Mad Katy

A 125W per channel KT88 Amplifier – Part 2

Here's a look at this unit's power supply and construction guidelines.

By Dennis Colin

Back

POWER SUPPLY SUMMARY

1. +500V: KT88 plate supply, unregulated but very solid with 1500μF energy storage (188 joules—do not short!).

2. +450V regulated: plate supply for all other tubes. The two plate supplies are delayed about 20 seconds after mains power turn-on; they're shut down in standby or if the negative bias voltage fails; the +450V supply turns on with about a 1 second soft-start to avoid transients when switching from standby to active.

3. –200V regulated: supplies KT88 bias and linear resistive current sources for cathode-coupled input and driver tubes, and 6SN7 cathode-followers.

4. ±6.3V regulated: powers input and driver tubes' heaters and servo-balance op amps.

5. 12.6V AC: powers series-paired KT88 and 6SN7 heaters.

Five toroidal transformers (Hammond and Plitron) are used, but you could design one custom unit. The AC mains input is EMI filtered, current-surge limited by thermistors, and voltage-surge limited by an MOV. Six fuses are used with corresponding status LEDs.

Following is a detailed description of the power-supply schematic (**Fig. 17**):

AC INPUT

PE1 is an EMI-filtered power-entry module. CL1, 2, 3 are thermistor inrush-current limiters. These are *required*, because as Plitron points out, large toroids draw a large magnetizing current surge: connecting T2 *with no load* to the AC line in one test blew the 15A house breaker! (Once energized, though, the transformer draws only several mA unloaded.) With the added huge surge of the 1500μF cap bank (C1–4) charging to 500V, turn-on would be totally unmanageable. The thermistors' high cold R limits the inrush current to 11A RMS.

A 10A SB fuse, heavy-duty switch, and an MOV voltage-transient limiter complete the AC input.

+500—T1, a 9V 9A toroid, is used as an auto transformer to increase the primary voltage to T2 by 9V. This was needed to obtain 500V DC output. The increased T2 primary V is well within ratings, because T2 is rated for 50Hz as well as 60Hz. At 60Hz a transformer can handle 20% more V than at 50Hz, because it's the V/F ratio that determines flux (therefore closeness to saturation) in a given winding and core.

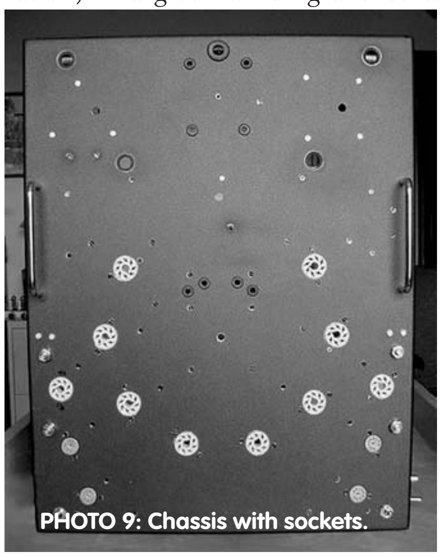


PHOTO 9: Chassis with sockets.

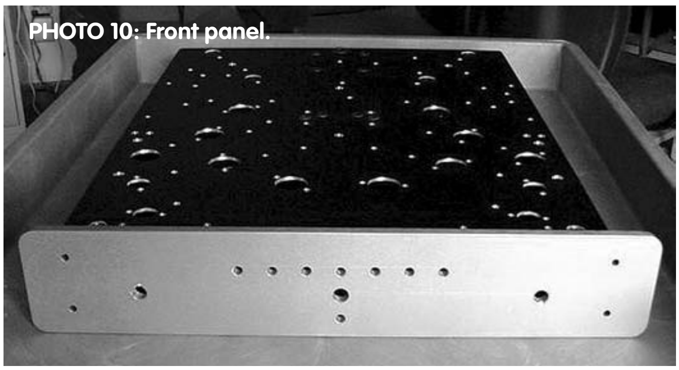


PHOTO 10: Front panel.

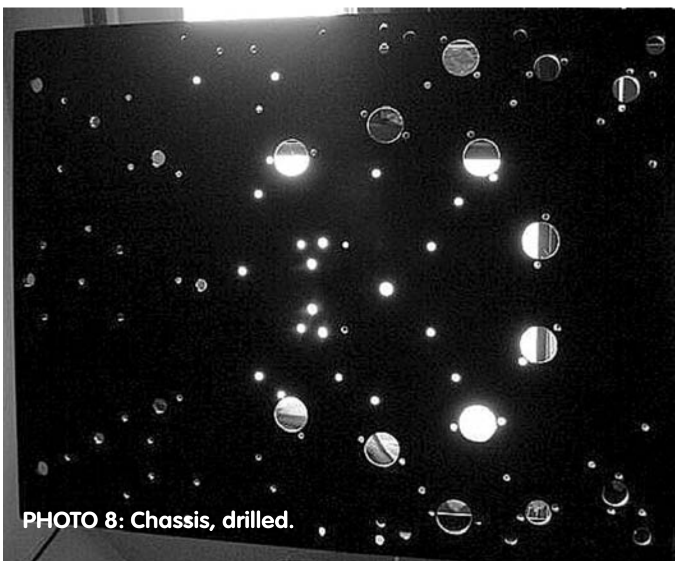


PHOTO 8: Chassis, drilled.

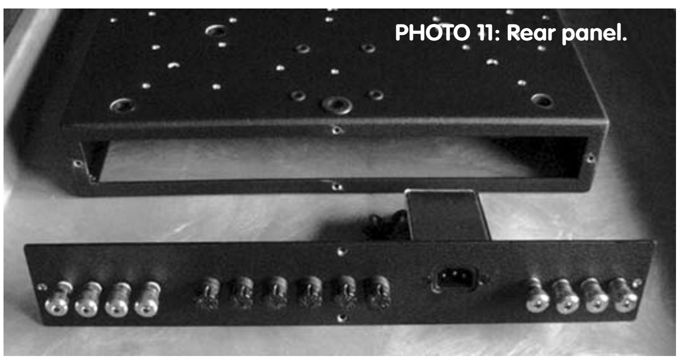


PHOTO 11: Rear panel.

BR1 and C1–4 complete the basic DC supply.

Q1 and associates are not a regulator (because I wanted maximum peak power), but a 500V switch for standby (SB) and delayed turn-on. When the network of R20, 21, 22 allows, Q2 is held off, allowing C5 to charge to the HV input through R5, with a 27mS time constant for some "softness." Then Q1 is fully conducting with only about 3V drop at full load (1.2A). Note: increasing the R5 C5 time constant much, or trying to use Q1 as a regulator, will blow Q1 with 1.2A load current. With the switch used here, there are no problems.

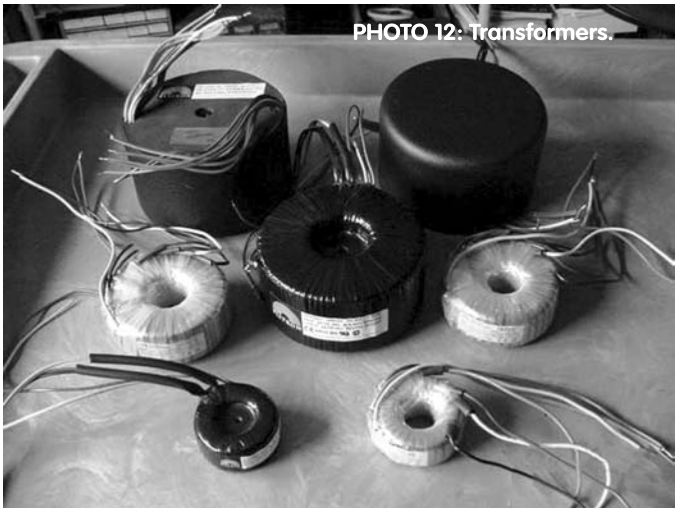


PHOTO 12: Transformers.

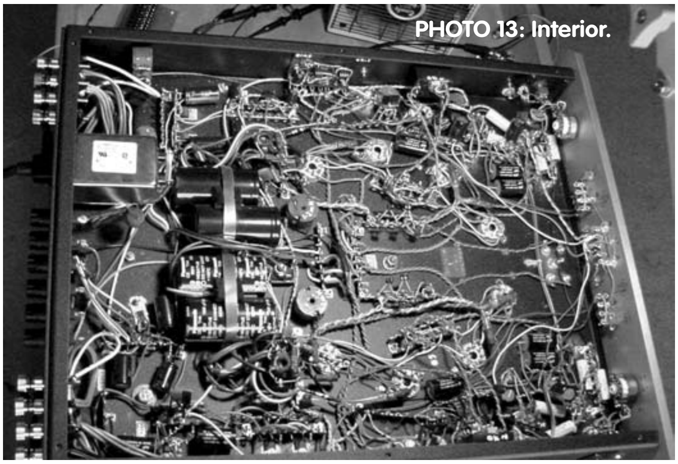


PHOTO 13: Interior.

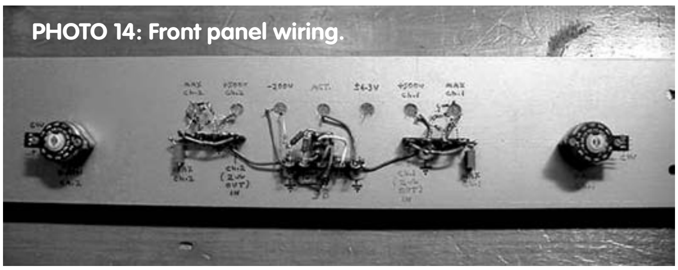


PHOTO 14: Front panel wiring.

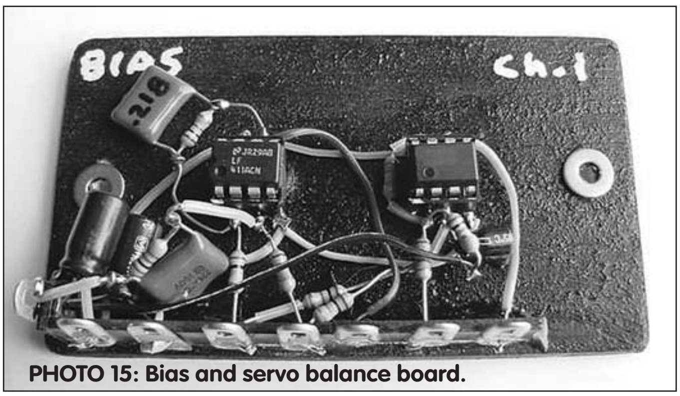


PHOTO 15: Bias and servo balance board.

But to give a sense of the power this small (TO-220) FET can switch, I connected a 500Ω 500W resistor to the raw +500V across the cap bank, *very carefully* with clip leads (using one hand, rubber shoes on dry carpet, no other body part within a foot of any conducting object). When I disconnected one clip lead, interrupting 1A at 500V DC (much worse than AC due to lack of cycle dips), a brilliant, beautiful, sizzling arc grew to a length of about ½″—this removed any ideas I had about using a relay! But the FET works well and eliminates a mechanical component.

With no output from the –200V supply (due to this bias voltage failing or its turn-on lag), Q2 is quickly turned on by R20; this switches and keeps Q1 (and the output) off. The –200V supply would be enough to overcome this, biasing the Vgs of Q2 negative through R22, which would activate the 500V output, except for Q5.

Upon AC turn-on, the +6.3V supply is

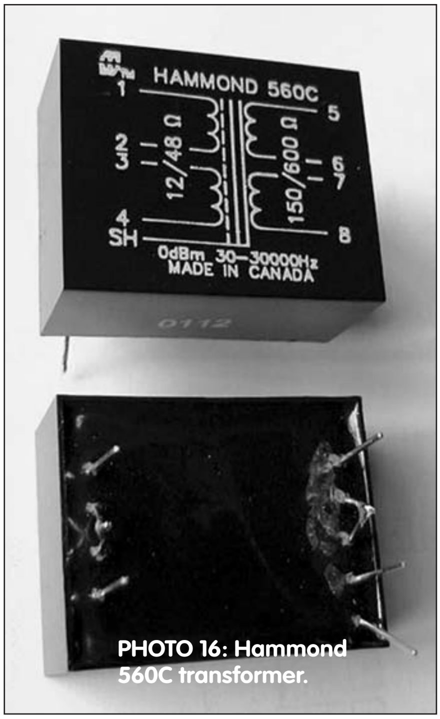


PHOTO 16: Hammond 560C transformer.

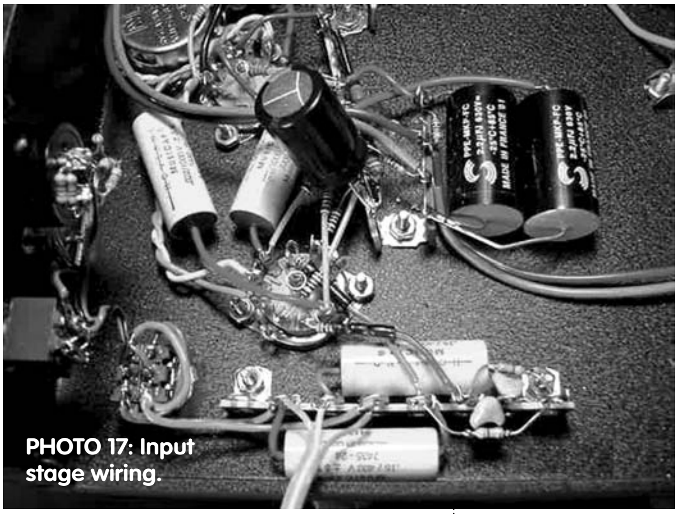


PHOTO 17: Input stage wiring.

PHOTO 18: Optional fan.

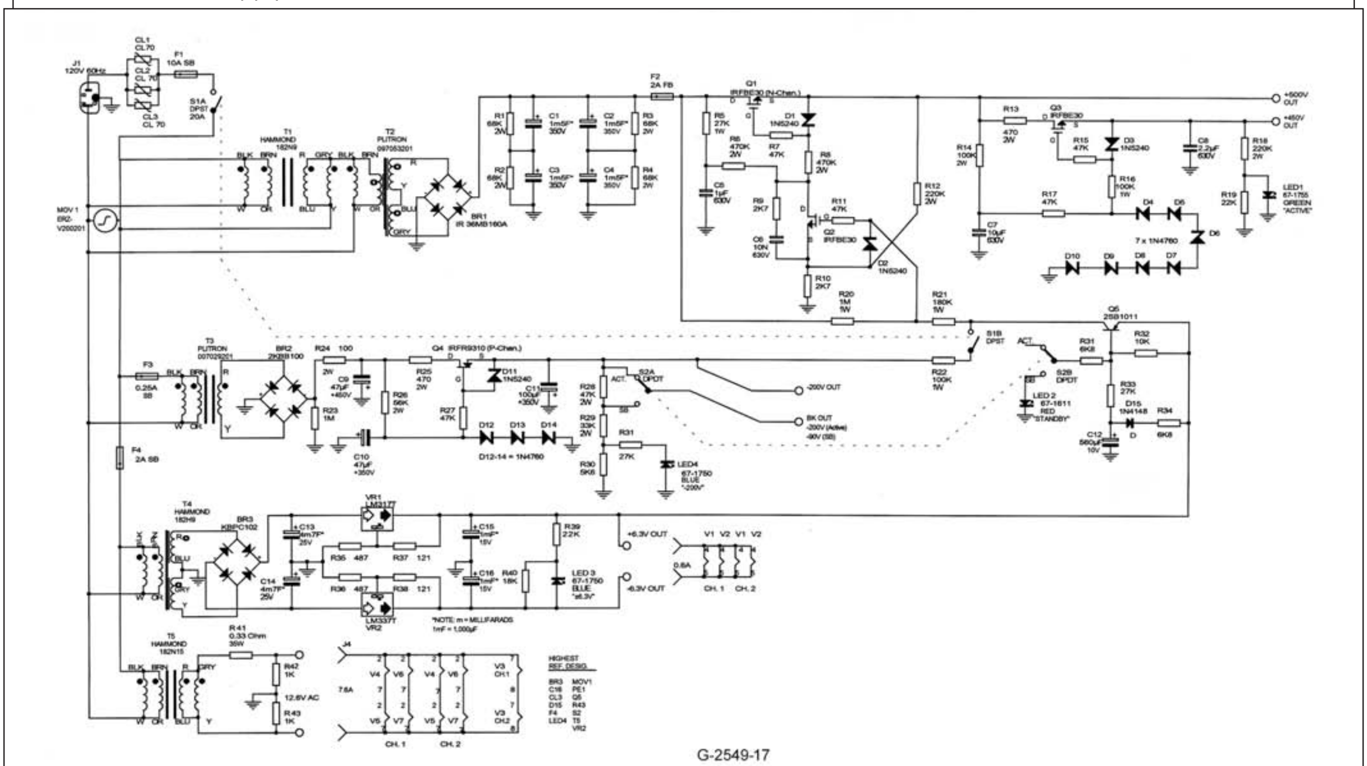
applied to the Q5 emitter. Because C12 is initially discharged, Q5 is quickly turned on (before the HV supplies charge up). Q5 collector current fed into R21/R22 turns Q2 on, keeping the 500V output off. After about 20 seconds, C12 charges enough to turn Q5 off, if S2B is in the "active" position, and the 500V turns on. With S2 in "standby" position, R31 and LED 2 keep Q5 on, and the 500V off.

The purpose of R12 (feeding Q2 source) is to provide some (positive FB) hysteresis to the switching circuit, to ensure no "hanging around" between on and off, which would blow Q1. Note the switch S1B in the –200V path through R22. This is a second pole of the main AC switch S1A, and the purpose is as follows: without S1B, if the amplifier was in standby when the AC was switched off, the amp became active several seconds later, producing a few seconds of decaying, distorted audio. This was because (a) the –200V decays slowly upon power-off, and (b) the –6.3V decays quickly, preventing Q5 from continuing the "standby" function long enough for the cap bank C1–4 to discharge. S1B interrupts the (decaying) –200V, making the 500V Q1 switch "think" the bias has failed; this keeps the 500V off.

The turn-on timing cap C12 is discharged upon AC power-off by D15 and R34; without R34 the discharge would be as quick as that of the –6.3V (quick because it's supplying tube heaters). Before adding R34, a ¼ second AC power glitch during a storm shut the amp off, and I had to wait the 20-second delay for the music—not acceptable! With R34 = 6.8k, the AC power can be interrupted for about 2 seconds, without initiating the 20-second turn-on delay.

+450V REGULATOR—Q3 is a conventional regulated source-follower,

FIGURE 17: Power-supply schematic.



with D4–10 as the reference. Because the load is only about 50mA (input and driver tubes), Q3 is not strained as a linear regulator, nor by the one-second "slow-start" time constant of R14–C7. The latter prevents bias surges or other audible transients from occurring at AC power and standby switching. All such switching is completely smooth and free of audible transients.

-200V BIAS REGULATOR—T3 is a 200V AC toroid, supplying about –300V DC to C9. Q4 and associates are similar to the +450V slow-start source-follower regulator, except for using a P-channel FET.

Note the "BK out" tapped down to –90V by R28, 29, 30, and S2A. "BK" stands for "Bias, Cathode," and its purpose is to reduce the voltage driving the 6SN7 cathode followers during standby; without plate voltage, the 6SN7 cathodes would otherwise reach –200V, which is the peak heater-cathode 6SN7 rating.

The KT88s need only about –130V peak, but I wanted –200V because the 6SN7 cathodes (directly driving the KT88 grids) must maintain enough current to keep their low output resistance on negative cycle peaks, avoiding slewing distortion.

±6.3V REGULATORS—Not much to say here; perfectly conventional linear regulators supplied by toroid T4. In addition to the servo-balance op amps, the ±6.3V outputs power (differentially) the 12.6V heater pins (4, 5) of the 12AX7 and 12AT7 tubes.

12.6V AC—Powering the 6SN7 and KT88 heaters (series pairs), this uses a 15V 8A toroid. R41 drops the loaded voltage to very close to 12.6V, and provides some surge-current limiting. With this plus that provided by CL1–3, the KT88 heater surge is only 3.9A (2.4 × the 1.6A hot current). Without any limiting, the cold surge would be about 10A.

FIGURE 18: Squarewave responses.

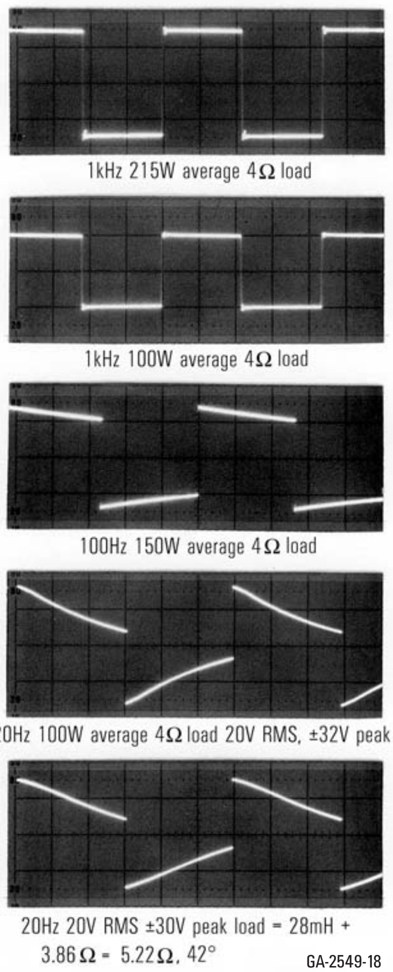


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FIGURE 19: Stability with extreme loads.
1kHz square wave response, output = 28.3V RMS (would be 200W with 4Ω load).

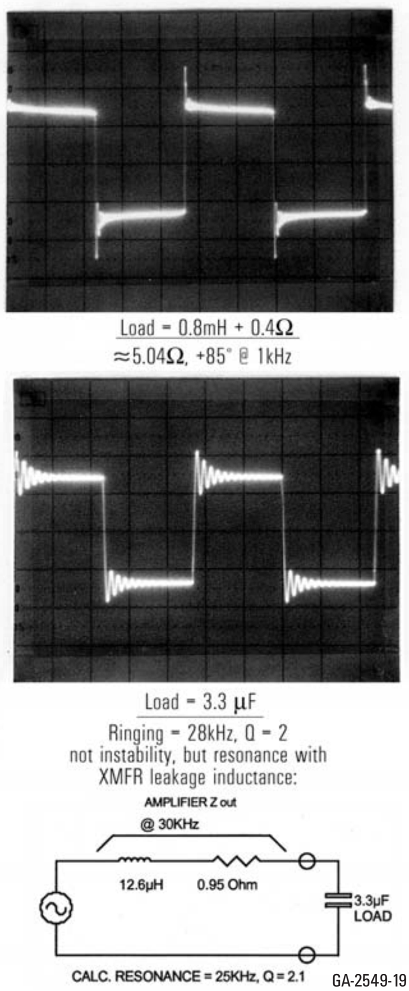

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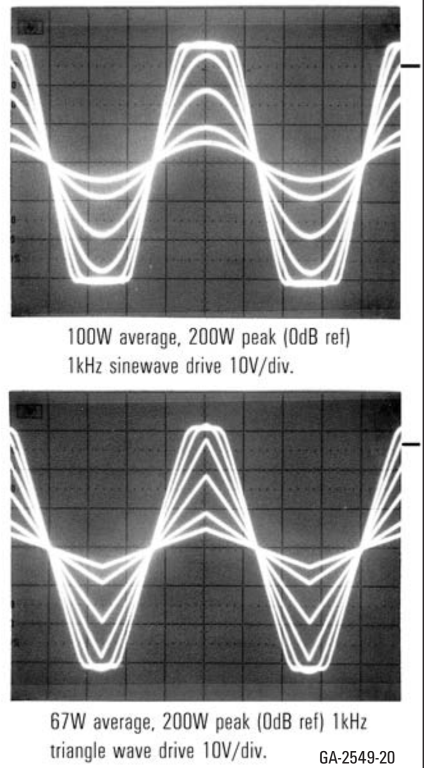
FIGURE 20: Overdrive limiting characteristics.
4Ω load 0dB ref – rated maximum power. Input levels (re 0dB ref) = +4.4, +2.5, 0, –3.5, –9.5, –15.5dB



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This power supply is probably more extravagant, and certainly more expensive (five toroid transformers!) than necessary. But I wanted it to be very clean (including very low magnetic leakage) and rugged. Regarding the latter, it (and the amplifier) has withstood hours of abuse (extended overdriven square-wave tests, shorting the amp outputs to test the current-limiting, driving a ⅙ HP motor, making sparks) and months of normal music playing.

CONSTRUCTION

The chassis is a Plitron PAT-CASE-22 (22″ × 17″ × 3″), about $220 (US). Extremely solid, it's also very good-looking, with ⅛″ thick black-crinkle finished aluminum surfaces and a ⅜″ thick gold-painted front panel (**Photos 8–11**). One safety caution: The chassis is supplied with black (anodized?) machine screws. These do *not* provide front, rear, and bottom panel electrical contact with the chassis! (In case of some short, would you want the front panel charged up to 500V?)

You *must* scrape the screw threads and the inside panel threads at least partially bare. Likewise, chassis mounting holes for all exposed components (handles, transformers, controls, and so on) and internal ground points (terminal strips, and so on) must be surrounded by a ring of bare metal (a hand drill grinding tip works well). Please observe the utmost safety precautions—when measuring in the chassis, use only one hand; let no other body part come near any conductive object!

CHASSIS LAYOUT

I don't have dimensioned layout drawings, having "winged it" on grid paper. But you can scan the photos and computer-scale them if you want the same layout I used. If so, the KT88s are on a 10″ diameter circle, spaced 36° apart (ten tubes would complete the circle; eight are used).

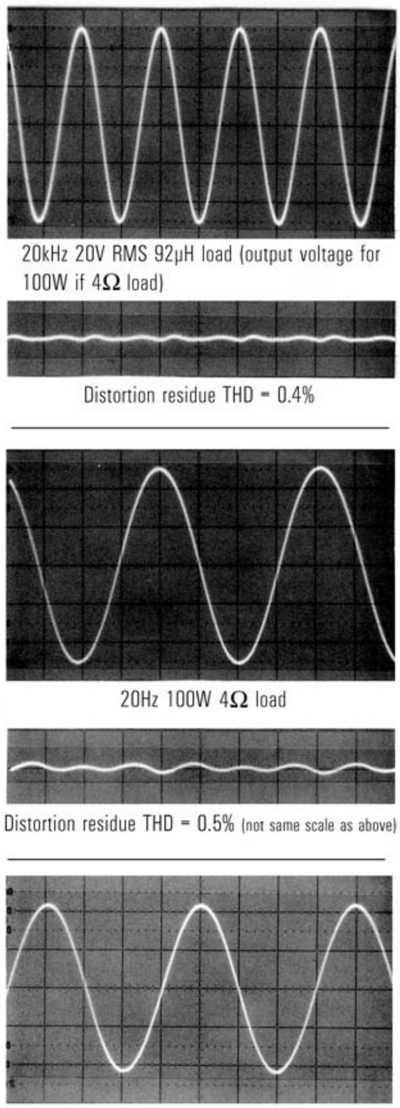
Five toroid transformers are used in the power supply (**Photo 12**). Chassis placement, front to back, is:

1. T1 stacked atop T5, centered on KT88 circle.
2. T2, the plate supply transformer.
3. T3 stacked atop T4, at the back of the chassis.

While there is no problem stacking the toroids (very low magnetic leakage and heat), Plitron mentions a "shorted turn condition": If you connect an AC voltmeter from chassis to the mounting bolt of, say, T2, it will read about 0.7V RMS. The bolt and meter/leads constitute a one-turn secondary looping through the core; 0.7V/turn is the winding induction. The warning is to not have any grounded metal (strap, metal enclosure if used, and so on) contact the toroid mounting bolt top. With low enough path resistance, that 0.7V AC could (with the capacity of T2) produce 1500A of current in the mounting bolt, and you'd have quite an arc-weld to remove!

On the chassis top are (1) polarity switches—near front panel, non-inverting with handle away from panel, and (2) bias pots, just behind the 6SN7s. Note: the pots to the front of the bias-setting ones are not used—they were planned as linearizing adjustments, but proved to be unnecessary.

FIGURE 21: Sinewave outputs.

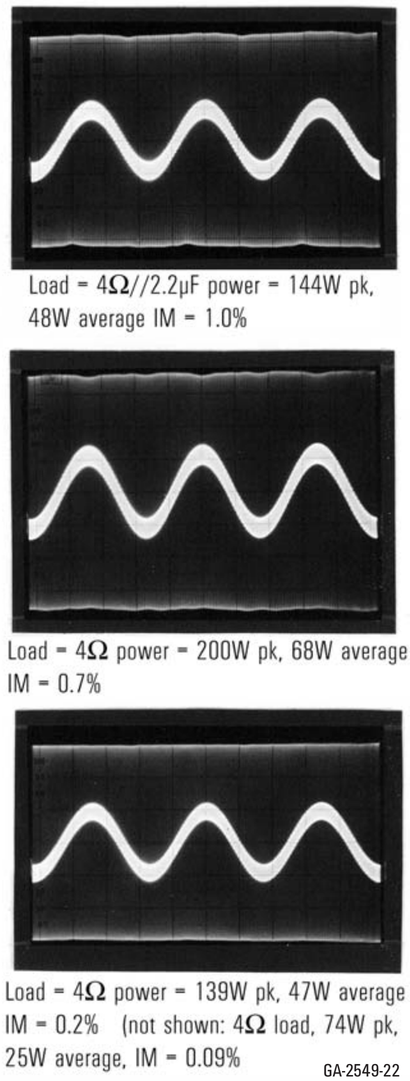


TUBE LAYOUT AND WIRING

I gave much thought to minimizing hum, noise, crosstalk, and unwanted feedback ("self-crosstalk"). The effort was well worth it: output noise (20Hz–20kHz) is 0.053mV RMS, hum is 0.3mV, and crosstalk is –86dB up to 10kHz, -75dB at 20kHz. Steps taken were:

1. Tube layout: admittedly, I wanted the circular pattern of KT88s for its

FIGURE 22: Amplifier IM test.
200Hz + 10kHz, 4:1 voltage ratio. Inner trace = amplifier output. Outer trace = filtered 10kHz output.



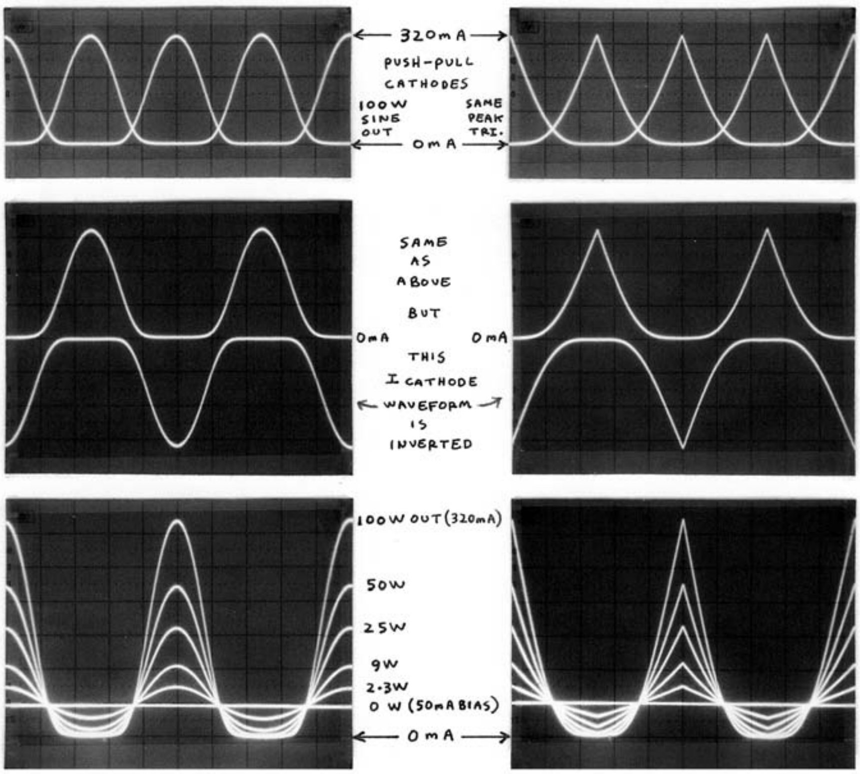
aesthetics, the glowing "ring of fire." But it also serves audio purposes: First, the centered heater transformer toroid is close to all the KT88s; minimum voltage drop and hum radiation. Second, the KT88s' placement alternates push, pull, push, pull, rather than adjacent paralleled tubes. This significantly cancels the radiated electrostatic field of each plate's 700V p-p maximum signal, to minimize HF capacitive feedback to the input wiring.

The 12AX7 input tubes and associated components (**Photo 17**) are nestled tightly near the front corners of the chassis; audio wiring is close to the chassis floor.

2. Wiring: I used Alpha 600V #24 for the +500V and +450V wiring, 300V #16 for the AC line feeds, 300V #18 for the 12.6V AC heaters, and 300V #22 for everything else.

Note that the KT88 plates and screens are wired with twisted pairs, each conducting a balanced push-pull signal. This is facilitated by the KT88s' adjacent push-pull placement described above. The KT88 heaters are wired in series pairs of push-pull tubes; this has a nice advantage that if one tube's heater opens, its push-pull partner will also become deactivated, thus preventing a huge DC imbalance in the output transformer. Actually, the servo-balance alone would reduce such an imbalance to about 4mA, roughly quarter-saturating the transformer but allowing reduced-power functionality.

FIGURE 23: Class AB current waveforms (per KT88; 4 used).



Sine wave

Po average W	Po peak W	I/KT88 average mA
100	200	110.0
50	100	82.9
25	50	67.4
9	18	56.2
2.25	4.5	51.8

Square (not shown)

Po average W	Po peak w	I/KT88 average mA
200	200	160.7
100	100	114.2
50	50	84.3
18	18	62.1
4.5	4.5	53.0

Triangle wave

Po average W	Po peak W	I/KT88 average mA
67	200	92.5
33	100	72.5
17	50	62.1
6	18	54.3
1.5	4.5	51.2

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I used many terminal strips to keep the extensive amount of wiring as uncluttered and close to the chassis as possible. One point worth mentioning is that the KT88 base shell (pin 1) is grounded; I've seen some schematics that don't show this. Ground it for safety!

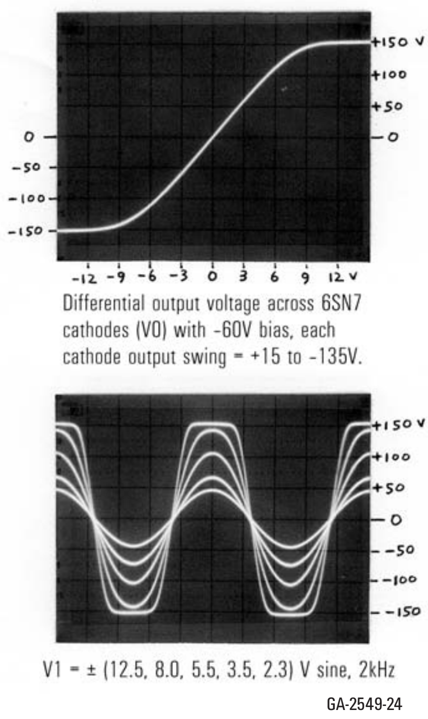
OPERATING TEMPERATURES

Table 2 shows the temperatures of various parts of the amp, after being on for one hour, measured with an IR thermometer. Also shown is the cooling provided by a small, quiet fan assembly blowing down over the toroids centered among the KT88s (**Photo 18**).

Without the fan, the hottest spot (excluding tubes, of course) was the chassis atop the 0.33Ω heater dropping resistor (R16, **Fig. 17**)—this spot reached 76° C (170° F). This is not excessive, because (1) all components are conservatively operated with regard to their ratings, and (2) the most heat-degradable components, the electrolytic supply caps, are rated for 105° C.

The temps in **Table 2** were measured at an ambient of 24° C (75° F) and with the amp on but no signal, where the AC line consumption is 398W. For a

FIGURE 24: 12AT7 Driver + 6SN7 cathode follower transfer function and limiting waveforms (used to linearize output stage).



worst-case heat scenario, consider both channels driven to clipping with typical music (500W AC consumption) and an (unlikely) room ambient of 100°F (38° C). Then the hottest chassis spot would reach about 103° C. So the fan is probably advisable if you listen at full power in the tropics with no air conditioning, but under more reasonable circumstances you should not need it.

All components are conservatively operated. Maximum KT88 plate + screen dissipation is 28W; the Genelex rating is 40W recommended, 46W absolute maximum. The tubes should last a very long time.

With the JJ KT88s, performance changes very little over a (cathode current) bias range of 45–65mA. After about 30 hours of break-in (measuring and listening), bias was set to 50mA (±2mA among all eight tubes). One year later, with about 150 accumulated hours, the bias had changed by only about 1mA.

Figures 18–25 show a variety of test waveforms.

THE SOUND

Ideally, an amplifier shouldn't have any. In the real world, an added "warm," "romantic," "tubey" sound may be valued to compensate recording "dryness," and so on, or simply for preference. But the goal of Mad Katy is faithful signal (therefore sound) reproduction of the source, be that good or bad.

Over the year since the amp was completed, I've done much listening and performed several comparison tests. Following is a summary of results. But please note: the tubes are biased, but I'm not—after spending two years on this project, I certainly wanted to know whether there were any problems with the result—so I've almost fanatically searched for sonic anomalies.

Also, my hearing is good, but extends to 14kHz (at 85dB SPL). So those who can hear that highest half-octave (to 20kHz) might hear things I didn't (not much musical energy up there, though). Summarizing my observations:

1. Normal listening: very satisfying; natural, uncolored, and resolving with well-

FIGURE 25: AC Line input waveforms.

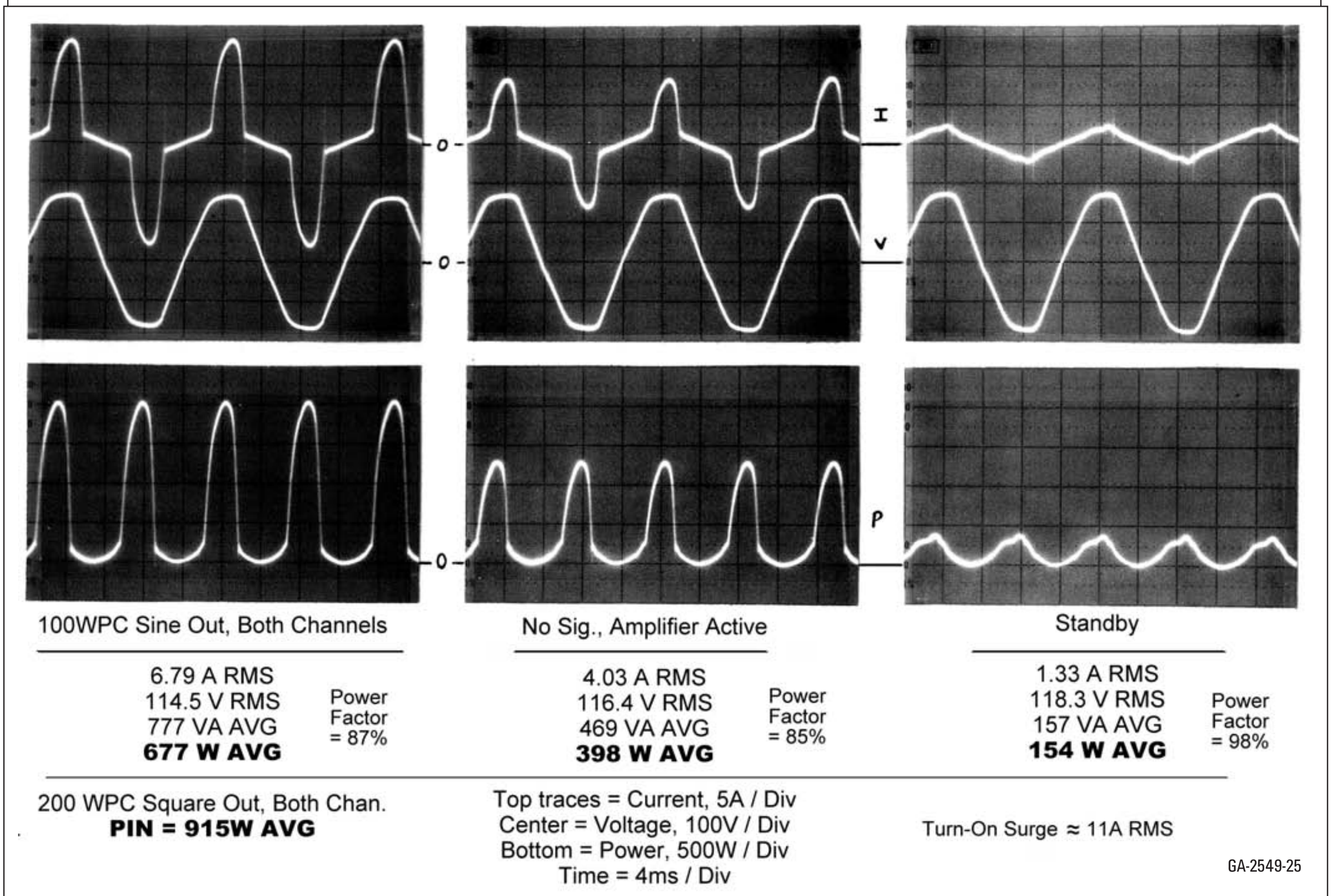


TABLE 2: OPERATING TEMPERATURES.

Temps after 1 hour on (active, no signal)
Ambient T = 24° C = 75.2° F°
Fan: Papst 3412 L (on 6.3V DC – virtually inaudible)
Rated 12V; used at + 6.3V, 61mA
Mounted over 9V and 12.6V transformers, blowing down

Item		*T, ° C no fan*	*T, ° C with fan*	*Fan cooling ΔT, °C°*
Tubes	KT88	195°	163°	32°
(maximum	6SN7	128°	111°	17°
envelope	12AT7	118°	100°	18°
temperature)	12AX7	81°	68°	13°
Transformers	+500V	51°	40°	11°
(usage	12.6V AC	70°	51°	19°
specified)	9V AC	63°	45°	18°
	-200V	58°	51°	7°
	±6.3V	48°	47°	1°
	output	33°	31°	2°
Chassis over 0.33Ω 12.6V AC ballast		76°	60°	16°
Near KT88s		65°	51°	14°
Top, near front		57°	46°	11°
Sides, mid		47°	41°	6°

recorded SACD music. No sense of strain up to clipping (155W per channel peaks).

2. Live-miked voice and a 2″ diameter bell: I used the Panasonic WM-60 AY capsule (used in Mitey Mike II, *SB* 4/97) and the Swans M1 speaker with excellent ribbon tweeter, coherence, and neutrality (*SB* 3/99).

With the bell, the amp was driven to just below clipping on the (very high peak) metal impact transients, which were reproduced cleanly and as solidly as with a comparison solid-state amp. But both the transient “clink” and the resonating “clang” sounded more like the actual metal bell, with the tube amp. Voice was more natural with the tube amp; vowel sounds had that natural (not euphonically softened) “roundness” or “fullness” of tone.

3. Intrinsic fidelity test: This is based on “Sonic Comparison of Power Amp Output vs. Input” (*aX* 12/04). **Figure 26** is the test setup I used with Mad Katy. The setup includes:

a) a reactive and varying load. This does not produce the typical speaker’s bass resonance impedance rise, but Mad Katy had not shown sensitivity to LF impedance variations in previous tests. However, the amp did appear to produce a slight “softening” of HF detail with a speaker whose impedance dipped to 3Ω from 10–20kHz, when connected to the amp’s 4Ω tap. So I chose the load in **Fig. 26** to have a large |z| variation (2.84:1) from 2–20kHz, reaching a low of 3.46Ω at 20kHz. Load phase angle ranges from +12 to –32°.

b) The exceptionally clean and resolving Sennheiser HD 650 headphones. These have a –3dB BW of 16Hz–30kHz and can reproduce an SPL of 125dB. They are expensive but worth every penny.

c) The phone amp described in “A High Quality Solid State Headphone Amp” (*aX* 11/05). Pure Class A, very transparent, can drive the HD 650 to 119dB SPL, noise floor is 4dB SPL.

With a test tone, the 10k pot was adjusted (both channels, one shown in **Fig. 26**) for A/B (input/output) level matching to within 0.05dB. The amp’s input attenuators were set up so that 0dBFS (2.0V RMS) full-scale peaks drove the amp to 150W per channel, just below clipping. I listened with headphone volumes ranging from about 70–100dB SPL average, about 82-112dB peak.

With a variety of SACD and CD music, I switched between the amp’s input and output, sometimes rapidly, sometimes after hearing a complete musical selection, and sometimes rapidly A/B’ing the first 1–3 notes of a piece.

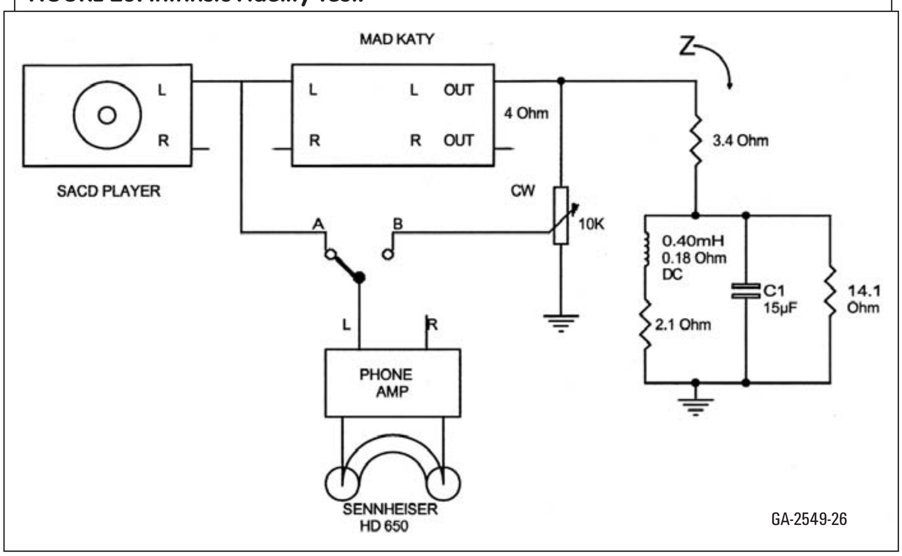
I could not hear any difference I was certain of. By this I mean that (1) for the most part I heard no difference at all, and (2) when I occasionally thought I might have heard some difference, which if at all existing was on the edge of perceptibility, the possibly-heard difference evaporated upon extended switching repetition.

The lack of audible input/output differences may lead some to believe that I have ears of tin, am biased more than the tubes, and/or am in denial. However, despite the current plethora of audibility claims regarding amplifiers (not to mention a few oxygen atoms in a wire), there are much less-publicized (and much more scientifically rigorous) evaluation studies of amplifier sonics, including one by Peter Walker of Quad fame. The latter test, among some others, concluded that the amps compared produced no audible difference.

Among those power amps designed for the most faithful reproduction (as opposed to those designed to euphonically compensate/complement recording/playback chain deficiencies or one’s tastes), I suspect that the intrinsic fidelity test of **Fig. 26** would reveal little or no audible in/out differences.

Therefore, considering the largely ignored studies mentioned above, I would conclude *not* that Mad Katy is by any means “perfect” or “the world’s best,” or any such nonsense, but rather that it is sufficiently neutral, transparent, solid, and resolving to allow one to set it, forget it, and enjoy the music, with 250W (⅓ horsepower) coming from electrons working in a vacuum. ***aX***

FIGURE 26: Intrinsic Fidelity Test.



PARTS LIST FOR CHASSIS

Part	**Manufacturer**	**Part#**
Chassis	Plitron	PAT-CASE-22