1. Summary

VASE PA100, S.N. 116/100/ T. 6 microphone input channel PA amplifier.
$121.40 eBay Jan 2009

Each microphone channel with BC109 input, followed by Baxandal Bass & Treble tone controls, and final BC108 output to volume pot. 6 channels summed to Master Volume pot. 2x BC107 input to mono valve amplifier stage. 12AX7 long-tail splitter and fixed bias push-pull output, with secondary side feedback, using KT88 tubes in Class AB1. Plate supply from voltage doubler semiconductor diode rectifier and capacitor filter, resistor dropping to the screen supply, and resistor dropping to the transistor circuit supplies. Output stage grid bias is from a separate supply.

Input Stage	6x Mic Channels with common master volume. BC109 & BC108. Bass, Treble and Vol pots per channel
Driver Stage	BC107, BC108 with 12AX7 splitter
Output stage	2x 7S or 7AC socket pentodes, KT88, mounted 3” apart with pins 4 and 8 in line.
Output Transformer	Ferguson OPM13A [Rated at 55W, with 15/8/3.7/2 ohm outputs]
Power Transformer	Ferguson, PVD110, 8-69, V3
Power supply	2x 200uF 350V in series for output stage.
POTs	IRC CT545 FO 500K Likely 1965, week 45.
Product information	No specific info available. Similar VASE Trendsetter 100 schematic indicates similar design. Similar Fender Bassman design.

2. Aim

- Replace faulty screen grid stopper and standby pre-charge resistors. Done.
- Check electrolytic caps and replace or bypass faulty units.
- Adapt the multiple mic inputs to allow a variety of bass/electric guitar inputs, and a send/receive loop. Eg. 1x clean bass; 1x clean guitar; 2x overdrive guitar. Use the original pots for tone-stacks etc.
- Replace the XLR mains socket with either new XLR or IEC.
- Review use of new output sockets – need to retain shorted output if no speakers connected – check Speakon options – check if 8Ω and 4Ω outputs can be accomodated.
- Add low value cathode-to-0V resistors, and include meter for reading bias current level on each output tube. Eg. 1 ohm, 1% with 30mA bias will give 30mV. Use PRO2 resistor.
- Split the grid bias V5 to allow output tube bias currents to be matched.
- Add in grid bias failure protection circuit (48V relay that pulls out if bias is lost, and isolates the plate voltage from the tubes). Add in plate/screen supply over-current protection (fused transformer HT secondary). Add in open-circuit output protection (loading resistor on 15Ω output winding).
- Adjust the voltage signal level at the output of the splitter (trim the 82K resistor value to get matched split levels; trim and check distortion level changes).
- Add 2x 40mm computer fans into the wooden chassis base vent cutout. This should provide improved air circulation in the hottest region – cooler tubes last longer.
- Measure hum levels and minimise (check balancing circuit for connection to ground; check magnetic shielding; check star ground configuration; check output ground points and star ground to feedback circuit).

3. Measurements

Voltage rails (No valves, no heaters) 30K precharge.

Rail	10K5 load on V1 100K load on V3 Standby / ON	3K6 on V1 19K on V3 ON	2K4 on V1 19K on V3 ON	2K on V1 19K on V3 ON	2K on V1 19K on V3 ON
V1	26V / 540V 28W	501V 70W	490V 100W	480V 115W	468V 156W
V2	26V / 521V 2.7W	482V	471V	462V	444V
V4	26V / 521V	477V	467V	458V	444V
V5	-52V / -52V	-58V / -57V			
V6	30.8V / 30.8V	20V	19.8V	20V	22V
V7	15.3V /				
Heater	6.9Vrms /				
Sec HT	202.2Vrms / 201Vrms				

V5 bias pot has a marking effectively at max R.

12VAC 50Hz nominal applied to OPM13A output transformer

Winding	Voltage rms	Turns ratio; Impedance for 3K5 pri; Spec level; Notes
Pri P-P: BLU to BRN	176	
Sec: BLK to OR	4.46V	39.5; 2.2 Ω; 2 Ω;
Sec: BLK to YEL	6.05V	29.1; 4.1 Ω; 3.7Ω;
Sec: BLK to WH	9.07V	19.4; 9.3 Ω; 8Ω; "8Ω" output winding
Sec: BLK to GRN	12.36V	14.2; 17.3 Ω; 15Ω; feedback winding

Note: unsolder output connection to 6.5mm output jack, as this shorts to ground with no speaker connection.

Output transformer primary DC resistance: 72Ω plate-to-plate.

4. Design Info

The splitter stage and output stage are equivalent to the Fender Bassman 5F6-A circuit, except the rail voltages are somewhat higher. The following info is based on the description by Ben Verellen (who primarily references Richard Kuehnel's book on the Fender amp). The 12AX7 and KT88 valve types discussed are the best estimate based on what was originally used in other VASE equipment. The design discussion below substantiates that choice.

4.1 Splitter stage

In this stage the input signal is split and amplified into two signals, 180˚out of phase from one another, and presented to the push-pull output stage. The long-tail splitter configuration is a differential amplifier made up of the two triodes in a 12AX7. DC analysis is based on capacitors as open circuits, feedback voltage is zero, and the two load resistors are both equal (at R_L=100kΩ). Each triode plate circuit shares the cathode resistance to ground, and so the effective cathode resistance to each distinct triode is double the circuit value. The plate current versus plate voltage load line for each triode is given by the equation:

$$Ip = \frac{V_p}{R_L + 2(R_K)}$$

where R_k = 1kΩ + 6.8kΩ + 4.7kΩ = 12.5kΩ. The plate voltage Vp axis intercept is 520V (point A) for no plate current, and the plate current Ip axis intercept is 520V / 125KΩ = 4.2mA (point B). The gate-cathode voltage (Ec on the graph) varies with plate current through the 1kΩ gate-cathode resistance, but with a 2kΩ characteristic, and this characteristic is shown on the graph as a line passing through Ip=1mA for Vgk=-2V, and through Ip=1.5mA for Vgk=-3V. The intersection of the two lines is the nominal biased operating point. This operating point moves when the supply voltage sags under heavy output loading, as shown by the dashed load line.

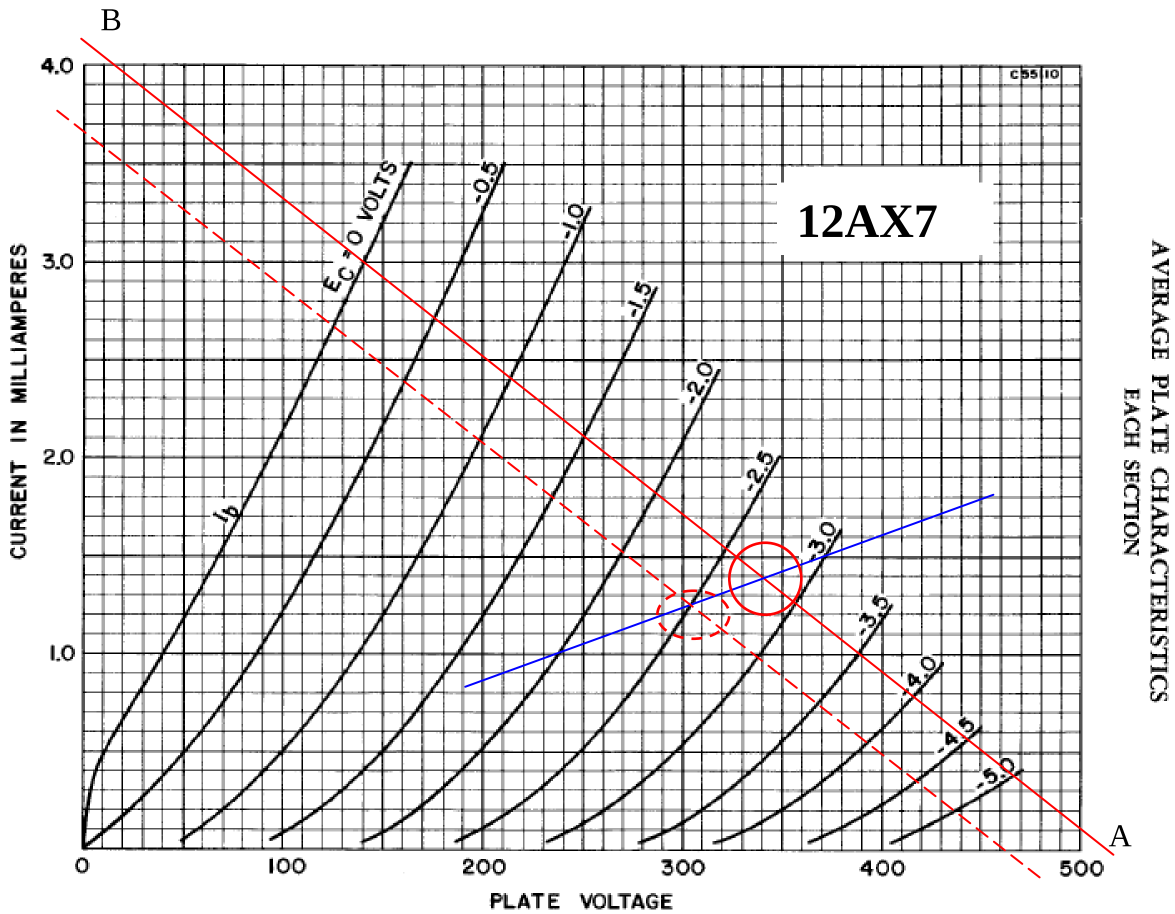
The nominal operating point levels of Vgk=-2.8V and Vp=350V are used to determine the parameter values of r_p and gm and μ from the 12AX7 average transfer characteristics graph (note that Eb is Vp).

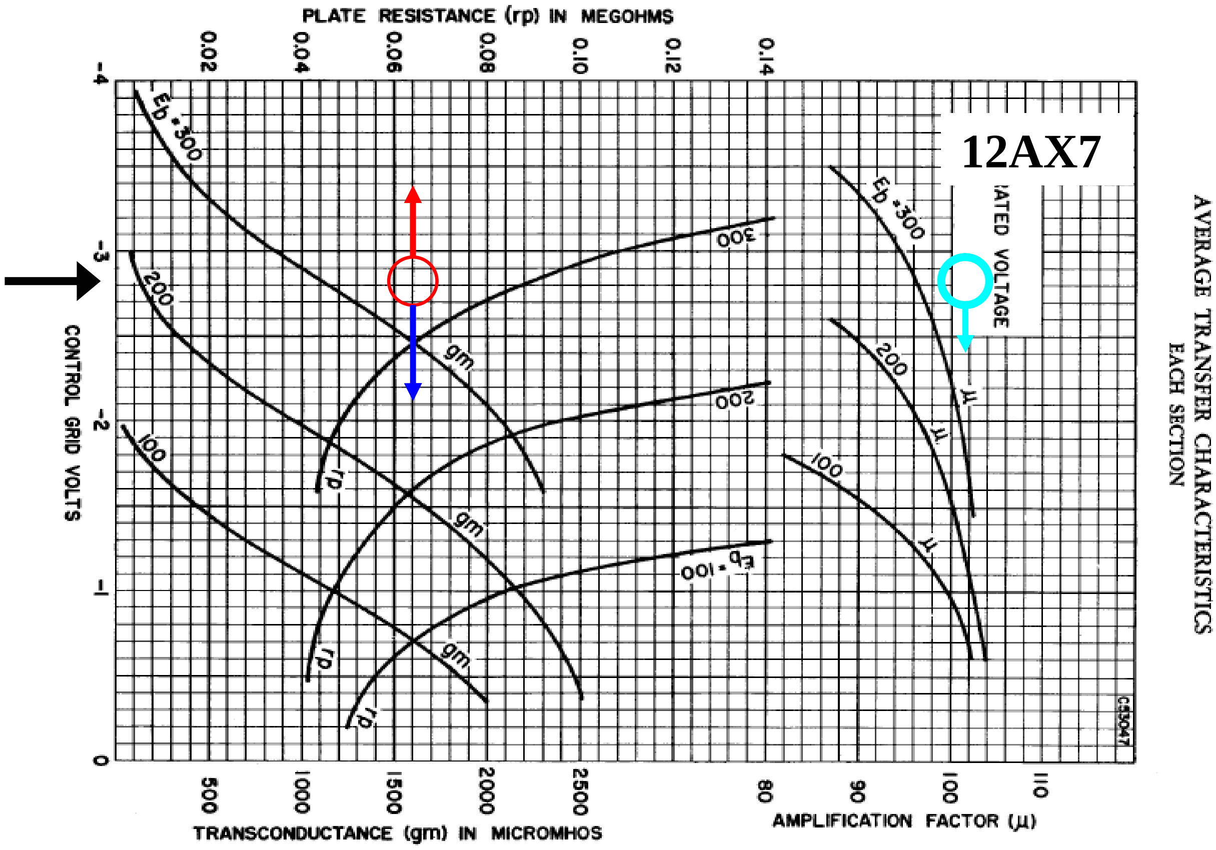
The analysis by Kuehnel shows that the gain of each triode is slightly different, due to a small level of common-mode gain adding to the out-of-phase output but subtracting from the in-phase output, which is compensated by lowering the load resistor for the out-of-phase output to 82KΩ nominal. The input voltage swing limit is from the bias point at Vgk=-2.8V to Vgk=0V, which is about 5.6Vpp or 2Vrms.

The voltage gain G is about 30x. Hence, the signal voltage swing available to each control grid of the output stage is up to 2.8Vpk x 30 = 84Vpk, which exceeds the output stage's requirements of about 60Vpk max. The voltage gain remains effectively constant as the supply voltage sags – this is shown more clearly in the 7025 datasheet. The input loading of the output stage will reduce the output voltage swing – the 220k bias resistors will load up to 0.4mApk.

The rated output voltage at the feedback winding is nominally √(100W x 15Ω) = 39V. The feedback voltage from the output is attenuated to 10% (3.9Vrms) by the 4K7 and 47K divider, with a single pole roll-off at f = 34Hz due to the 0.1uF cap bypassing 4K7.

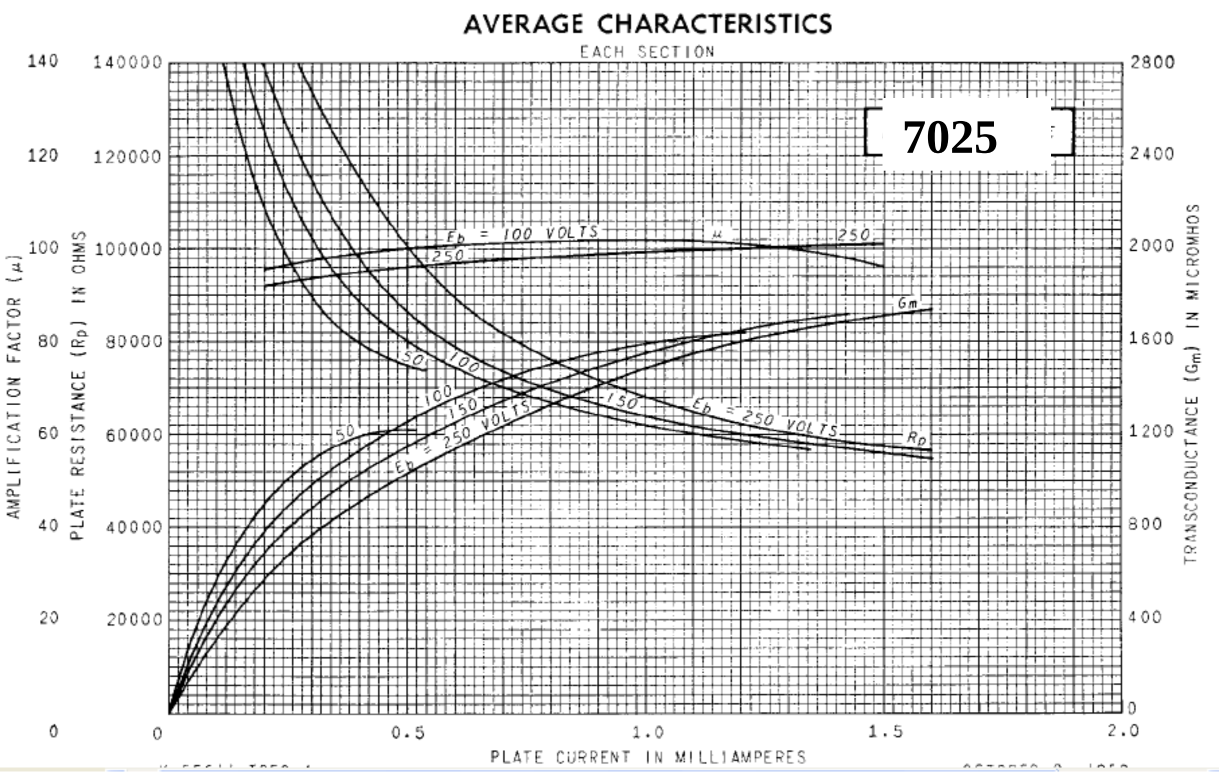
The 12AX7 was a common valve, with manufacturers such as RCA, Sylvania, GE and Tung Sol. The 'A' version has tighter heater tolerances to allow it to be used in series heater connections. The ECC83, 7025 and CV4004 are equivalent and interchangeable, and the 7025 was a low hum version. VASE used the 12AX7 as a typical preamp tube (eg. Trendsetter 100 Deluxe).


B
A
12AX7
AVERAGE PLATE CHARACTERISTICS
EACH SECTION
CURRENT IN MILLIAMPERES
PLATE VOLTAGE
EC = 0 VOLTS
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
-5.0
Ib
0
100
200
300
400
500
1.0
2.0
3.0
4.0


12AX7
PLATE RESISTANCE (rp) IN MEGOHMS
0.02
0.04
0.06
0.08
0.10
0.12
0.14
AVERAGE TRANSFER CHARACTERISTICS
EACH SECTION
CONTROL GRID VOLTS
TRANSCONDUCTANCE (gm) IN MICROMHOS
AMPLIFICATION FACTOR (μ)
Eb = 300
200
100
gm
rp
μ
500
1000
1500
2000
2500
80
90
100
110

Parameter	No signal	Heavy load	Notes
R_L	100k	100k	
Vsupply	520V	460V	= V_{RLoad} + V_P + Vk
I_P	1.4mA	1.25mA	From bias position
V_{gk}	-2.8V (-2.8V)	-2.5V (-2.5V)	From bias position = I_P x 2 x 1KΩ
Vk	32V	29V	= 6.8KΩ x 2 x I_P
V_P	350V	300V	= 521V – 32V - (100KΩ x I_P)
r_p	65kΩ	65kΩ	= ΔVpk / ΔIp
Gm	1.5mS	1.5mS	= ΔIp / ΔVgk
µ	102 [98]	98 [98]	Graph [= gm x r_p]
G	~30	~30	= (u/2) x R_L / (R_L + r_p)
B	.1	.1	= 4K7 / 47K
Headroom	5.6Vpp	5.0Vpp	

Table 1. Phase Splitter Analysis Results for 12AX7



4.2 Output Stage

In this Class AB push-pull output stage, one tube is pushed into conduction and the other tube is pulled into cutoff, and there is a region of overlap where both tubes conduct equivalent levels of current. The cathodes are grounded, and each tube operates in a fixed bias mode with a negative gate voltage. The 3K5Ω impedance plate-to-plate OPT from Ferguson (OPM013A), presents each tube with an 875Ω load impedance (with a matched secondary load) for signal currents. To achieve 100Wrms into a 3k5Ω loading requires Ipk > √ (2 x 100W / 3500Ω) = 240mA.

It is likely that guitar amp design was influenced by the known speaker load used in the combo. Most guitar speakers were just 12" drivers, whose likely impedance was significantly above nominal 4 or 8 ohm over the frequency range of most use. This would have presented a higher load impedance to the output stage via the output transformer.

Determining a suitable bias current level for the PA100 is not an empirical design approach, rather it is based on the following recommendations:

- Start with the lowest bias current possible (ie. most negative grid bias voltage), and based on listening tests, increase the bias current until the sound character is acceptable, but:
- use the lowest possible bias current level, as this generally increases the life of the tubes, and decreases the chance of operating at excessive plate dissipation; and
- keep the bias current level below 70% of the recommended design max plate dissipation (ie. <25W); and
- assess the dynamic loadline to see if it moves into region of increased plate dissipation.

As the output loading increases, the supply voltage V1 to the output valve plates sags from about 540V to as low as 460V. Plate DC voltage will be lower than V1 by an amount up to ~10V; ie. OPT half resistance of about 36Ω with a peak current of up to about 0.3A.

The screen voltage V3 will correspondingly sag from about 520V to about 430V. Screen current level increases as Vg approaches 0V, possibly to over 100mA, which lowers V3 by an additional ~56V, with an additional 20V across the screen stopper resistor, hence the screen voltage may sag down to under 400V. The screen supply capacitance is less than the plate supply capacitance and will likely track fairly closely as output loading increase.

For any given control grid voltage, screen voltage will increase if plate voltage increases as the increased screen current will drop more voltage across the screen dropping resistor, and vice-versa, which produces negative feedback and reduces the plate resistance of the tube. Increasing the screen dropping resistance will effectively lower the plate resistance.

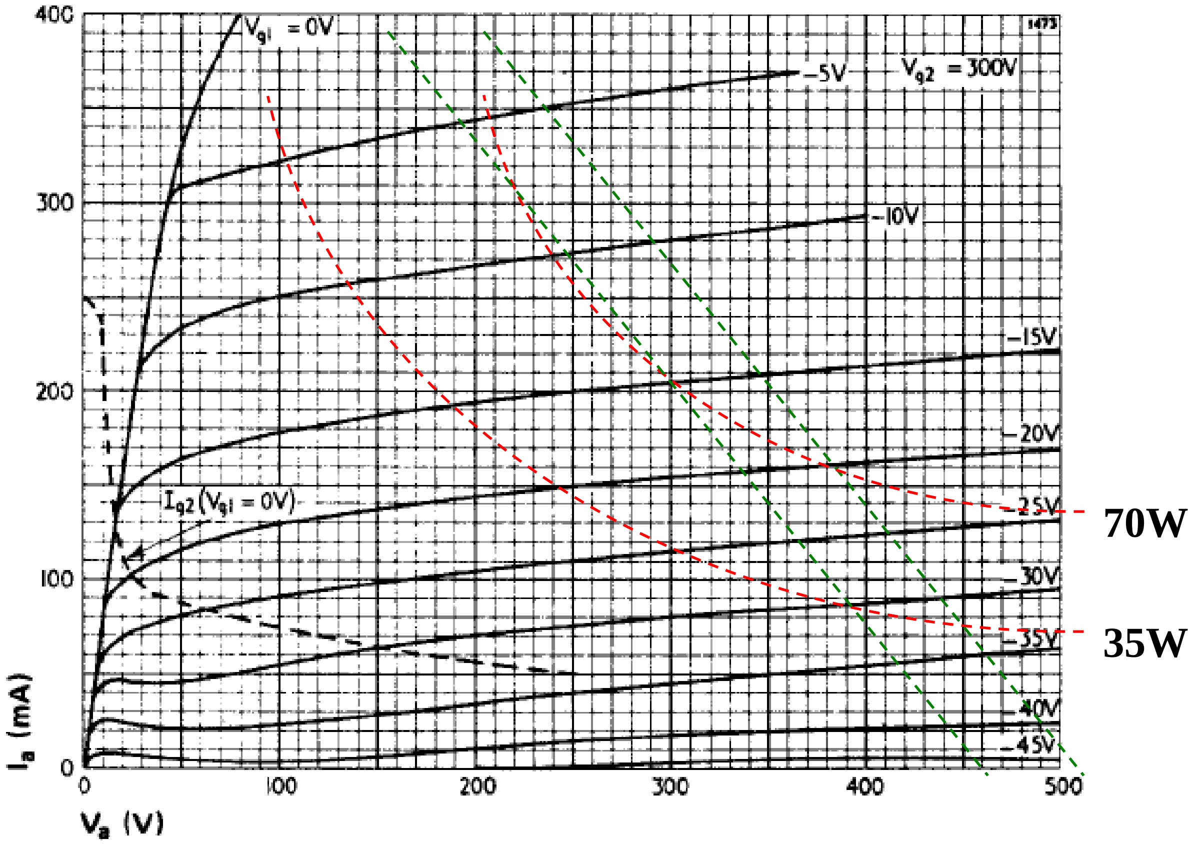
As screen current increases with increasing grid drive voltage, less cathode current gets to the plate – as the screen current is bypassed to ground - which effectively lowers the plate resistance.

The maximum output valve bias current allowed is dependant on the maximum recommended plate dissipation of 35W for the KT88: Ibias(max) = Pd / Vb = 35W / 540V = 65mA. The gate bias voltage required for this current is significantly influenced by the screen voltage (ie. ~-18V at Vs=200V; ~-32V at Vs=300V), however tube graphs are not available for higher screen levels, but can be inferred. At idle, the PA100 operates the screen at close to the plate voltage (~520V), and the gate bias voltage is adjustable down to -58V. During dynamic conditions, the plate dissipation must continue to remain below 35W, and so the load line must on average remain in a region below the constant power curve for 35W shown on the plate current/voltage graph. Each valve has an 'off' period for 50% of time, where the average plate dissipation is relatively low and expected to be in the range between the upper limit of the bias level power dissipation, down to a few watts when most of the period is spent in deep cutoff due to very negative grid voltage levels. As such, the average dissipation during the 'on' period can extend dynamically above the 35W curve. For the simple sinewave scenario, with a 70W average over a half-sine, the plate current level that gives 70W steadystate would dynamically peak at 41% higher.

Assessing the KT88 plate curves, which show 35W and 70W constant power contours, indicate how the amp will dynamically go into higher plate dissipation levels. Note that these curves are for only a 300V screen level, with no compression influences, and the load lines are for 3K5, which would slope more to the left for higher impedance (eg. speaker impedance above 8Ω nominal).

The general textbook design process involves choosing a suitable OPT plate-plate impedance to position the Vg=0 and maximum plate current point at the 'knee' of the Vg=0 curve on the plate current-voltage graph. This knee position has a net minimum level of 2nd and 3rd harmonic levels, where moving away from the knee by increasing the load impedance will increase the 3rd harmonic level, and decreasing the load impedance will increase the 2nd and lower the 5th – which is generally perceived as the preferred outcome. The screen grid voltage is normally reduced from the plate supply level to accommodate a given primary impedance. As the screen grid voltage is raised or lowered, the characteristic curves expand or contract in the vertical direction. The optimum screen voltage is the one that places the knee of the Vg1 = 0 curve on the load line.

The only valve types that are specified with screen voltage levels at and above 500V are the KT88, KT90, and possibly the 8417.



Parameter values for fixed bias, PP, Class AB1 circuits from datasheets.

	6L6GC	KT66	6550	6550	KT88 Svetlana	KT88 Genelex
Heater A	0.9A	1.3A	1.6A	1.6A	1.6A	1.6A
Plate V	450V	525V	450V	600V	560V	560V

Screen grid	400V		310V	300V	300V	300V
Grid	-37V	-67V	-29.5V	-32.5V	-45V	-34V
Grid Vpp	70V		58V	65V		67V
Plate A no sig	116mA	35mA	150mA	100mA	120mA	120mA
Plate A max sig	210mA	80mA	295mA	270mA	290mA	290mA
Screen A no sig	5.6mA		9mA	5mA	3.4mA	3.4mA
Screen A max sig	22mA		38mA	33mA	30mA	30mA
Load R p-p	5600Ω	8000Ω	3500Ω	5000Ω	4500Ω	4500Ω
Power Out	55W	50W	77W	100W	100W	100W

4.3 Power Supplies

Standby power switch setting pre-charge resistor appears to be a 20X 2W resistor. Initial voltage across this resistor after power turn-on is about 300V during diode conduction with discharged V1 caps. Given nominal 2W rating then resistance should be around $R = V^2/P = 45K$. Replace with 3x 10K PRO2 resistors in series. V1 caps will charge to voltage level where the load is about 1W, which will be at about an output valve bias current (guess) 100V and 5mA for each side – <u>check measured levels</u>.

The power supply circuit is almost identical to the VASE Trandsetter 100 Deluxe, and differences may be due to prevailing design rules at the time and what parts were available.

The capacitance levels for the plate and screen supplies should not be increased, as that may markedly increase the KT88 average dissipation levels under heavy loading.

4.4 To do

Determine the operation and influence of 1nF caps from plate to screen – most likely a local negative feedback path for higher frequencies.

5. Protection

5.1 Loss of grid bias

If the grid bias supply voltage fails, then the grid will rise and become positive to cathode, and plate current will increase without control - the tube first glows cherry red, then fails. A 48VDC relay, Omron G2R-2 48V, has a coil resistance of 4.2K, and a must release voltage of greater than 7.2V, and de-energises due to gross failure of the bias power supply. The coil loads the power supply, reducing the raw voltage from XX to YYV. The relay contacts are used to disconnect the plate voltage, and although the contacts are not rated for the DC voltage, the 2 poles are connected in series, and hopefully should do the job for the one off fault situation (the contacts will be closed during standby when no plate voltage is present).

5.2 HV breakdown

If the B+ rail shorts to ground, due to a flashover, or insulation breakdown, then a 0.5A fuse in the transformer secondary line provides gross failure protection by de-energising both the plate and screen rails. If an output valve breaks down, the cathode current sense resistor has a low wattage rating, and may go open – hence acting as a fuse.

5.3 Output open circuit

Add a 470R 10W resistor to the 15Ω output tap, to act as a high resistance limit in case the speaker load goes open circuit. The 6.5mm output jack has the tip switch connected to 0V, to short the output if no speaker is connected – this is a much more acceptable loading for pentodes than an open circuit.

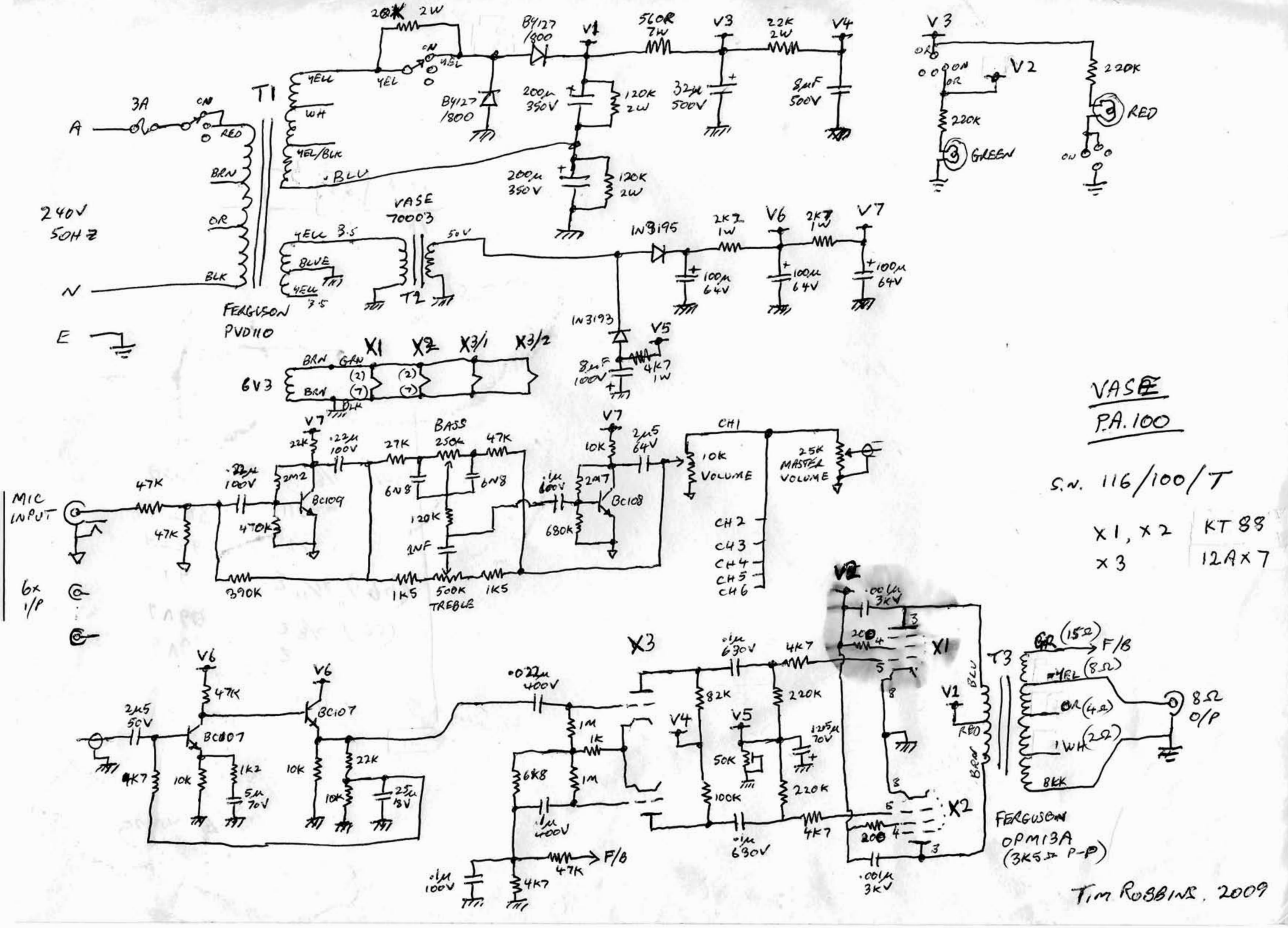
6. Other changes

6.1 Hum reduction options

To minimize filament AC feedthrough to the Cathode of the tubes, both legs of the filament circuit may need symmetry adjustment with respect to the chassis potential (0-volt). A balancing resistor network or pot is used to vary the resistance of one side, versus the other side, to ground – start with 1watt 100-ohm wire wound pot.
The ground connection of the speaker circuit to the audio circuit is used only to provide DC voltage reference to the Feedback circuit. Check if star wiring to circuit ground gives lower hum pickup.
Check if metal shielding the OPT is noticeable.
Check star ground arrangement.

6.2 Distortion variation

Use TrueRTA to view harmonic levels.
Output valve bias.
Lighter loading of output stage – eg. Apply 8Ω loads to 4Ω tapping.
Unbalancing the 12AX7 output and check harmonic change – aim for increasing even order relative to odd order – and determine if noticeable.



VASE P.A.100

S.N. 116/100/T

X1, X2 KT88

X3 12AX7

TIM ROBBINS. 2009