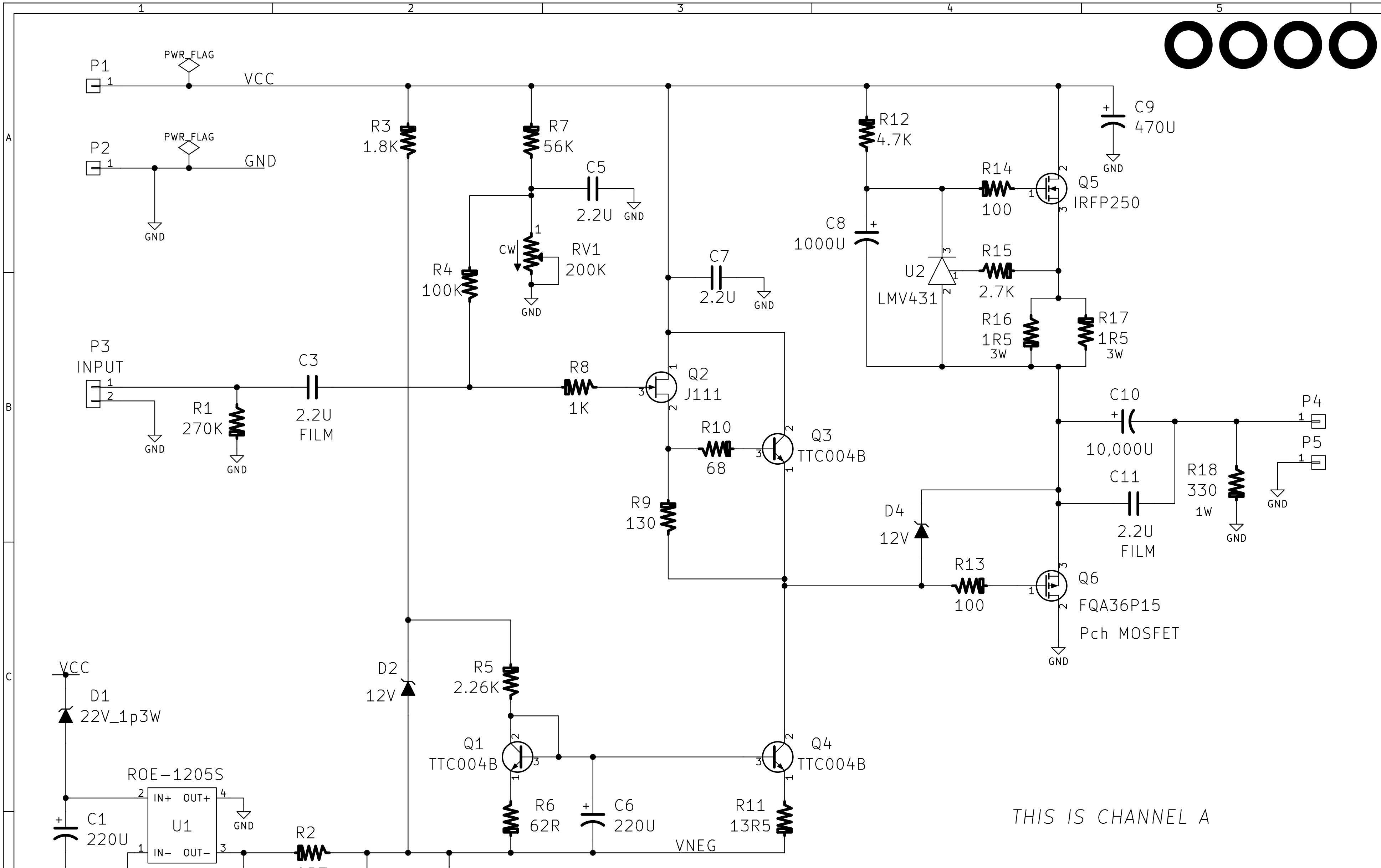
This project extends the limited-edition Nelson Pass / diyAudio “VFET” kits, by introducing several new circuit modules which are compatible and interchangeable with the modules in the original kit. At this writing, the Ship Of Theseus includes seven new Front End cards, a new PSU filter card (with turnoff thump suppression), and a new output stage card which uses active-production MOSFETs instead of rare and obsolete VFET transistors.

Owners of an original VFET kit can experiment with different Front Ends to customize their amplifier, and tailor it to their own sonic preference. They also can drop in the new PSU filter card, to enjoy its turnon/turnoff thump reduction and improved 120 Hz filtering.

Builders without an original VFET kit will need Front End cards, a PSU filter card, and output stage cards. The Ship Of Theseus portfolio of choices, provides several possibilities.

MOSFET Output Stage

A Pchannel MOSFET (Q6) drives the output, operating as a source follower in Class A. 1.6 amperes of constant current bias are provided by Q5 and the IC shunt reference U2. Q2 and Q3 drive the substantial gate capacitance of Q6. Because Q6 is an “enhancement mode” PMOSFET, its source voltage is always higher than its gate voltage. To increase the available output swing on negative peaks, the gate of Q6 is fed by a special power supply module (U1) that provides negative five volts (circuit node “VNEG”). Variable resistor RV1 adjusts the quiescent voltage on the source pin of Q6. It should be set to half of the supply voltage.



REV.B 23 JAN 2022

THESEUS-MOS OUTPUT STAGE	
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Title:	
Size: USLetter Date:	**Rev:**
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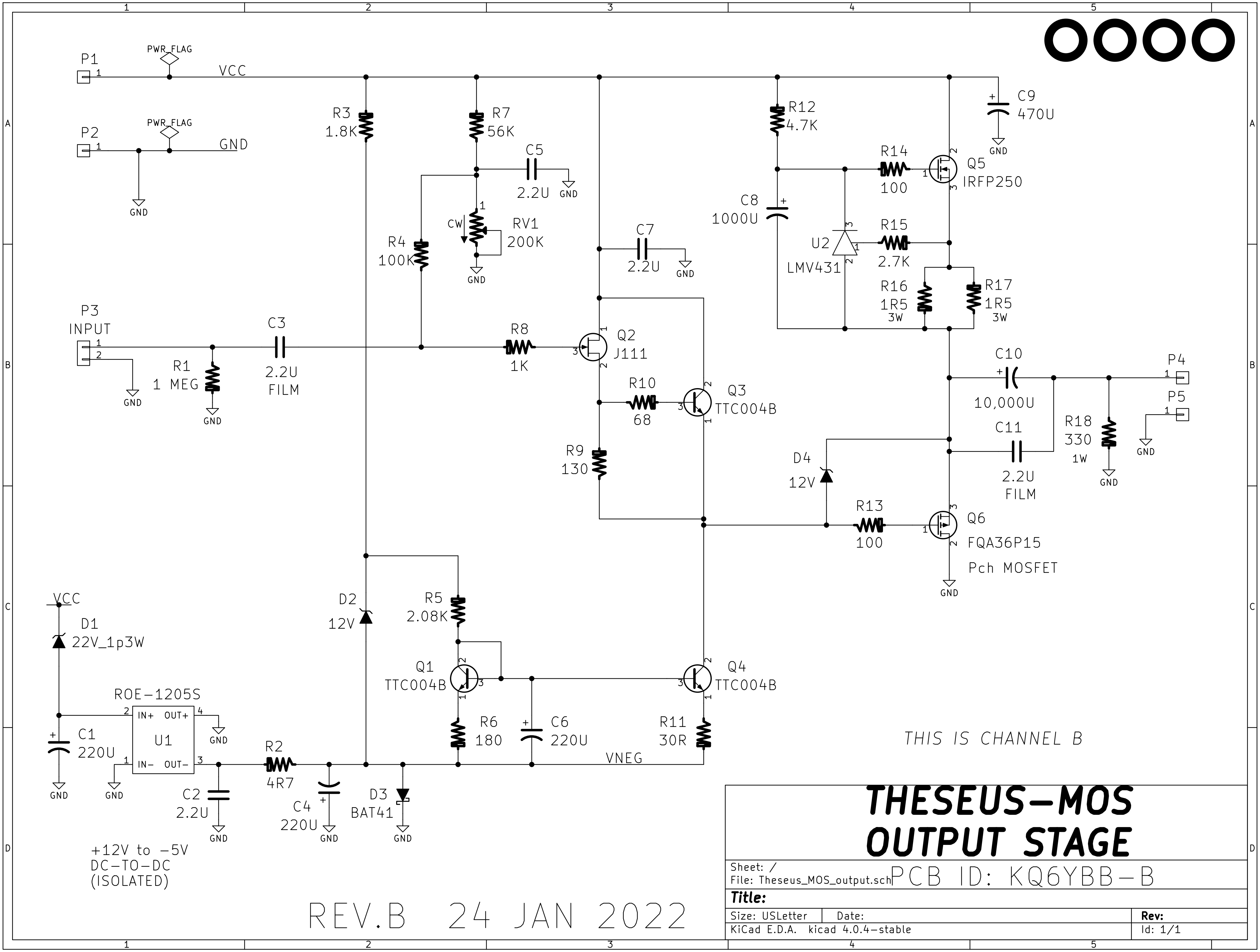
P1
PWR_FLAG
VCC
P2
PWR_FLAG
GND
GND
P3
INPUT
GND
R1
1 MEG
GND
C3
2.2U
FILM
R3
1.8K
R7
56K
C5
2.2U
GND
RV1
200K
CW
GND
R4
100K
R8
1K
Q2
J111
C7
2.2U
GND
R10
68
Q3
TTC004B
R9
130
R12
4.7K
C8
1000U
U2
LMV431
R14
100
Q5
IRFP250
R15
2.7K
R16
1R5
3W
R17
1R5
3W
C9
470U
GND
C10
10,000U
P4
P5
GND
C11
2.2U
FILM
R18
330
1W
GND
D4
12V
R13
100
Q6
FQA36P15
Pch MOSFET
GND
VCC
D1
22V_1p3W
ROE-1205S
U1
IN+
OUT+
IN-
OUT-
GND
C1
220U
GND
GND
C2
2.2U
GND
R2
4R7
C4
220U
GND
D2
12V
D3
BAT41
GND
R5
2.08K
Q1
TTC004B
R6
180
C6
220U
Q4
TTC004B
R11
30R
VNEG
+12V to -5V
DC-TO-DC
(ISOLATED)
THIS IS CHANNEL B
REV.B 24 JAN 2022
THESEUS-MOS
OUTPUT STAGE
Sheet: /
File: Theseus_MOS_output.sch
PCB ID: KQ6YBB-B
Title:
Size: USLetter
Date:
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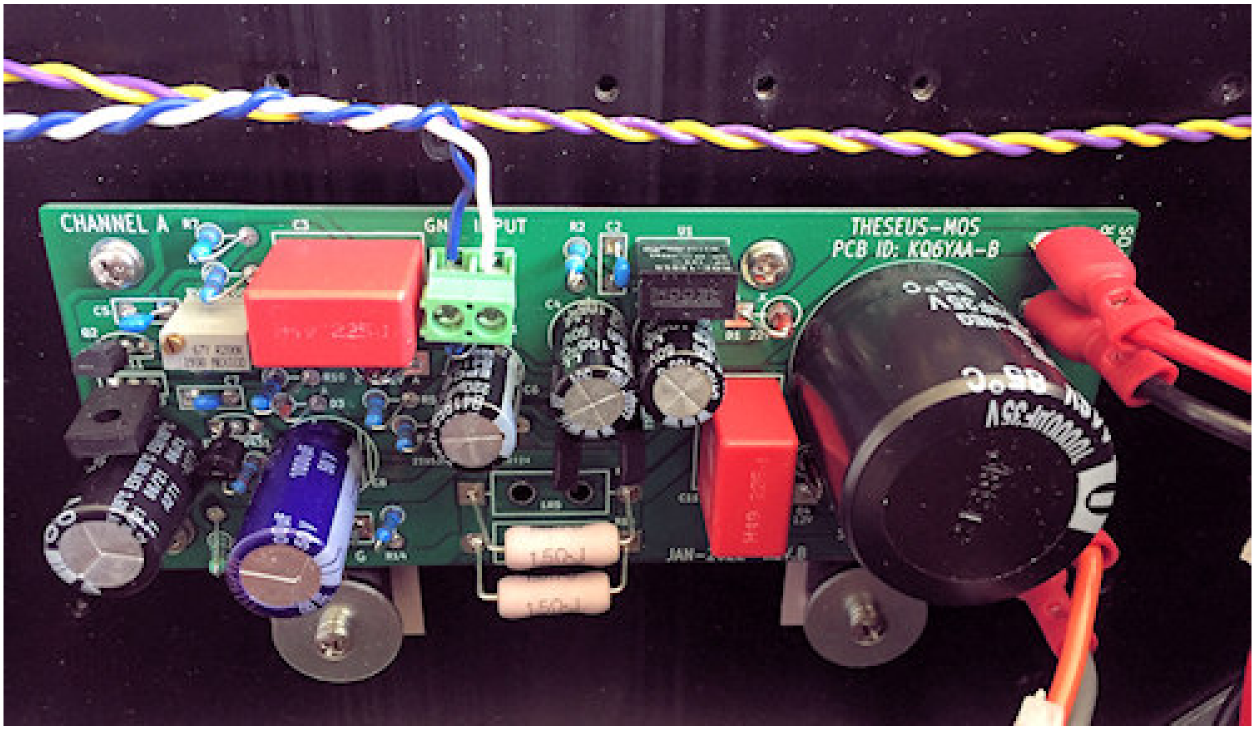


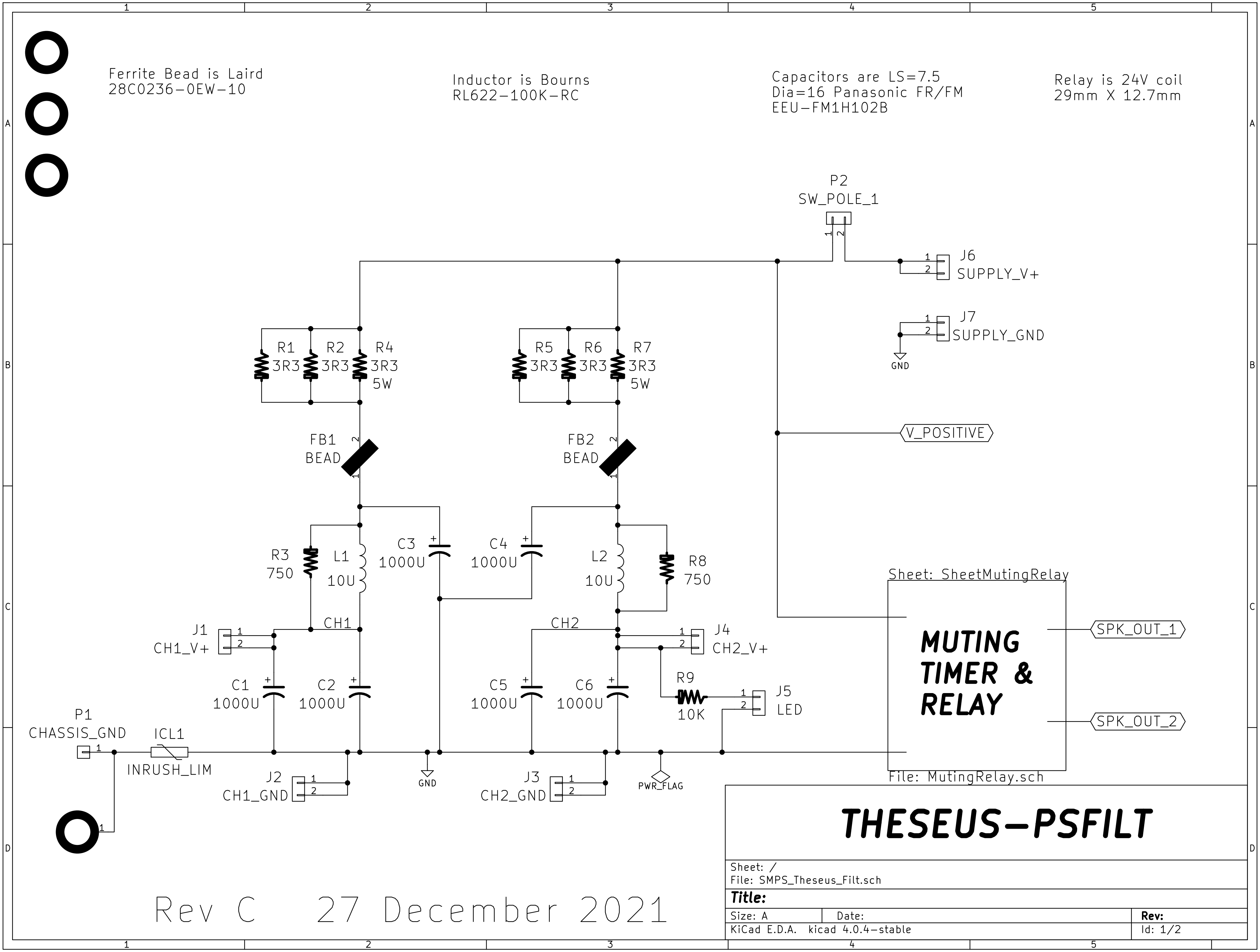
Photo 1: MOSFET output stage card. FastOn blade connectors at right

Its circuit topology closely follows the original Pchannel VFET circuit design, which had a P-type VFET follower and a 1.6 amp constant current load, provided by an IRFP250.

PSU Filter Card

Two different PSU filter cards were provided with the original VFET kits from the diyAudio Store. One card (containing an LC filter) came with the Pchannel VFET kits, and another card (containing an RC filter and a thump suppression relay) came with the Nchannel VFET kits. To remain backward compatible with both types of VFET output cards, this new Ship Of Theseus filter contains both an LC filter (L1-C1) and an RC filter (R1-C3). Ferrite beads were added, for additional high frequency noise filtering.

A more elaborate circuit for thump prevention (2nd schematic page) was included, giving user-selectable muting time at turn on, and near-instantaneous muting at turn off.


Ferrite Bead is Laird
28C0236-0EW-10
Inductor is Bourns
RL622-100K-RC
Capacitors are LS=7.5
Dia=16 Panasonic FR/FM
EEU-FM1H102B
Relay is 24V coil
29mm X 12.7mm
P2
SW_POLE_1
J6
SUPPLY_V+
J7
SUPPLY_GND
GND
R1 3R3
R2 3R3
R4 3R3 5W
R5 3R3
R6 3R3
R7 3R3 5W
V_POSITIVE
FB1
BEAD
FB2
BEAD
R3
750
L1
10U
C3
1000U
C4
1000U
L2
10U
R8
750
Sheet: SheetMutingRelay
MUTING
TIMER &
RELAY
File: MutingRelay.sch
SPK_OUT_1
SPK_OUT_2
J1
CH1_V+
CH1
CH2
J4
CH2_V+
C1
1000U
C2
1000U
C5
1000U
C6
1000U
R9
10K
J5
LED
P1
CHASSIS_GND
ICL1
INRUSH_LIM
J2
CH1_GND
GND
J3
CH2_GND
PWR_FLAG
Rev C 27 December 2021
THESEUS-PSFILT
Sheet: /
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Title:
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Date:
Rev:
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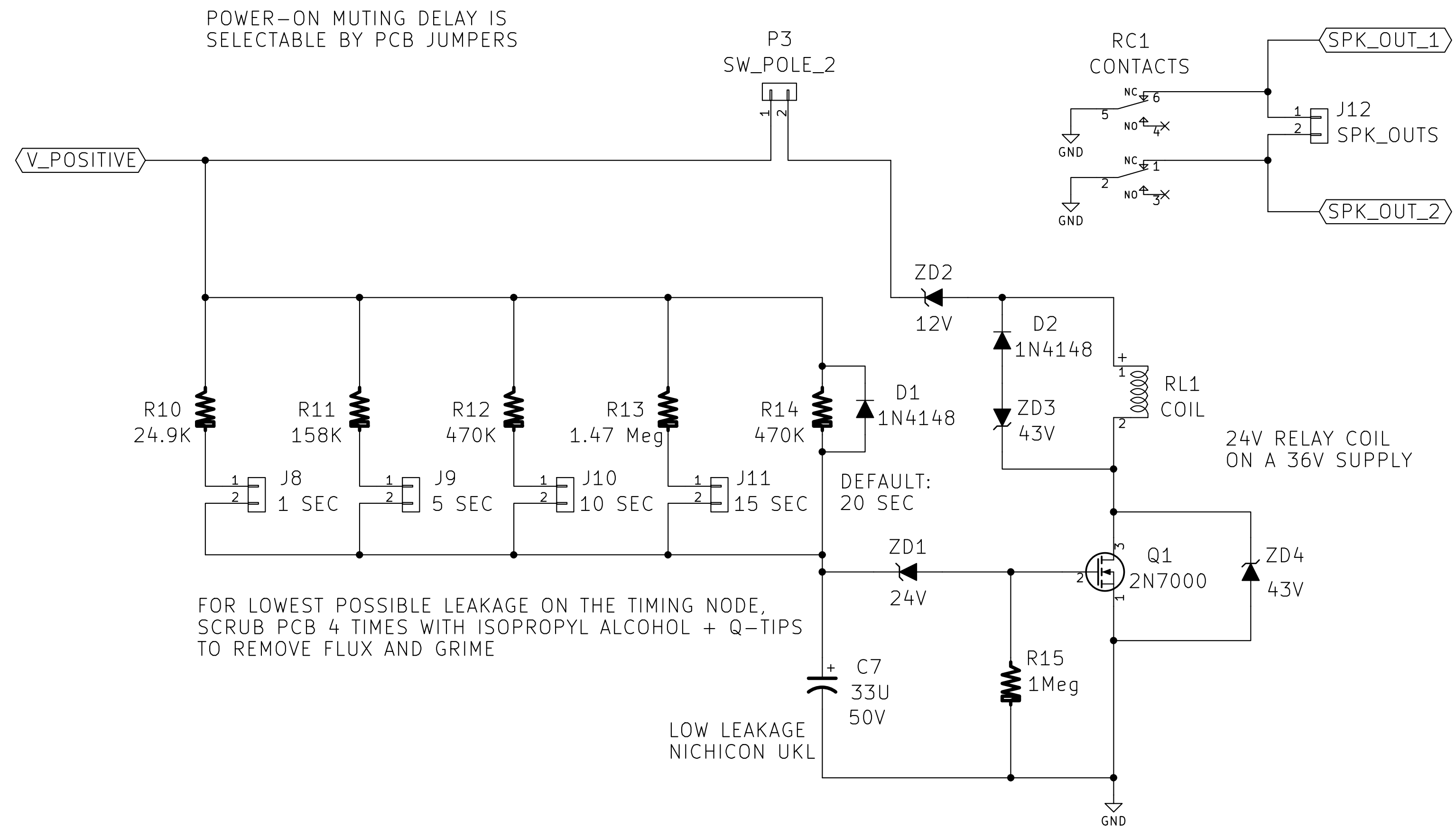

MUTING RELAY FOR THESEUS-PSFILT

Sheet: /SheetMutingRelay/
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Title:

Size: A4 Date: **Rev:**

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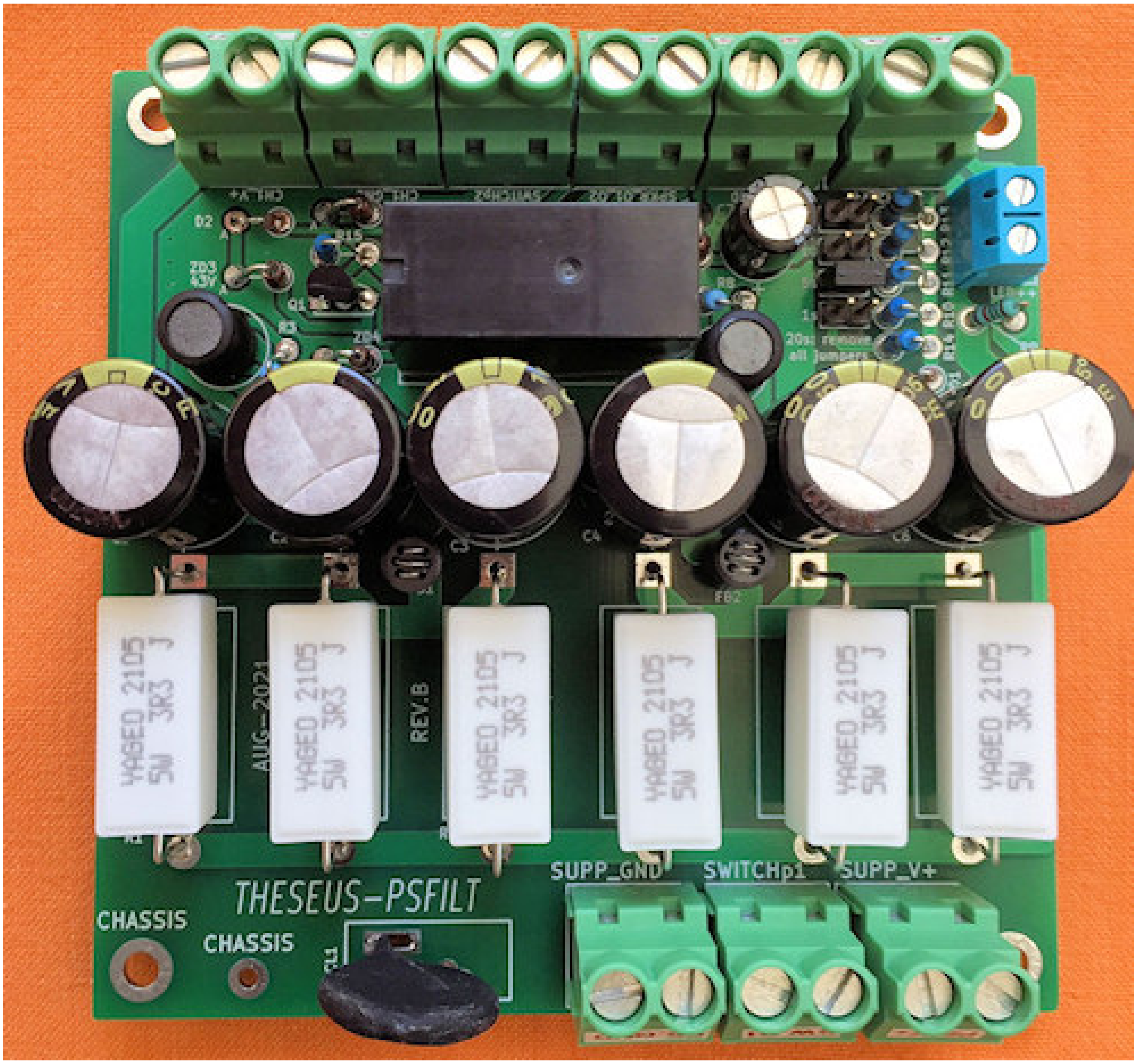


Photo 2: PSU filter card. Muting relay at top center

Front End cards

Ship Of Theseus provides seven new front ends, in addition to Nelson Pass's original card (Toshiba JFETs) shipped with the diyAudio kits, and in addition to the Scourge, Bulwark, Marauder, and Dreadnought cards sold by the diyAudio Store. These new cards are named for American warships. A brief summary of their features is presented here; more thorough discussions follow.

Nimitz is a customizable Front End which accepts M2x daughter cards. Builders can bolt whichever M2x card they wish into Nimitz, and that becomes the Front End for a VFET or Theseus amplifier.

Missouri is a Front End that accepts balanced inputs. It uses the highly regarded THAT-1200 differential receiver IC for maximum CMRR

Bon Homme Richard is a high performance opamp (AD797), plus a discrete JFET input stage, fed by a shunt-mode voltage regulator for maximum PSRR

Kitty Hawk is a transconductance (current output) amplifier, which uses a Rush Cascode input stage: PNP follower + NJFET common gate.

Lexington is a folded cascode discrete opamp, using a self-generated high voltage supply ("JBOOST2") and no Edcor transformer. The boost circuit includes an isolated DC-to-DC converter module plus extensive filtering.

Hornet is a discrete opamp whose unusual all-JFET output stage has no degeneration resistors. The supply filter is cascoded, each of the two constant current sources are cascoded, and the input is a Rush Cascode.

Pequod was Captain Ahab's whaling ship in "Moby Dick." Although not a warship, it was American. The Pequod Front End is a simple opamp follower with few parts and relatively modest parts cost. It accepts either dual opamps (e.g. LM4562) or single opamps (e.g. LT1122) and the two opamp sockets are surrounded by blank empty zones, making it easier to fit discrete opamp modules such as Sparkos or Burson, if desired.

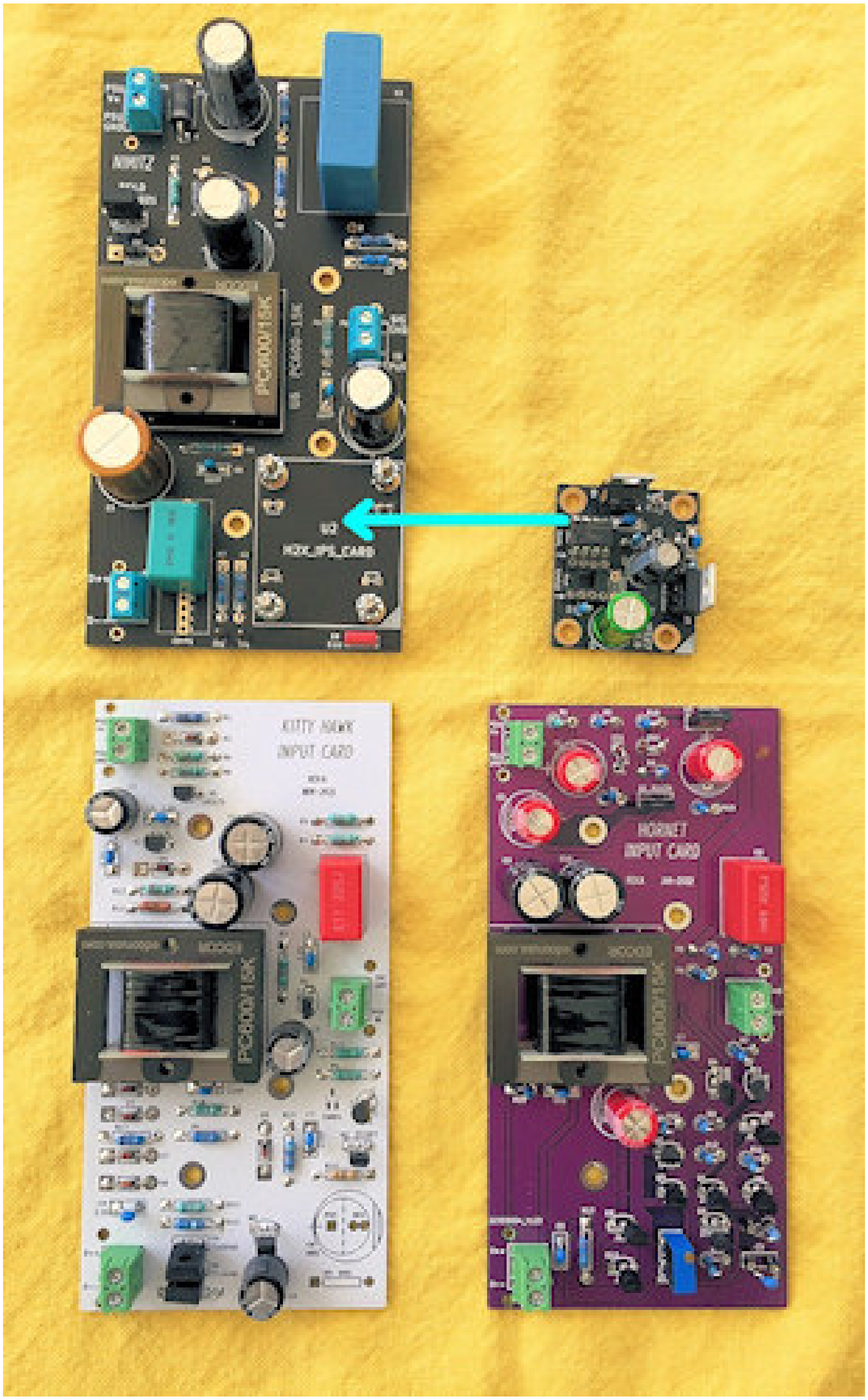


Photo 3: Nimitz, daughter, Hornet, Kitty Hawk

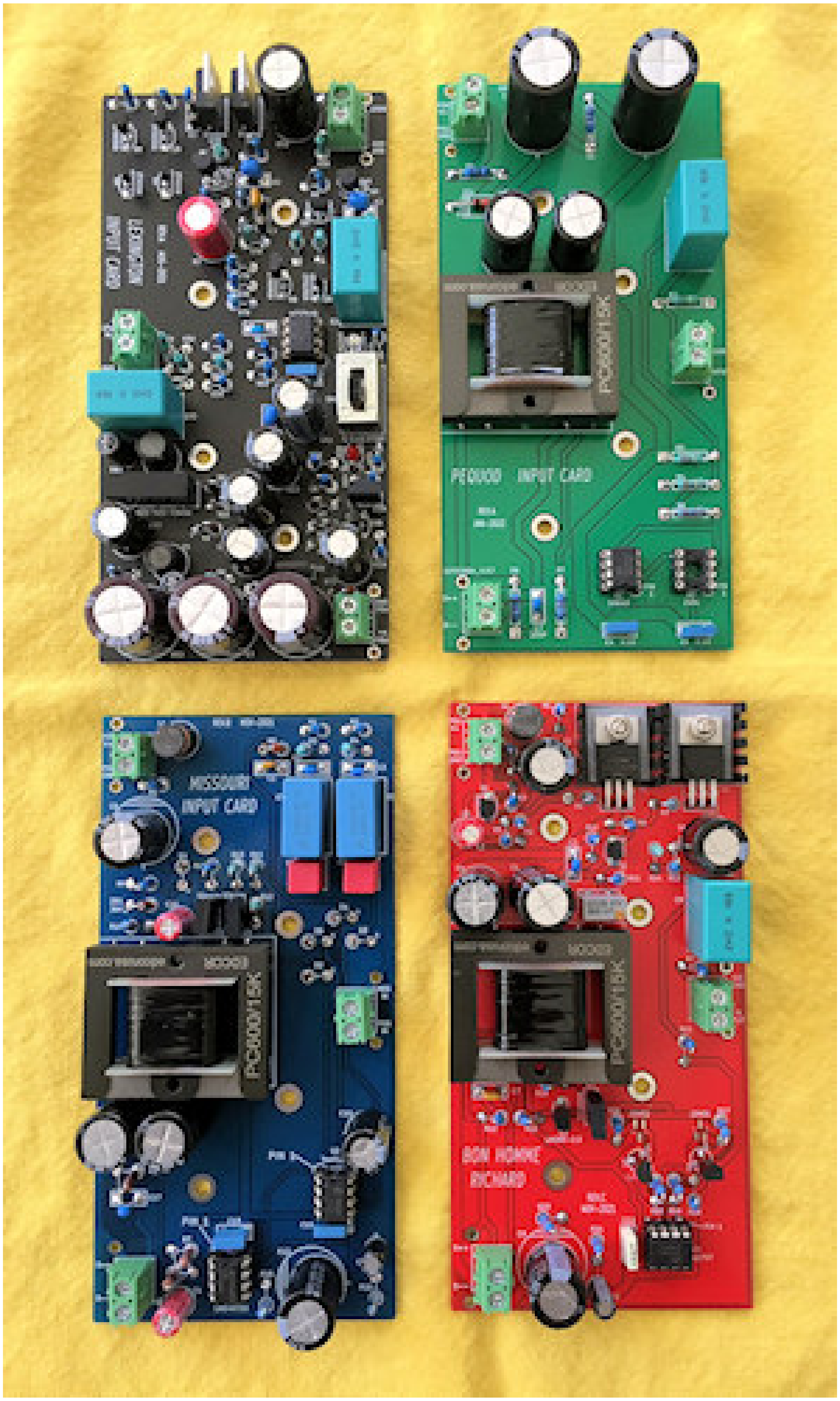


Photo 4: Lexington, Piquod, Bon Homme Richard, Missouri

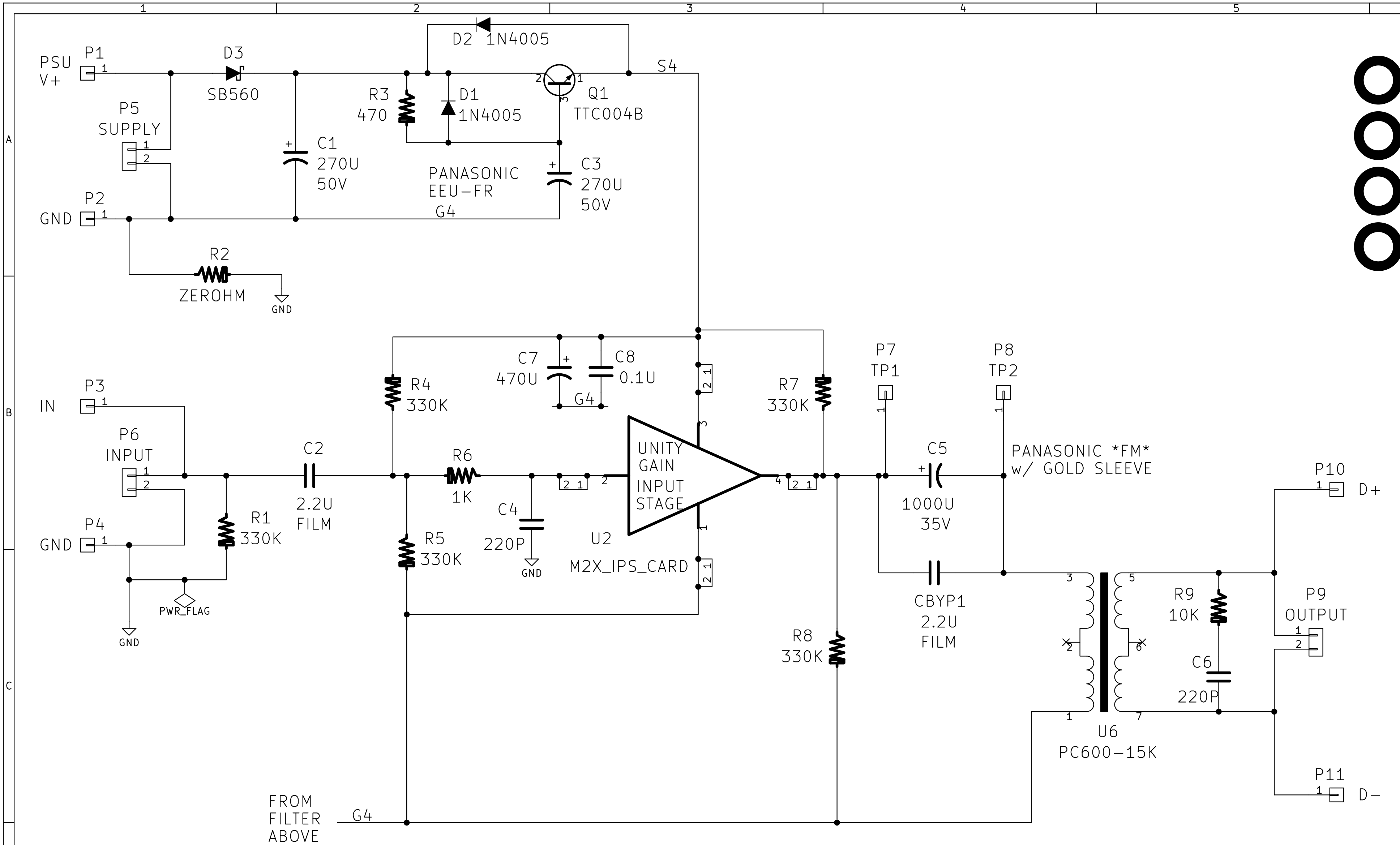
Nimitz Front End

Theseus / VFET builders who already own an M2x amplifier, probably have a favorite M2x input daughter card. Nimitz allows them to try out that M2x input card in the new amplifier. Maybe lightning strikes twice (?).

Schottky diode D3 attempts to protect the daughter card, and indeed all of Nimitz, if the supply is accidentally connected backwards. It would be a shame to destroy the Front End because of such a mistake, but a *crying shame* to also destroy a Norwood or a Cedarburg card in the process.

Capacitance multiplier Q1-R3-C3 attenuates any 100 or 120 Hz ripple that might be present on the DC supply, by about 35-40 dB.

Nimitz's electrolytic output capacitor (C5) is bypassed by a polypropylene film capacitor (CBYP1), in an attempt to becalm nervous audiophiles. Test points TP1 and TP2 are provided, allowing courageous builders to perform various kinds of invasive and potentially dangerous surgery upon the circuit. An opportunity for creative ingenuity.



DIY SIT AMP
NIMITZ FRONT END

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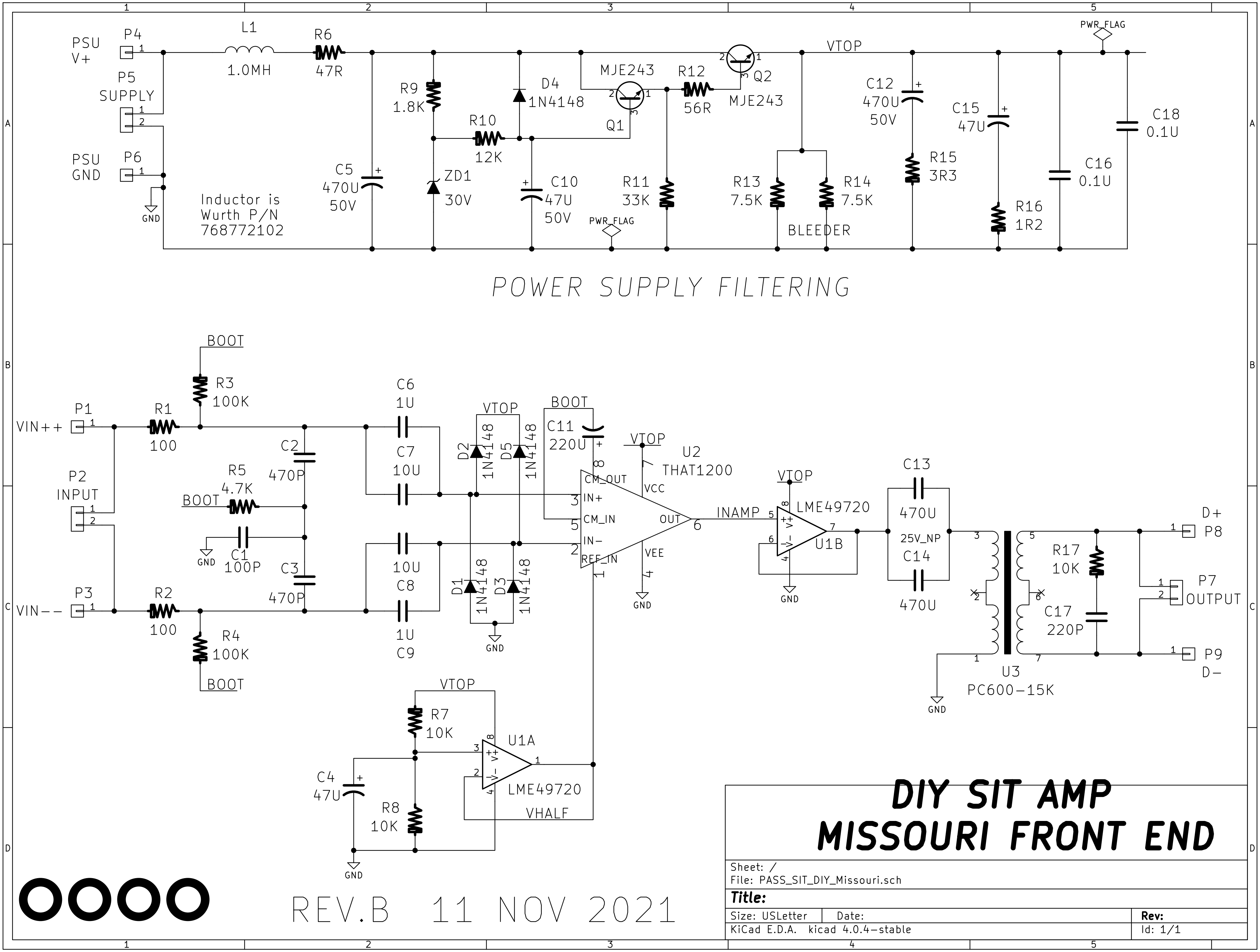
Missouri Front End

Only a small percentage of First Watt / diyAudio Store amplifiers, have the ability to accept XLR or balanced inputs, a limitation which some builders consider a deal breaker. Missouri is an attempt to correct that, for the VFET and Theseus families of amplifiers.

A balanced input signal is provided at input connector P2 (XLR pin 1 is connected to the amplifier chassis). This is applied to a professional audio IC called “THAT-1200” whose patented design maximizes common mode rejection. Compare the Missouri schematic to the THAT Corp datasheets and application notes; you’ll discover that Missouri carefully implements all of THAT Corp’s recommendations.

R7-R8-C4 generate a mid supply bias voltage, which opamp U1A buffers and drives with very low impedance, into pin 1 (“REF_IN”) of the THAT chip. Then U1B, whose output current specification is quite significant (23 mA into 600 ohm load), drives the Edcor transformer primary.

Missouri includes high frequency noise filtering (L1-R6-C5), and also a darlington capacitance multiplier (R10-C10-Q1-Q2) for ripple attenuation at low frequencies.



PSU V+
P4
L1
1.0MH
R6
47R
P5 SUPPLY
R9
1.8K
D4
1N4148
MJE243
R12
56R
Q2
MJE243
Q1
VTOP
PWR_FLAG
C12
470U
50V
C15
47U
C18
0.1U
R10
12K
PSU GND
P6
GND
Inductor is
Wurth P/N
768772102
C5
470U
50V
ZD1
30V
C10
47U
50V
PWR_FLAG
R11
33K
R13
7.5K
R14
7.5K
BLEEDER
R15
3R3
R16
1R2
C16
0.1U
POWER SUPPLY FILTERING
BOOT
R3
100K
C6
1U
VTOP
BOOT
C11
220U
VTOP
U2
THAT1200
P1
VIN++
R1
100
C2
470P
C7
10U
D2
1N4148
D5
1N4148
CM_OUT
IN+
CM_IN
IN−
REF_IN
VCC
VEE
OUT
INAMP
VTOP
LME49720
U1B
C13
470U
25V_NP
C14
470U
P2
INPUT
R5
4.7K
BOOT
C1
100P
C3
470P
10U
C8
D1
1N4148
D3
1N4148
GND
D+
P8
R17
10K
P7
OUTPUT
C17
220P
P9
D−
U3
PC600-15K
P3
VIN−−
R2
100
R4
100K
BOOT
1U
C9
VTOP
R7
10K
U1A
LME49720
C4
47U
R8
10K
VHALF
DIY SIT AMP
MISSOURI FRONT END
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Bon Homme Richard Front End

This Front End card is a shining example of the audiophile mantra "anything worth doing is worth over-doing." BHR starts with a wicked good (expensive!) opamp, adds wicked good power supply regulation, and finishes up with painstakingly hand-matched components.

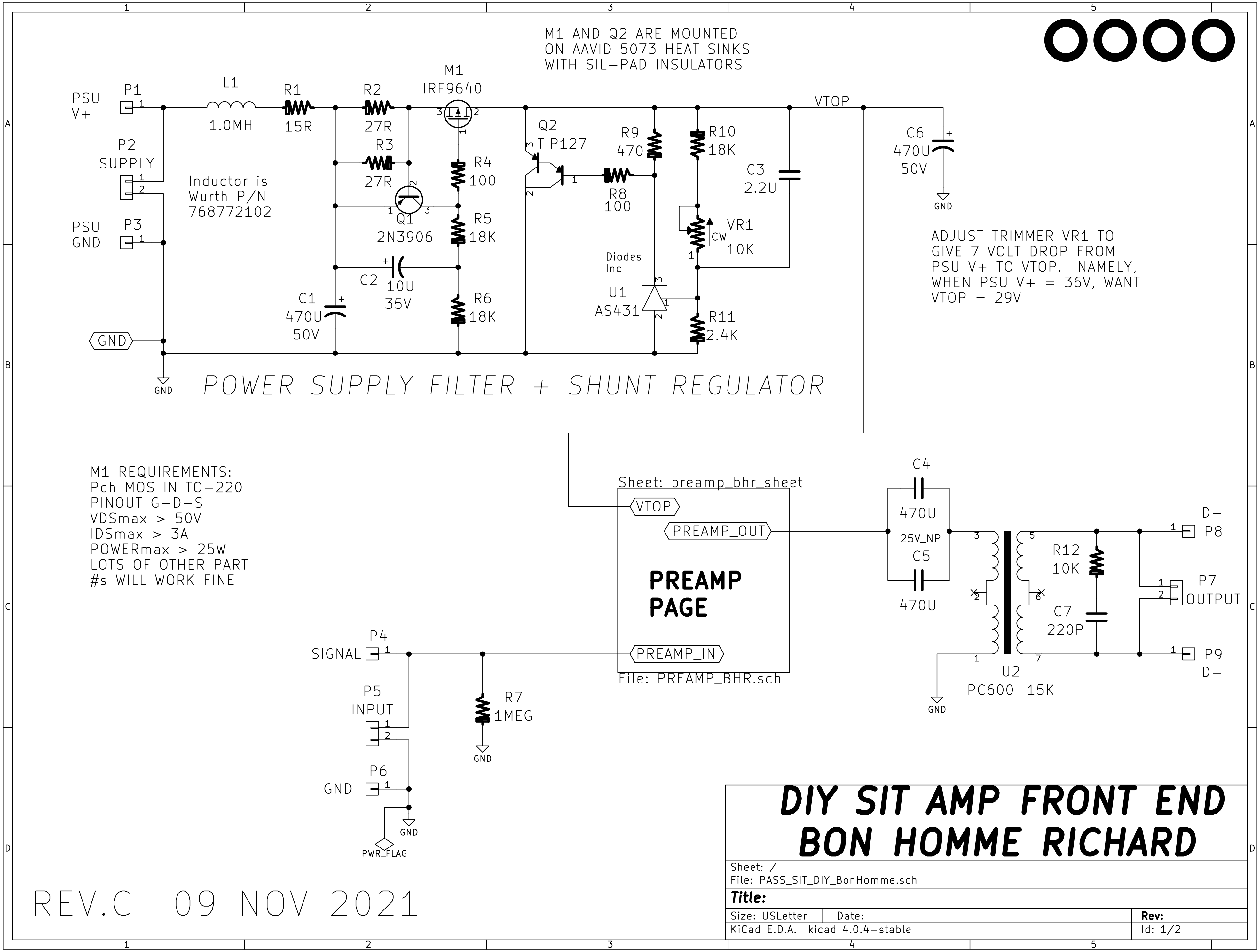
The resistor matching exercise was discussed / beaten to death during Nov 2021, in a diyAudio thread entitled "Resistor matching error starting with six 1% resistors". I will attempt to link that thread here:

https://www.diyaudio.com/community/threads/resistor-matching-error-starting-with-six-1-resistors.379344/

The power supply section of BHR includes a passive noise filter (L1-R1-C1), followed by a shunt voltage regulator. The regulator consists of a constant current source (Q1-M1), a darlington power transistor as the shunt (Q2), and an error amplifier (U1) connected in a negative feedback loop around Q2. Circuit performance, PSRR, is set by a simple impedance divider, whose upper impedance is the output impedance of the CCS, and whose lower impedance is the output impedance of the shunt device (including NFB). The former is very large and the latter is very small, so the division ratio is extremely small, and the PSRR is a very large negative number of dBs.

The wicked good opamp, AD797, is notoriously temperamental when operated at unity gain, as is done in Front End cards using an Edcor step up transformer. BHR's solution is to attenuate the input by a factor of 4X, then operate the AD797 at a gain of 4. Presto, stability and adequate phase margin are preserved. {math note: 470/120 = 3.917, in fact}

The attenuator (schematic page two) is a differential-in, differential-out discrete circuit consisting of two JFETs and four resistors. Its PCB layout accepts either surface mount JFETs or thru-hole JFETS; the builder can choose either.


M1 AND Q2 ARE MOUNTED
ON AAVID 5073 HEAT SINKS
WITH SIL-PAD INSULATORS
PSU
V+
P1
L1
1.0MH
R1
15R
R2
27R
R3
27R
M1
IRF9640
R4
100
Q1
2N3906
R5
18K
C2
10U
35V
C1
470U
50V
R6
18K
P2
SUPPLY
Inductor is
Wurth P/N
768772102
PSU
GND
P3
GND
Q2
TIP127
R8
100
R9
470
Diodes
Inc
U1
AS431
R10
18K
VR1
CW
10K
R11
2.4K
C3
2.2U
VTOP
C6
470U
50V
GND
POWER SUPPLY FILTER + SHUNT REGULATOR
ADJUST TRIMMER VR1 TO
GIVE 7 VOLT DROP FROM
PSU V+ TO VTOP. NAMELY,
WHEN PSU V+ = 36V, WANT
VTOP = 29V
M1 REQUIREMENTS:
Pch MOS IN TO-220
PINOUT G-D-S
VDSmax > 50V
IDSmax > 3A
POWERmax > 25W
LOTS OF OTHER PART
#s WILL WORK FINE
Sheet: preamp_bhr_sheet
VTOP
PREAMP_OUT
PREAMP
PAGE
PREAMP_IN
File: PREAMP_BHR.sch
C4
470U
25V_NP
C5
470U
R12
10K
C7
220P
U2
PC600-15K
D+
P8
P7
OUTPUT
P9
D-
P4
SIGNAL
P5
INPUT
P6
GND
PWR_FLAG
R7
1MEG
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DIY SIT AMP FRONT END
BON HOMME RICHARD
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MATCH R16,R20 WITHIN 0.4%
MATCH R17,R21 WITHIN 0.4%

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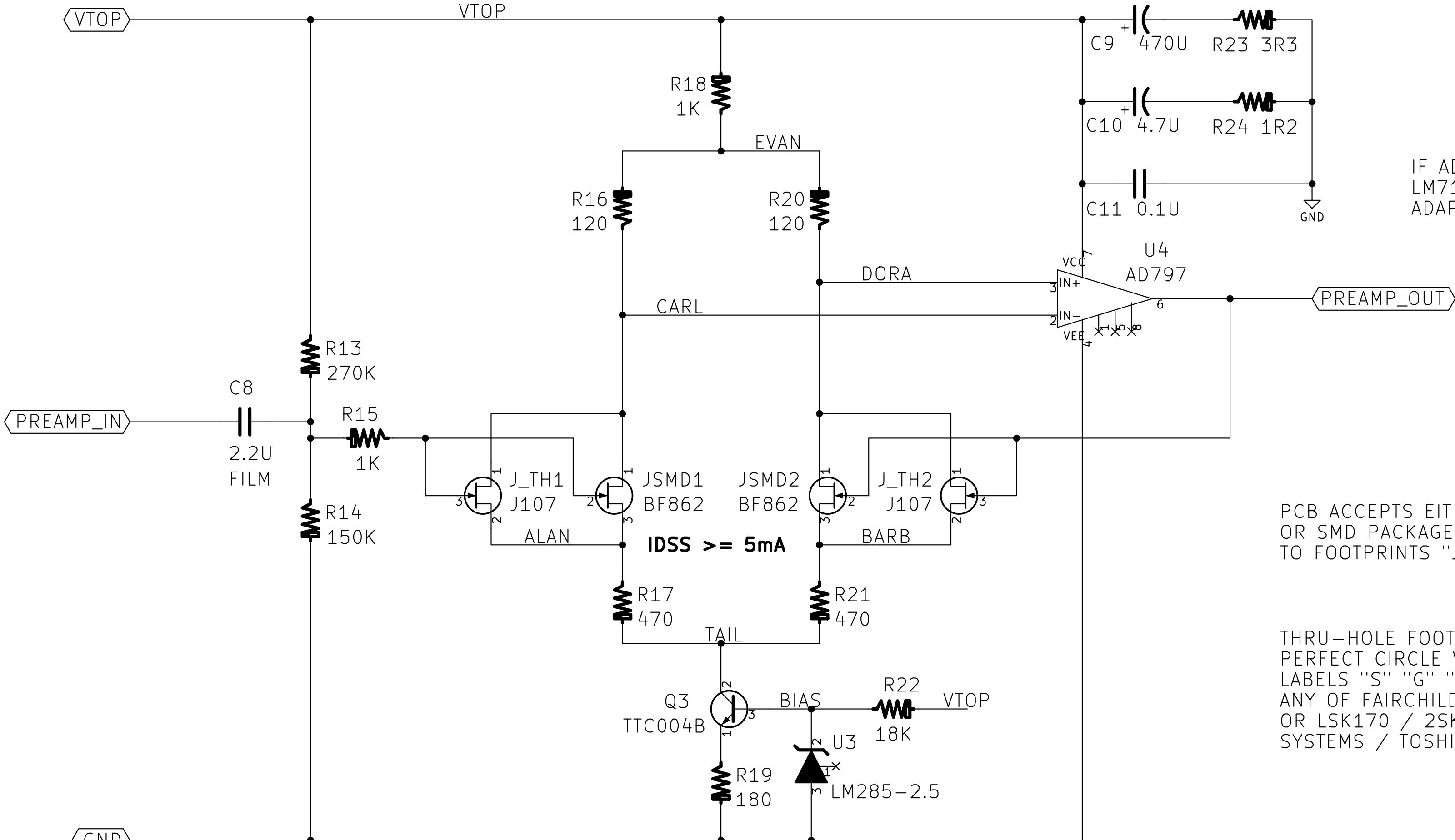

IF AD797 IS BACKORDERED:
LM7171, LT1112, LT1363,
ADAPTER + OPA1611 / AD825

PCB ACCEPTS EITHER THRU-HOLE
OR SMD PACKAGED JFETS. SOLDER
TO FOOTPRINTS "J_TH" OR "JSMD"

THRU-HOLE FOOTPRINT IS A
PERFECT CIRCLE WITH SILK TEXT
LABELS "S" "G" "D". CAN ACCEPT
ANY OF FAIRCHILD J107, J112, J113
OR LSK170 / 2SK170 FROM LINEAR
SYSTEMS / TOSHIBA.

TO MATCH R16,R20 WITHIN 0.4% :
BUY 6 PCS 120 OHMS 1% METAL FILM
MEASURE ON 3.5 OR 4.5 DIGIT DMM
CHOOSE THE PAIR WITH BEST MATCH

REPEAT WITH 6 PCS 470 OHM 1% MF

GENERAL CASE USING *N* 1% RESISTORS:
GUARANTEED MATCH <= 2% / (N − 1)

PREAMP_BHR

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Kitty Hawk Front End

Kitty Hawk was born after ruminating upon the weaknesses of the Rush Cascode circuit. Eventually it emerged that the Rush Cascode's DC offset, drift, and temperature sensitivity are not significant, if (a) operating at low gain; and also (b) when the input and output are AC coupled. Presto! Ship Of Theseus Front Ends with Edcor transformers are low gain and AC coupled. The requirements are met.

In Kitty Hawk, a "hybrid" Rush Cascode is used, consisting of one JFET (J1) and one BJT (Q2). Together with constant current load Q1, they form the first stage of the Kitty Hawk preamp. The second stage is composed of Q3-Q4, with constant current load Q5. The output is taken from the collector of Q4 and is a current, not a voltage. Thus Kitty Hawk is a current output amplifier, also known as a transconductance amplifier.

Ultra low capacitance diode D5 is applied as an anti-saturation clamp, but this may be unnecessary since the output power transistors will almost certainly go into clipping at far smaller signal swings than the giant swings necessary to saturate Q4.

Kitty Hawk's supply is passively filtered by R1-C2 and then actively regulated by two LM317L voltage regulator chips (in the cute TO-92 transistor packages) connected in series. Supply is regulated, and that regulated supply is regulated again. Zener diode D3 guarantees that U1's input-to-output voltage always remains comfortably below the datasheet Absolute Maximum rating (30 volts).

Component footprints C6, R9, R10 are provided for the convenience of the builder, to allow experimentation with other choices of voltage gain.

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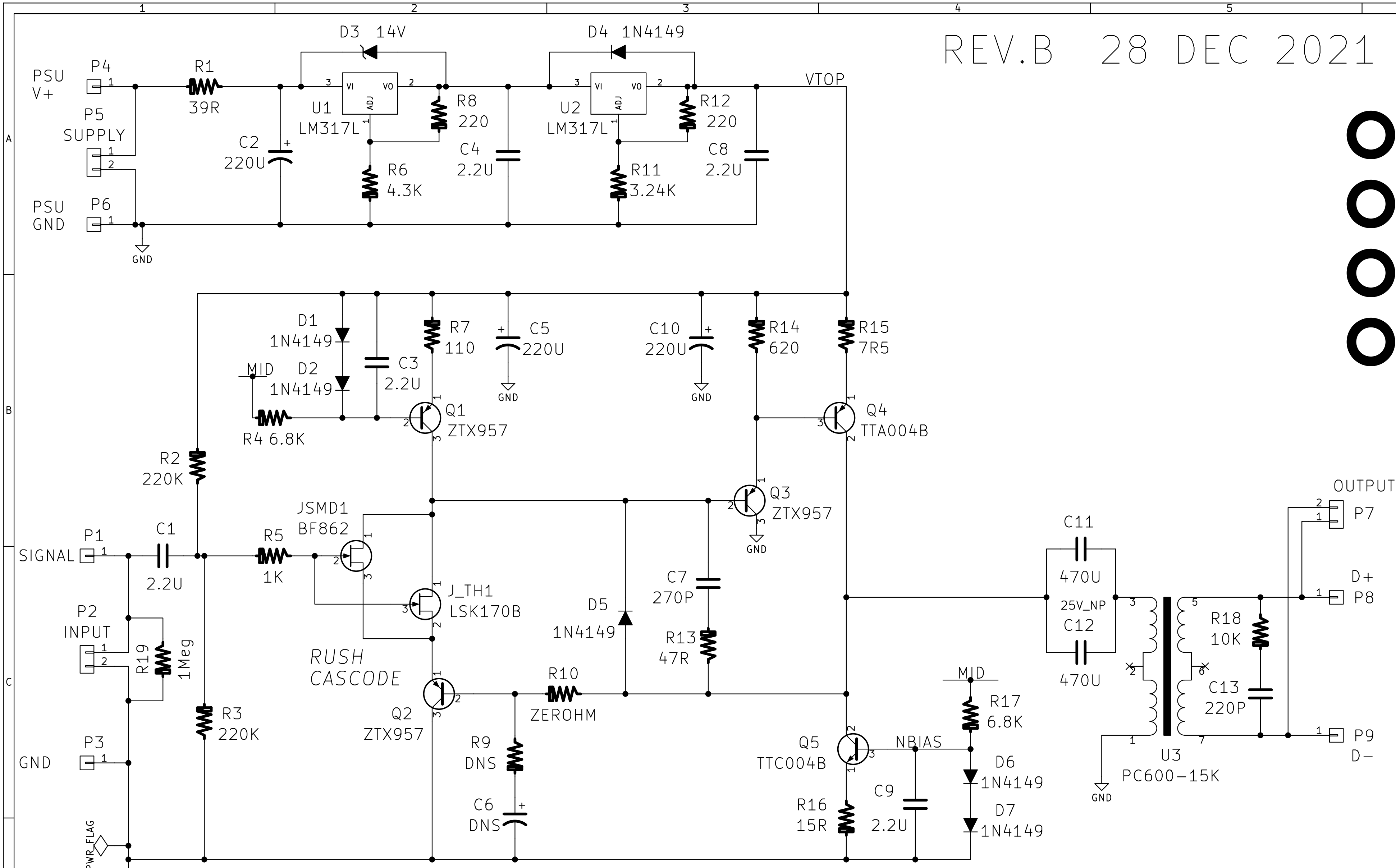

PCB HAS FOOTPRINTS FOR BOTH SMD (''JSMD1'') AND THRU HOLE (''J_TH1'') FETs. STUFF & SOLDER ONLY ONE OF THE TWO.

FOR J_TH1: ANY OF LSK170B, J107, J112, J113 WILL WORK. MEASURE EACH UNIT AND VERIFY IDSS > 5mA

DIY SIT AMP
KITTY HAWK FRONT END

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Lexington Front End

Lexington, like its British warship predecessors Marauder and Dreadnought, has no Edcor step-up transformer. Instead it has an onboard DC-to-DC converter called JBOOST2 (third schematic sheet) which provides a supply named POS_BOOSTED, in the neighborhood of 55-60 volts. The circuit technology of JBOOST2 is different from JBOOST1 used previously; now it's an isolated DC-to-DC converter module, manufactured by CUI Inc. 24V DC input, isolated 24V DC output.

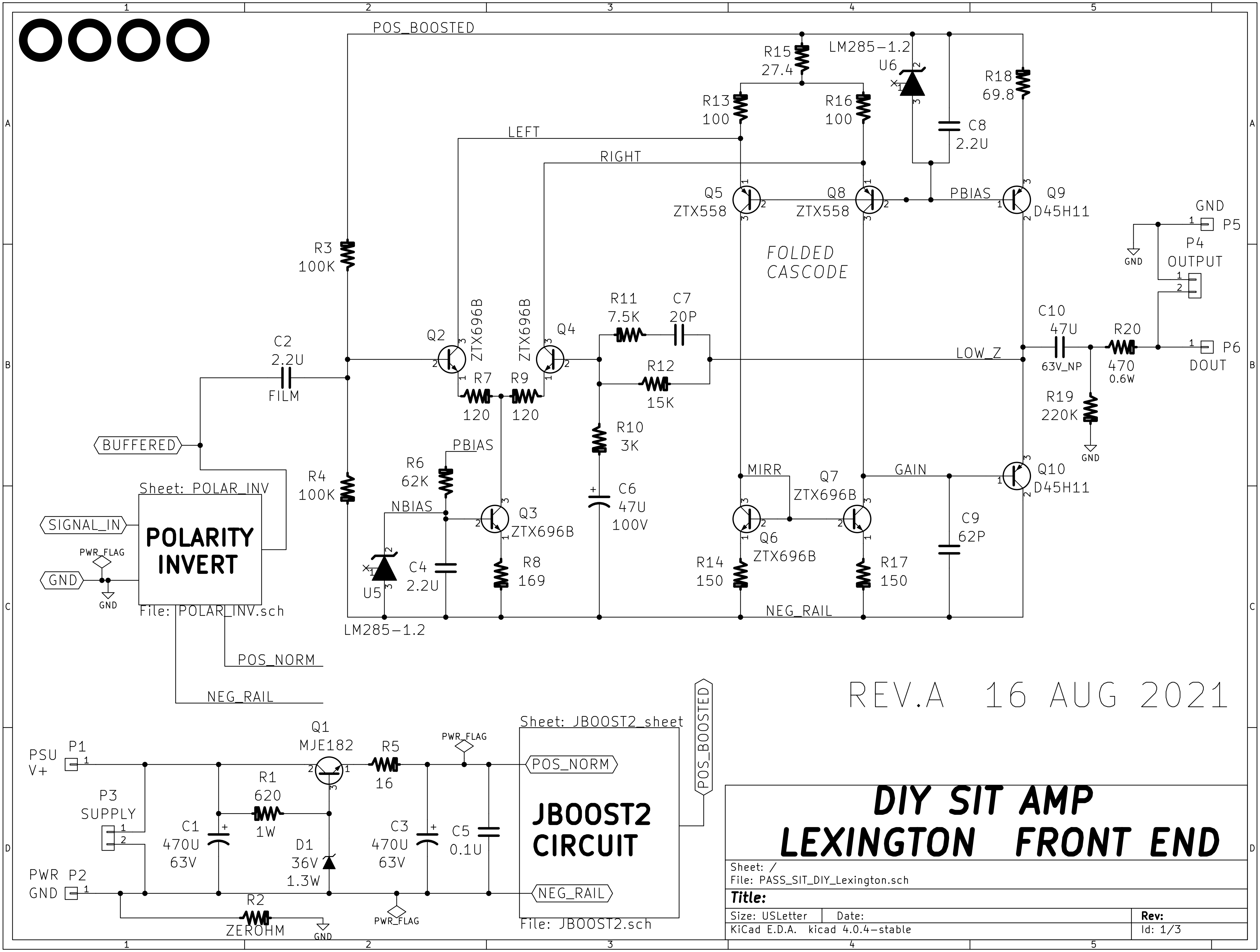
Zener diode D4 drops the ~34 volt supply down to 23 volts, within the spec range of U8. The isolated 23 volt output, presented between pins 4 and 6, is added to the 34 volt input, creating an output between node CAROL and ground, of about 57 volts. This is passively filtered by L2-C18 and run through a darlington capacitance multiplier for additional smoothing. D7 gives over voltage protection and R34 is a bleeder.

Front Ends with an Edcor transformer can invert their output phase via the simple trick of swapping the transformer output leads. Lexington, having no transformer, resorts to opamps and a switch, as shown on the second schematic page.

Lexington's signal path includes an input differential pair of NPNs (Q2, Q4) with resistor loads (R13, R16).* These differential signals are applied to the emitters of a pair of PNPs (Q5, Q8) operating in common base mode. They drive an NPN current mirror (Q6, Q7). Overall, this topology is called a Folded Cascode, and it functions as a single amplifying stage whose gain is simply the gm of the input pair with degeneration.

The mirror output drives the (grounded) frequency compensation capacitor C9, thus Lexington uses simple lag compensation (not the more common Miller compensation). Hefty emitter follower Q10, in a TO-220 power transistor package, drives the Front End output. Q10 is loaded by constant current source Q9, also a TO-220 device.

*what about R15?? It is merely a level shifter. The current in R15 is constant, therefore the voltage across R15 is also constant.


POS_BOOSTED
R15
27.4
LM285-1.2
U6
R18
69.8
R13
100
R16
100
C8
2.2U
LEFT
RIGHT
Q5
ZTX558
Q8
ZTX558
PBIAS
Q9
D45H11
GND
P5
P4
OUTPUT
FOLDED
CASCODE
R3
100K
R11
7.5K
C7
20P
C10
47U
63V_NP
R20
470
0.6W
P6
DOUT
Q2
ZTX696B
Q4
ZTX696B
C2
2.2U
FILM
R7
120
R9
120
R12
15K
LOW_Z
R19
220K
BUFFERED
R10
3K
R4
100K
R6
62K
PBIAS
NBIAS
Q3
ZTX696B
C6
47U
100V
MIRR
Q7
ZTX696B
GAIN
Q10
D45H11
Q6
ZTX696B
C9
62P
Sheet: POLAR_INV
SIGNAL_IN
POLARITY
INVERT
PWR_FLAG
GND
U5
C4
2.2U
R8
169
R14
150
R17
150
NEG_RAIL
File: POLAR_INV.sch
LM285-1.2
POS_NORM
NEG_RAIL
REV.A 16 AUG 2021
Q1
MJE182
R5
16
PWR_FLAG
Sheet: JBOOST2_sheet
PSU
V+
P1
P3
SUPPLY
R1
620
1W
C1
470U
63V
D1
36V
1.3W
C3
470U
63V
C5
0.1U
POS_NORM
JBOOST2
CIRCUIT
POS_BOOSTED
PWR
GND
P2
R2
ZEROHM
NEG_RAIL
File: JBOOST2.sch
DIY SIT AMP
LEXINGTON FRONT END
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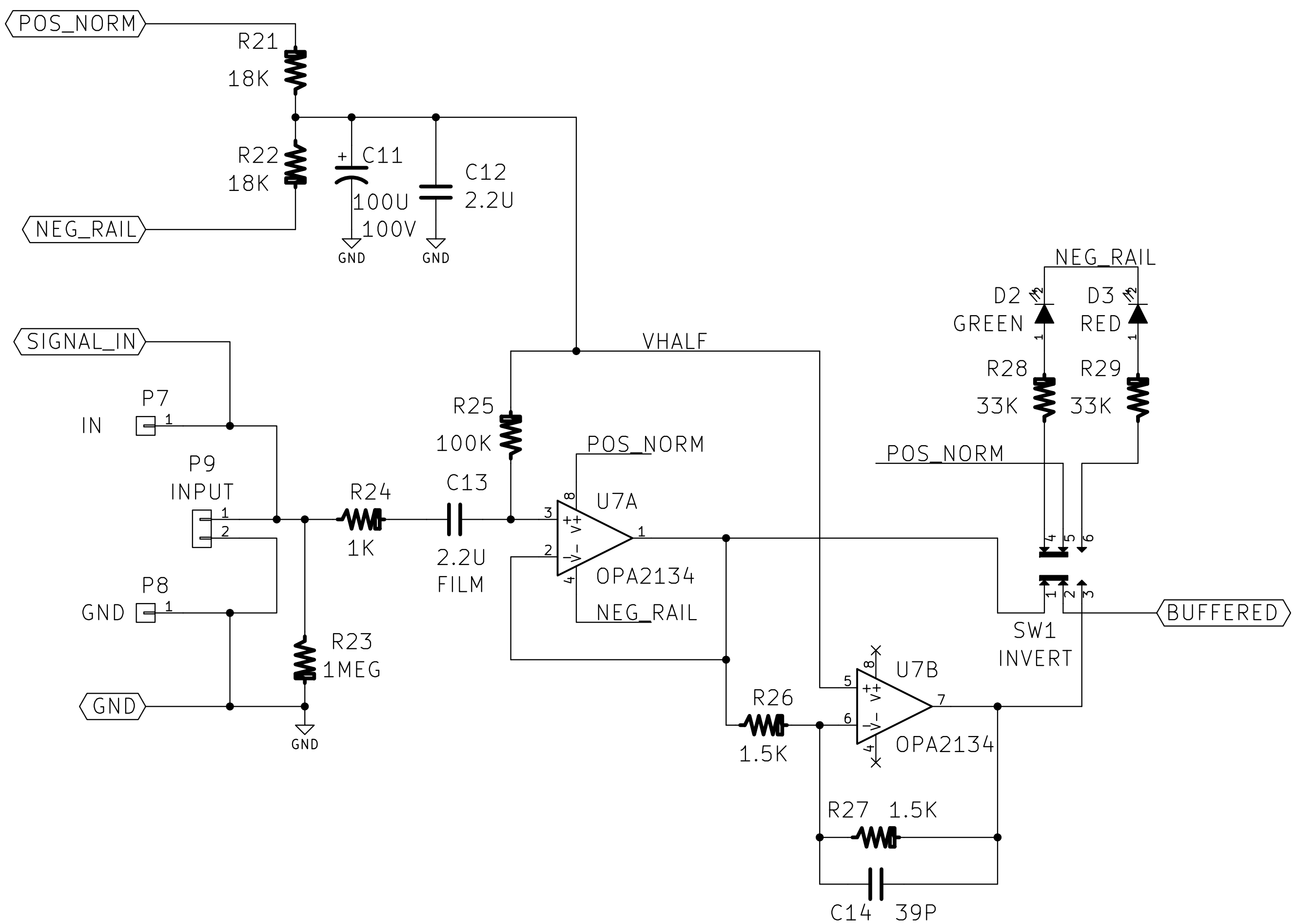
REV.A 16 AUG 2021



POLARITY INVERT

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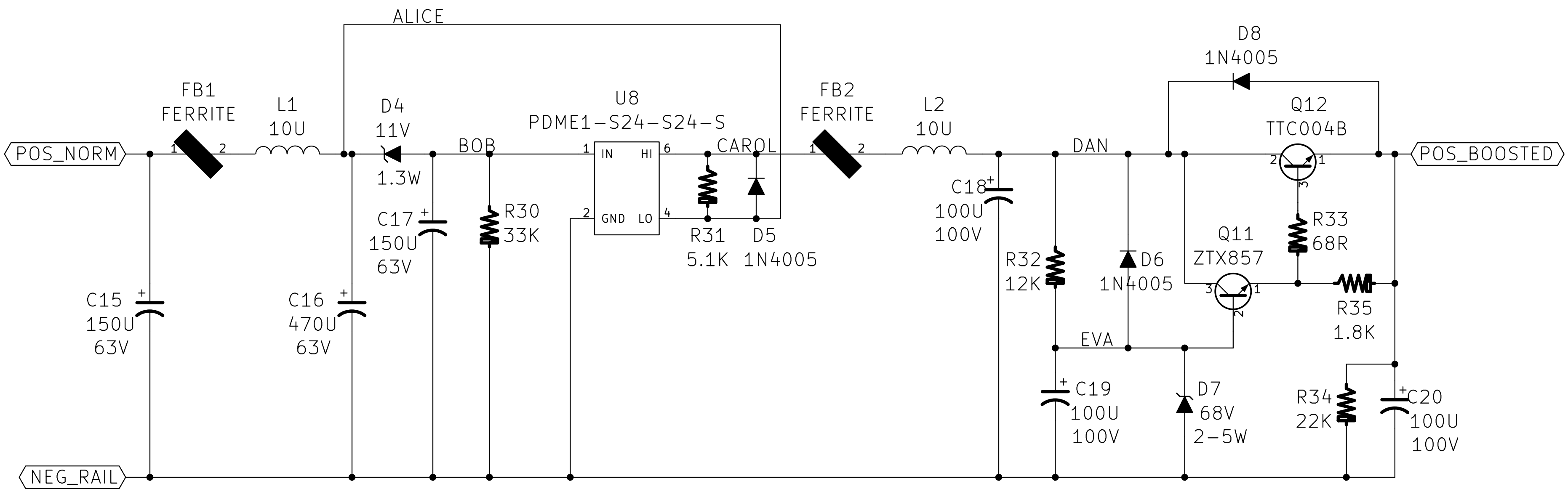
Rev:
KiCad E.D.A. kicad 4.0.4-stable
Id: 2/3

Ferrite beads are
Laird 28C0236-0EW-10
998 ohms @ 100 MHz
5 Amps 10 mOhm

Inductors are Bourns
RL622-100K-RC
3 Amps; 45 mOhm

Electrolytic caps are
Panasonic EEU-FR
or EEU-FM



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JBOOST2

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Hornet Front End

When DigiKey and Mouser each reported stocking more than fifty thousand pieces of NJFETs and PJFETs in thru hole packages, it suddenly became practical to create a Front End which put them to use. In particular, the complementary source follower pair *without degeneration resistors* is now a viable and pragmatic option for an output stage.

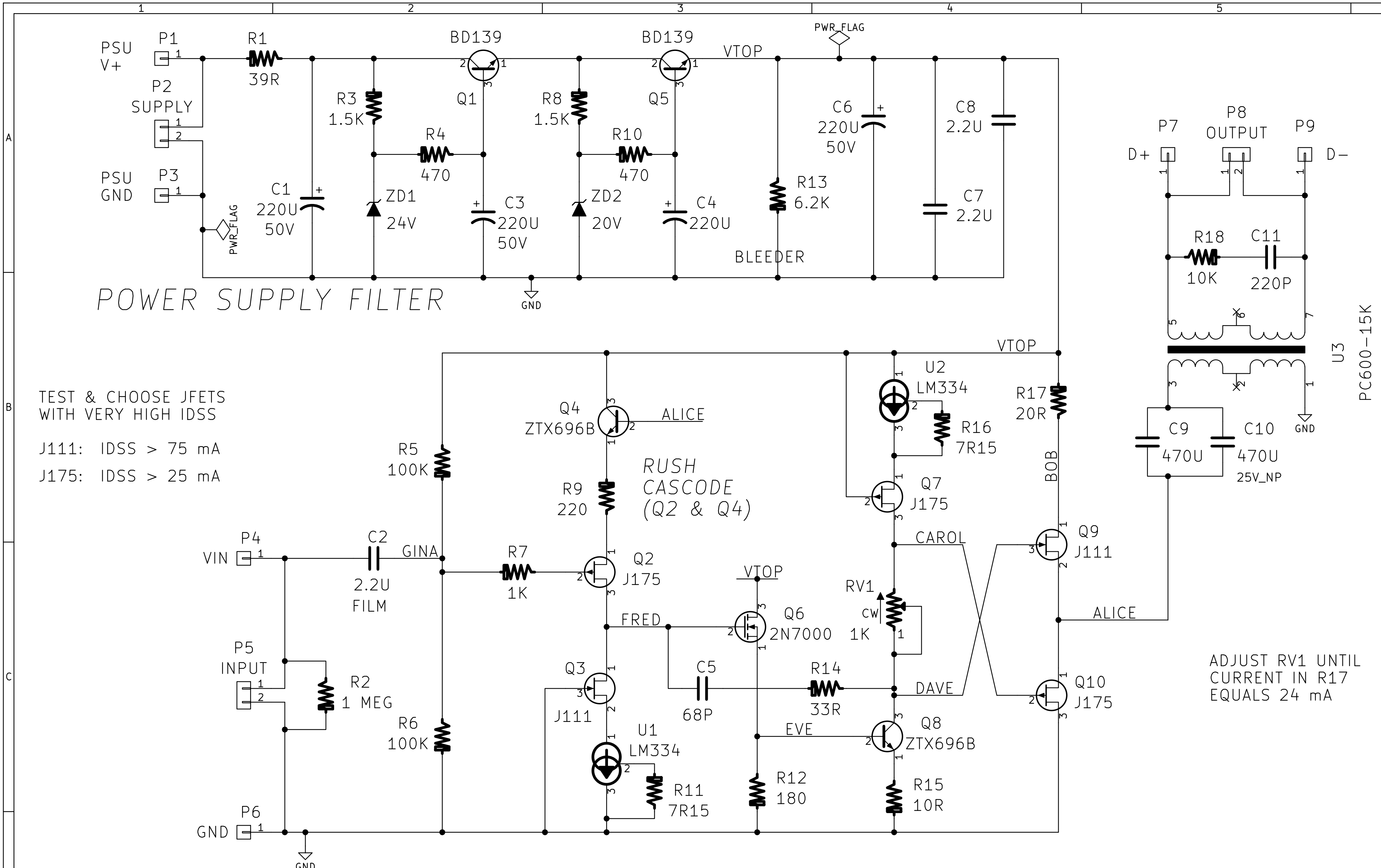
Additionally, since the J175 (Pch) and J111 (Nch) are both relatively high gm devices, they can be used as cascodes for constant current sources. A CCS built this way is simple (3 components), works well at high frequencies (the JFET shields the LM334 from HF signals), and eats relatively little headroom (thanks to the small Vgs requirements of a high gm device).

Putting this all together, we get a Front End loaded with cascodes. The supply filters/regulators are connected in cascode. The first gain stage's CCS load (Q3-U1) is a cascode. The second gain stage's CCS load (Q7-U2) is a cascode. And the input circuit itself (Q4-R9-Q2) is a Rush Cascode with degeneration. There's a whole lotta cascodin' goin' on.

The voltage between the output transistors' gates is V(CAROL) minus V(DAVE), and it appears across trimmer resistor R1. Since the current flowing in R1 is constant {set by U2}, changing the resistance of R1 changes the voltage dropped from CAROL to DAVE. This changes the Vgs's of the output transistors, and sets their Class A bias current.

Setting the output stage bias current is, therefore, simple. We merely clip our millivoltmeter's crocodile clips onto the legs of resistor R17 and monitor its voltage. From Ohm's Law, Current = Voltage / Resistance and we know both Voltage (it's the millivoltmeter reading) and Resistance (20 ohms). Voila! Just twirl the shaft of RV1 until the voltage across R17 is 480 millivolts and stop. Current = 480mV / 20ohms = 24 milliamps. Done!

Beware, these devices heat up quickly during IDSS measurement. Use a pushbutton and measure IDSS in the first half second after powering.



TEST THE THRESHOLD
VOLTAGE OF 2N7000
NEED VTH > 2.5V

DIY SIT AMP
HORNET FRONT END

REV.A 07 JAN 2022

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Size: USLetter	Date:	Rev:
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Pequod Front End

Pequod has only one objective: to deliver a simple Front End whose components are easy to source, inexpensive to buy, and straightforward to build. Make it easy for someone who already owns New-Old-Stock VFET devices, but has no PCBs at all, to put together a Ship Of Theseus amplifier inexpensively.

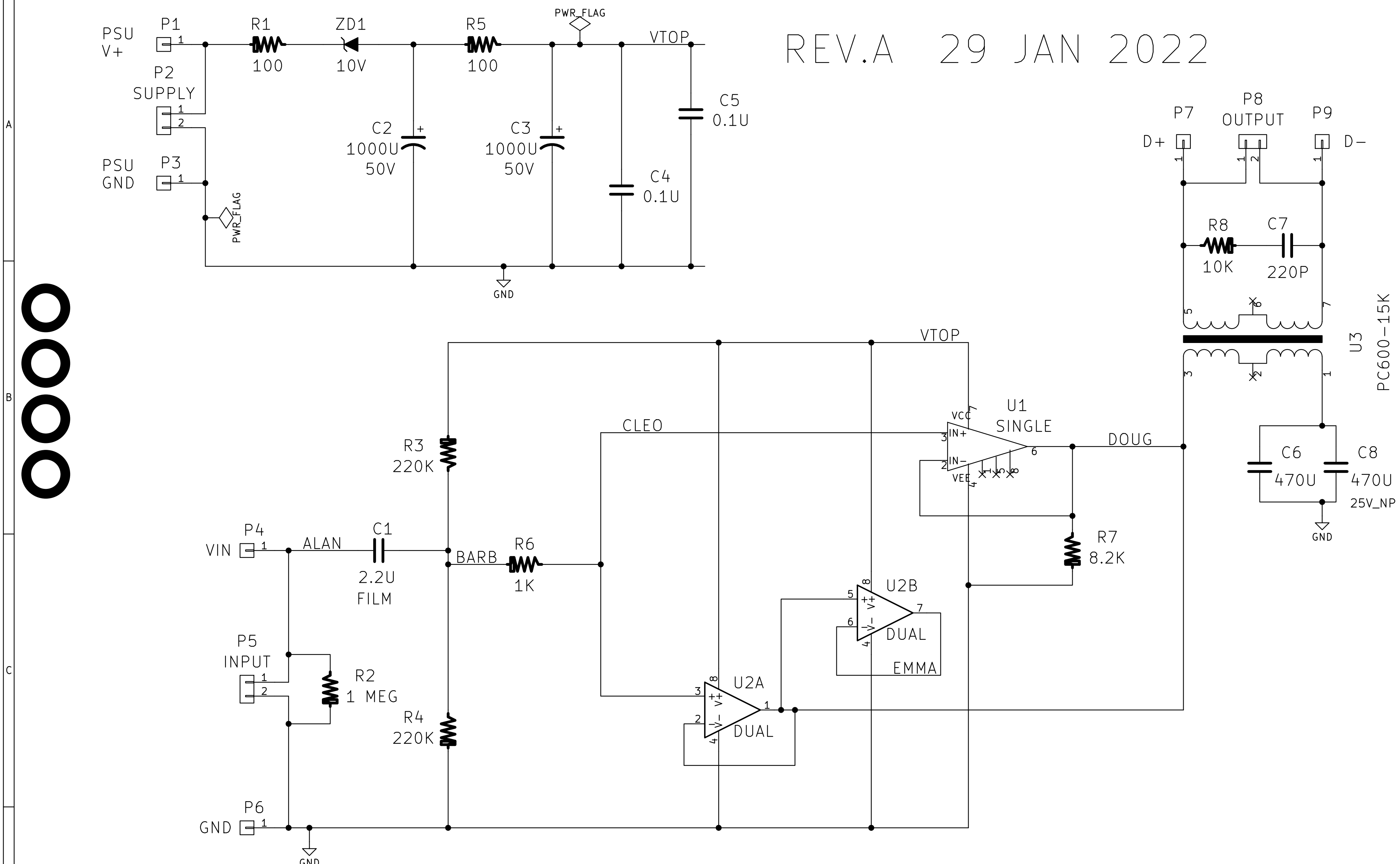
Pequod is merely an opamp follower driving an Edcor transformer, plus the AC coupling capacitors necessary for single ended supply operation. And that's all.

A couple of extras have been added, which increase flexibility without dramatically increasing cost or complexity. For example, there are two DIP-8 sockets on the PCB. One of them accepts single opamp chips like the LT1122, and the other socket accepts dual opamp chips like the OPA1656. This gives builders the flexibility to experiment with whichever opamp types they please.

The sockets are spaced far apart and away from other components, making it easier to fit discrete opamp modules like the products from Sparkos, Burson, etc. For even more experimentation.

Zener diode ZD1 drops the opamp supply below 26V, to accommodate chips that can work on 30V but not 36V supply.

Output load resistor R7 increases the bias current flowing in the opamp's output stage at all times, leading to reduced crossover distortion in many cases.



THE PCB HAS TWO DIP−8 SOCKETS. IT WILL ACCEPT *EITHER* A SINGLE OPAMP LIKE LT1122, *OR* A DUAL OPAMP (2 AMPS/PKG) LIKE OPA2134. THIS ALLOWS BUILDERS TO LISTEN TO ALL OF THEIR FAVORITE OPAMP CHIPS, BOTH SINGLES AND DUALS

DIY SIT AMP
PEQUOD FRONT END

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KiCad E.D.A. kicad 4.0.4−stable		Id: 1/1