TSX SERIES
HIGH CURRENT POWER SUPPLIES
SERVICE MANUAL

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Contents

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General

This manual has been prepared to aid the experienced engineer in the maintenance and repair of this series of high current power supplies. For detailed operating information the user should refer to the appropriate instruction manual.

SERVICE PRECAUTIONS

Recalibration or repair should only be attempted by skilled personnel in conjunction with high quality test equipment. If the user is in any doubt as to his competence to carry out the work, the supply should be returned to the manufacturer or their agent overseas for the work to be carried out.

The tracks on the printed circuit boards are very fine and may lift if subjected to excessive heat. Use only a miniature temperature-controlled soldering iron and remove all solder with solder wick or suction before attempting to remove a component.

SAFETY

WARNING!

When the power supply is connected to the AC line, terminals may be live and the opening of covers or removal of parts (except those to which access can be gained by hand) is likely to expose live parts. The supply shall be disconnected from all voltage sources before it is opened for any adjustment, replacement, maintenance or repair. Capacitors inside the supply may still be charged even if the supply has been disconnected from all voltage sources, but will be safely discharged about 10 minute after switching off power.

Any adjustment, maintenance and repair of the opened supply under voltage shall be avoided as far as possible and, if inevitable, shall be carried out only by a skilled person who is aware of the hazard involved.

DISMANTLING THE INSTRUMENT

Observe the above safety warning before attempting to dismantle the power supply.

1. To remove the case upper, remove the 6 screws (3 each side) and lift off.

2. To remove the upper (CPU) pcb on programmable versions remove the 3 flat cables and the 2-way supply connector next to the regulator heatsink; note the orientation of the flat cables (red stripe to pin 1). Remove the 2 RS232 and 2 GPIB screwjacks which secure the connectors (and therefore the pcb) to the rear panel. Remove the 2 self-tap screws which secure the pcb to the forward mounting pillars and lift it off.

3. To remove the main board disconnect the 2 leads to the output terminals from the M3 studs at the front of pcb and unplug the nearby sense connections, noting the polarity of both. Disconnect the flat cable from the control pcb (non-programmable versions only) and the 2 push-on connections at the rear of the pcb which feed the AC supply to the pcb from the power ON-OFF switch. Remove the self-tap screws which secure the heatsink to the case lower (1 for each heatsink). Remove the 9 screws which secure the main pcb support pillars to the case lower (i.e. the screws accessible **underneath** the case lower) and lift the pcb clear with its mounting pillars attached.

4. To remove the keyboard (programmable versions) or control board (non-programmable versions) first remove the control knob (keyboard) by undoing the collet nut beneath the knob cap or disconnect the output ON-OFF switch (control board) from the pcb. Remove the screws which secure the board to the front panel and lift free.

5. Reassemble in the reverse order. Take great care to ensure that the connections to the output terminals (front and rear) are exactly as found before dismantling and that no insulation creepage and clearance distances have been compromised. Ensure that the foil screen over the output wires in the case lower is properly earthed via the appropriate pcb support pillar.

Specification

OUTPUT SPECIFICATIONS:

Operating modes:	Constant voltage or constant current with automatic crossover.
Voltage Range:	0V to 35.3V (35V/10A) 0V to 18.15V (18V/20A)
Current Range:	0.01A to 10.2A (35V/10A) 0.01A to 20.2A (18V/20A)
Overvoltage protection range:	1V to 40V (35V/10A) 1V to 25V (18V/20A)
Setting Resolution:	10mV, 10mA
Load Regulation:	<0.01% for a 90% load change
Line Regulation:	<0.01% for a 10% line voltage change
Output Impedance:	<1mOhm in constant voltage mode >5kOhm in constant current mode
Ripple and noise:	<1mV RMS typical in constant voltage <3mA RMS typical in constant current
HF Common mode noise:	typically <3mV RMS, <10mV pk.
Transient load response:	<200us to within 50mV of set level for a 90% load change.
Temperature coefficient:	Typically <100ppm/^{o}C
Overvoltage protection delay:	<200us
Protection functions:	Overvoltage trip
Regulator overtemperature	Sense miswiring
Status indication:	Output on/off LED Constant voltage mode LED Constant current mode LED Trip message
Output switch:	Electronic
Output terminals:	4mm output terminals at front Screw terminals for output and sense at rear

INPUT SPECIFICATIONS

Input voltage range:	180V to 270V RMS 90V TO 135V RMS
Power requirement:	47 to 63Hz, 600VA max.
Voltage range selection:	Rear panel slide switch

METER SPECIFICATIONS

Meter types:	Separate 4-digit meters for voltage and current with 12.5mm (0.5") LED displays
Meter resolutions:	10mV, 10mA
Meter accuracies:	Voltage 0.2% +/- 1 digit Current 0.5% +/- 1 digit

FRONT PANEL CONTROLS

Voltage setting:	Direct keyboard entry or quasi-analogue rotary control
Current setting:	Direct keyboard entry or quasi-analogue rotary control
Overvoltage setting:	Direct keyboard entry
Output on/off:	Push button with dual indicator LEDs

Note: All voltage and current levels set via the keyboard are displayed on a separate 0. 0.3" 4-digit display. This entry preview system ensures that the user can observe the value entered before it is effected thus avoiding possible error. The display is also used for setting additional functions. When the output switch is on and no other function is selected, the display shows output power in Watts.

Additional keyboard functions:	Increase or decrease voltage or current in user-selectable steps (delta mode). Store and recall voltage, current and OVP levels from non-volatile memory (25 memories). Set digital interface type (RS232 OR GPIB), set baud rate, set address.

DIGITAL INTERFACES

Operational functions:	Set voltage; set current; set OVP; set output on/off; read output voltage; read output current; read output power.
RS232:	Variable baud rate, 9600 baud maximum. 9 pin D-connector (female). Fully compatible with ARC (Addressable RS232 Chain) system.
GPIB:	Conforming with IEEE488.1 and IEEE488.2

OUTPUT SPECIFICATIONS - REMOTE OPERATION

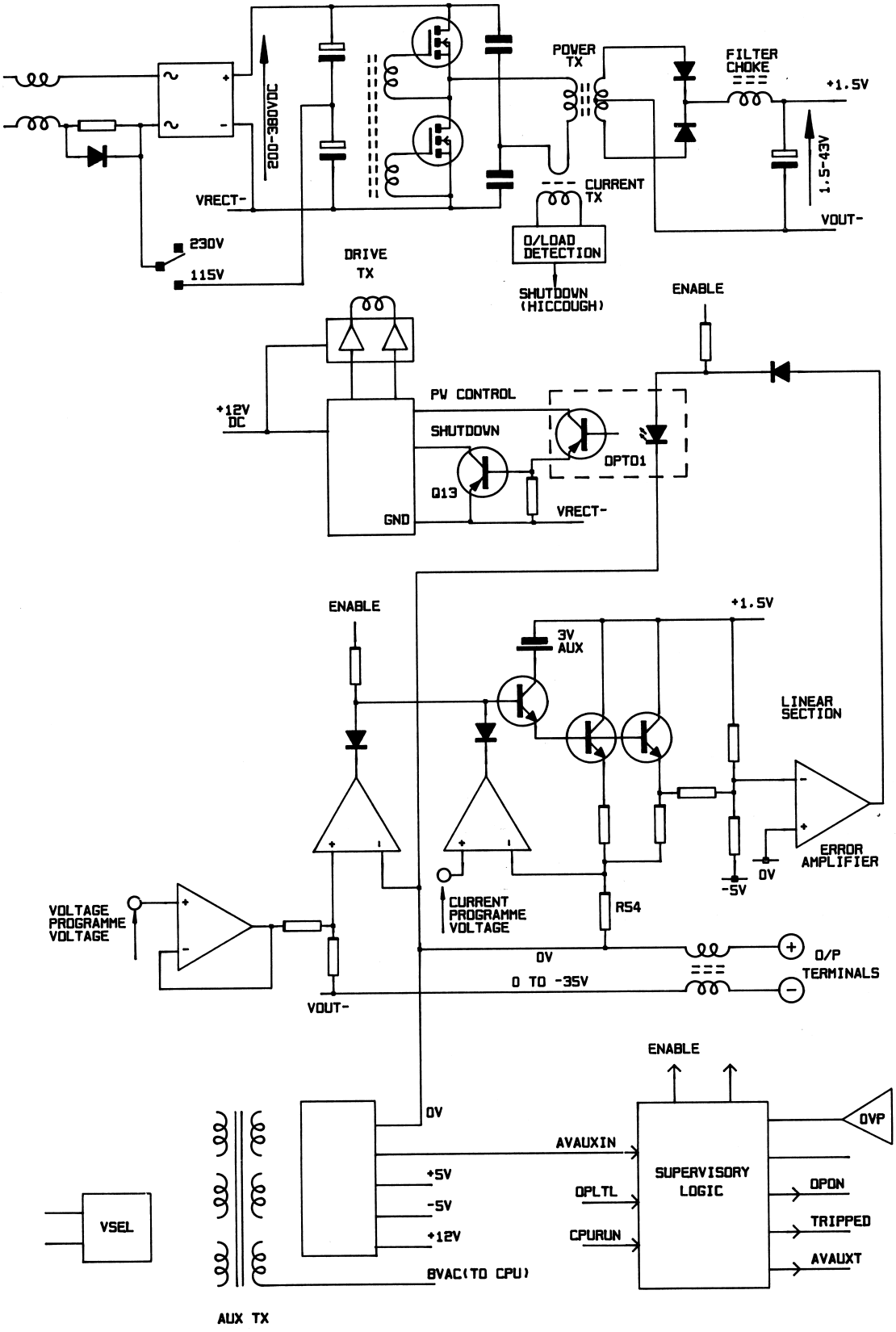
Output Voltage Setting:	12 bit resolution (10mV steps)
Output Current Setting:	12 bit resolution (10mA steps)
Setting Accuracy:	Voltage: ± (0.1% + 10mV) Current: ± (0.2% + 20mA)
Output Switch:	Electronic by interface command
Readback Resolution:	Voltage: 10mV over the entire range Current: 10mA over the entire range
Readback Accuracy:	Voltage: ± (0.2% of reading + 1 digit) Current: ± (0.5% of reading + 1 digit)

RESPONSE TIME OVER RS232/GPIB:

Interface:	<15ms (single command, buffer empty)
Power Supply:	An internal time constant, T, (typically 22ms) governs the settling time of a step voltage increase. Settling time to within 1% of the step change = 4.6T, to 0.1% = 6.9T, to 0.01% = 9.2T; for example, after a 10V step the output will be within 1 digit (10mV = 0.1%) of its new value in typically 150ms. For load currents of 1 Amp or more, settling times for downward steps will be very similar; however, response times will be longer at low loads.

GENERAL

Electrical safety:	Built to comply with IEC 348
Temperature specifications:	$5^{o}C$ to $40^{o}C$ operating, 20% to 80% RH $-40^{o}C$ to $70^{o}C$ storage
Size:	200 x 140 x 350mm (WxHxD) half rack width x 3U height (optional rack mounting kit available)
Weight:	5.5kg



Main Board - Skeleton Schematic

Main Board Circuit Description

OVERVIEW

The main board comprises a mains driven HF switchmode DC-DC isolating convertor using pulse width modulation (PWM) which feeds a linear regulator operating at low input-output voltage difference as shown in the skeleton circuit diagram opposite.

MAINS INPUT, SWITCHMODE AND LINEAR POWER SECTIONS

Component references are to sheet 1 of the circuit diagram unless stated.

Mains Input Components and Fusing - When the power supplies are used on 240V, fused plug tops should be fitted with a 5A fuse. The mains supply enters at the IEC receptacle on the rear panel and is wired, via the front panel mains on-off double pole switch, to Faston connectors on the main PCB. A 10A PCB mounted fuse F1 limits damage on switchmode failure. Varistor VDR1 clips mains 'spike' voltages for component protection. R212 provides safety discharge for C1,C2.

Input Noise Filter - Double wound filter choke L1, X capacitors C1,C2 and Y capacitor C4 provide low pass HF filtering to minimise noise currents injected into the mains supply by the switchmode section. Y capacitor C4 also provides a low impedance HF path from the switchmode section to case/earth.

Mains Voltage Selection - Voltage selector SW2 connects BR3 and series connected reservoirs C9,C10 for bridge/voltage doubler rectification and the two 120V primary sections of 50 Hz auxiliary transformer T1 in series/parallel in its 230/115V positions respectively. Rectified voltage is 200-380 VDC. R5,R6 ensure voltage sharing and provide a safety discharge path for C8,C9. C3,C7,C8 minimise rectifier snap-off transients and HF noise.

Mains Inrush Control - At switch on triac TC1 blocks and reservoirs C9,C10 charge up slowly via the 330hms of cold thermistor PTC1; this action also causes the primary peak voltage across auxiliary transformer T1 and the inrush control voltage across C6, derived from a T1 primary tap, to increase slowly. When the latter reaches about 8V enough current flows through R3,D10,R92 to trigger latch Q5,Q6 on, providing continuous drive to TC1 gate. D15 inhibits triggering during BR3 conduction to avoid sudden connection of rectified mains voltage to reservoirs C9,C10.

Once turned on TC1 remains conductive until AC supply ceases or falls to a very low level unlatching Q5,Q6. If TC1 fails to turn on, thermistor PTC1 switches into a high resistance state within a few seconds, protecting itself against overtemperature and disabling the power supply.

HF Power Switching Stage HV power FETs Q1,Q2 form a totem pole switch that switches the primary of the ferrite HF power transformer T2 to HV DC rails VRECT+ or VRECT- during on periods and presents an open circuit during the off period of the PWM waveform. C11,C12 allow the return end of the primary winding to assume about mid-rail voltage and provide low impedance HF returns to either rail for the primary current. Snubber C13,R7 absorbs most of the spike energy stored in the leakage inductance of T2 at FET switch off. T2 primary is returned via current transformer T4. Plug PJ4 allows disconnection of Q1,Q2 from the HV rail during testing.

Switchmode auxiliary supply - Stabilised +12V at 50 mA for the PWM driving circuits is derived from a primary side auxiliary winding on T1 via BR1,C25,IC2. PWM switching controller IC1 incorporates undervoltage lockout which inhibits operation until VCC reaches about 9V.

PWM Generation - The oscillator of PWM controller IC1 runs at about 160 kHz for 80 kHz PWM output and generates a master saw- tooth waveform across timing capacitor C19 swinging between about +0.9 and +2.8V. Minimum PWM dead-time of approximately 680 nsec corresponds to the reset (negative going) stroke of this waveform. The PWM on pulse starts at the beginning of the upward ramp and is terminated when the ramp voltage rises to about 1.25V below the DC level at the error amplifier output COMP.

Ramp charging current into C19 is proportional to the current drawn from pin RT and is set by R14 for the main part of the PWM on time. The positive pulse from IC1 CLK output turns on Q30 via C49,R49 discharging C50 during ramp reset. When the upward ramp starts, C50 recharges rapidly through R47 momentarily increasing C19 charging current and ramp slope over the first 300 nsec or so of the on period. This arrangement allows stable generation of very narrow on pulse widths required at very low output voltages.

HF Switch Drive - IC1 PWM outputs A and B are applied via driver IC11 to each end of drive transformer T3 primary, providing alternating antiphase PWM outputs of about 12V peak from each secondary. Gate resistors R18,R22 slow Q1,Q2 switching transitions to about 100nsec to limit RFI generation. R9,C14 and R10,C15 minimise drive waveform overshoot and cross conduction of Q1,Q2. Schottkys D8,D9 avoid IC11 substrate reversal.

Soft Start - If IC1 detects VCC undervoltage, PWM generation is inhibited and soft start capacitor C18 discharged. When VCC is adequate and PWM generation is enabled IC1 charges C18 slowly. The PWM on pulse width is internally limited by the voltage on C18. As C18 charges narrow PWM pulses appear at about +1.25V which widen steadily until IC1 error amplifier takes control. This feature allows orderly start up of the switchmode section after switch-on.

Dual Function Opto-coupled Control - OPTO1 provides both analogue feedback for PWM control and digital shut down control across the isolation boundary to the switchmode section. In normal operation OPTO1 input current drive is arranged to ensure a minimum output current of about 40 microamps. When switchmode shutdown is required the Supervisory System described later cuts off OPTO1 input turning off Q13, inhibiting PWM output via D7,R157,Q3,Q7 and clearing soft start capacitor C18.

PWM Control - OPTO1 collector feeds the error amplifier of IC1 (output at COMP) which is operated in virtual earth mode to maximise optocoupler bandwidth. Clamp Q20 improves amplifier overload behaviour. PWM output pulses cease at OPTO1 minimum current level.

Switchmode Protection - T2 primary current is returned via current transformer T4 primary. Virtually instantaneous protection against gross overcurrents following severe faults is effected when T4 secondary output rectified by D21,D22 generates enough voltage across R156 to turn on Q3,Q7 regeneratively via spike filter R121,C68. PWM output is immediately inhibited and soft start capacitor C18 discharged. If the cause of overcurrent persists the process will repeat (hiccough) after the subsequent soft restart. The limiting of peak operational current levels is described later under Switchmode Current Limiting.

If switchmode heatsink SK1 temperature exceeds about 100 deg C thermostat TS1 opens triggering latch Q3,Q7 on via Q13,D7,R157. This condition is registered elsewhere by supervisory logic to avoid automatic restart after cooling.

HF Rectification and Filtering - The centre tapped secondary of T2 feeds ultra fast epitaxial dual rectifier diode D14 which delivers rectified or freewheel current to HF power choke L3. R75,C65 and R66,C64 reduce diode reverse recovery voltage spikes. Ferrite choke L3 and reservoirs C73,(C74),C33 form a low pass choke input filter delivering low ripple DC output voltage proportional to pulse width. R55 provides the minimum loading necessary for control over the full 38 to 1.5 VDC output range.

Series Regulator Power Elements - Parallelled plastic cased bipolar power transistors are used. 35V/10A supplies use two devices sharing the single secondary side heat sink with rectifier D14 and driver transistor Q4 while 18V/20A supplies use four devices mounted on a separate heatsink. Emitter resistors (R38-R41 as appropriate) ensure current sharing. Device dissipation is minimised by using the switchmode section to regulate the collector-emitter voltage at about 1.5V.

Driver transistor Q4 is mounted on the same heatsink as D14. To avoid the premature driver collector saturation of the Darlington connection, Q4 collector voltage is maintained about 3V above the output transistor collectors by a floating auxiliary supply. R44,Q29 limit driver current to about 2A. Voltage and current error amplifier outputs are applied to the driver via predriver circuitry D11,D12,R34,Q8,R12. Driving ENABLE low shuts down the linear regulator.

Auxiliary Supplies - Several control auxiliary supplies are derived from 50/60 Hz auxiliary transformer T1 secondaries:

(i) +5V 270mA DC via BR2,C27,IC4 for linear control, ADC, (DACs) and drive for the two meter LED displays.

(ii) -5V 50mA DC via D2,C28,IC3 for linear control, ADC (and DACs).

(iii) 3V 1.5A DC floating, unstabilised via D18,D42,D26 for driver Q4 collector.

(iv) 10V 0.9A AC via PJ2 for the CPU board.

(v) 12V DC via BR1, C25 and IC2, supplies IC1, IC11 and Q20.

Only programmable versions incorporate CPU board and DACs. Reference diodes D35 and D36 provide +2.45V and -2.45V reference voltages respectively. R80 bleeds current from +5V to the negative output terminal to provide a small output current sink capability.

Inadequate auxiliary control supplies are detected by positive and negative voltage detectors R42,D51,R48,Q23 and R43,R50,Q23 respectively via on delay Q21,C48,IC12-B. Status lines AVAUXT and AVAUXT bar go high and low respectively only when IC4 input, IC4 output and IC3 output voltage have maintained about +7, +4 and -3.5 VDC respectively for about 150 msec.

Linear Regulator Collector Voltage Control System - Virtual earth error amplifier IC6-B current drives OPTO1 input via D49,Q24 so as to maintain low collector-emitter voltage across the linear regulator power transistors. At zero collector current the collector voltage sets to about +1.85V determined by the -5V supply and R127,R136. At higher currents increasing voltage drops across emitter sharing and current sense R54 resistors and, in 35V/10A supplies current feed-forward via R126, give a linear reduction in collector-emitter voltage to about 1.2V at the maximum output current of 5A per device. This arrangement provides increased Vce "headroom" at low output currents to accommodate the larger transient dip in switchmode output voltage that follows maximum current demand without increasing maximum dissipation. R129,R130,R11,C38 assist stability while D31,D39,Q28 speed amplifier overload recovery. R128 is selected to normalise control loop gain.

Switchmode Shutdown Control - In normal operation ENABLE and ENABLE bar are high and low respectively. Even if IC6-B output goes transiently negative, reverse biassing D49, OPTO1 input is still maintained at about 300 microamps by R133,Q24; low enough for PWM output to cease although Q13 in the switchmode section remains on and IC1 active.

The switchmode section is shut down by driving ENABLE and ENABLE bar low and high respectively; turning off Q24 and driving OPTO1 input and output currents to zero. Q13 in the switchmode section then turns off inhibiting PWM output and holding soft start capacitor C18 discharged. IC6-B output is also driven negative via D62 to avoid switchmode surging on re-enablement.

Switchmode Maximum Current Limiting - The maximum current demanded from the switchmode section will be the sum of the maximum DC output current and the maximum transient current required to charge switchmode filter capacitor(s) C73,(C74). The former is limited to 10/20A, depending on the model while the latter is proportional to the maximum positive rate of change of switchmode output voltage.

Diode D30 limits the current from IC6-B input via R132 to about 2 microamps. This is balanced by the current from feedback capacitor C39 limiting the rate of increase of power transistor collector voltage to about +1.3 V/msec, corresponding to a peak current into the filter capacitors of about 1.3/6.3A in the 35V/10A and 18V/20A units respectively **provided** the output voltage remains constant.

Protection outside constant voltage output mode is provided by circuitry around Q19. If the rate of change of output voltage approaches about +6/+3V per sec for 35V/10A and 18V/20A units respectively differentiating network C52,R124 begins to turn off Q19 injecting current into the amplifier input via R123,D17 to limit the switchmode section output. This mechanism protects even against the unlimited rate of rise of output voltage following connection of batteries to the output terminals.

LINEAR REGULATOR CONTROL AND SUPERVISORY SECTIONS

Component references are to sheet 2 of the circuit diagram unless stated. Note that 0V and the returns for the +5V and -5V auxiliary supplies for this circuitry are effectively at the **positive** output terminal potential of the power supply.

Voltage Control Amplifiers - When the output is switched on CMOS analogue selector IC7-A applies the voltage programme voltage at PJ1-19 to the input of noninverting buffer amplifier IC5-C and amplifier input current is removed via R74,IC7-C in non-programmable versions. Presets VR3,VR2 remove control loop offset and trim programme gain respectively. The buffered output is applied to the differential input voltage error amplifier around IC5-A. Preset VR1 is adjusted for maximum output-sense voltage rejection. Capacitors C41,C42 minimise noise and are matched. R70,R71,C36,C46 assist loop stability. D23-26 and feedback clamp D40,R77,R78 limit IC5-A input and output excursions and speed amplifier recovery. IC5-A controls the output via D11.

Current Control Amplifier - The current limit programme voltage at PJ1-20 is attenuated by VR6,R81,R79,R208. When output is switched on CMOS analogue selector IC7-B applies attenuated programme voltage from R79/R208 to the noninverting input of current error amplifier IC5-D. The voltage across the sense terminals of the four terminal output current sense resistor R54 is applied to IC5-D inverting input via R87,R115. At current limit IC5-D takes over output control via D12. Presets VR8 and VR6,VR9 remove control loop offset and trim maximum indicated and output current respectively. Network R56,R84,R88 compensates for output sink current removed via R80.

Output Off Control - Output on-off control is entirely electronic and exercised by OPCTL from the front panel output switch (or CPU board in programmable versions) via debounce C35,R26. When output is switched off OPON goes low so that CMOS analogue selector IC7-A applies a low negative voltage from R72,R73 to IC5-C input setting the supply output to about -200mV while selector IC7-B applies a low positive voltage from R82,R83 to IC5-D input setting the output current limit to about 50mA.

Constant Voltage/Current Status Detection - Transistor detector circuits Q25,R148,R149,R152 and Q26,R150,R151,R153 detect whether the output of the voltage or current error amplifier is controlling the output of the power supply and provide corresponding digital outputs from PJ1-29 and PJ1-30 to the metering/CPU boards.

Over Voltage Detection - The output of attenuating differential amplifier IC5-B is proportional to the output sense voltage. When this exceeds the OVP programme voltage applied to PJ1-18 amplifier IC6-A output goes high. During shut down OVP detection is inhibited via D32.

Supervisory Fault Latch - IC9-B,IC8-D, IC12-D form a master fault latch which can be tripped (set), driving IC9-B low and disabling switchmode and linear regulators via IC9-A, by a variety of faults detected by the surrounding circuitry:

(i). Activation of over voltage (OVP) detector/comparator IC5-B/IC6-A for about 200 usecs (C70,R139,IC12-A).

(ii). Opening of thermostat TS2/TS3 on 35V/10A or 18V/20A respectively, on overheating of secondary side heatsink SK2/SK3 via IC8-B.

(iii). If no switchmode output pulses are detected by pulse detector R45,C37,Q27,D60 for about 20 secs (C69,R140,IC8-B) due to TS1 opening on primary side heatsink overtemperature.

(iv). Transistors detectors Q16,R202,R203 or Q17,R204,R205 turning on due to excessive load-sense terminal podential differences for about 350 usecs (C71,R147,IC9-B) on miswiring of load or sense terminals.

The TRIPPED output at PJ1-28 goes high on tripping of the fault latch. The fault latch is reset at switch on via LED1,R27 or while reset line CPU RUN is driven low in programmable versions.

System Shutdown - Shutdown of both switchmode and linear regulators is asserted via IC9-A of the supervisory logic following power up, detection of inadequate auxiliary supplies, tripping of the master fault latch or, in programmable versions, during CPU board driven resetting of that latch.

Output Circuit Components - C16 and C34 assist linear regulator stability. D37 protects against reverse polarity connection of external batteries or other power supplies to the output. Coaxial toroidal choke L4 and front panel mounted ceramic capacitors CA,CB,CC form a lowpass HF filter attenuating common mode and differential noise generated within the power supply.

R57,58 maintain a working connection between output and sense terminals if the latter are left disconnected. R96,C51 and R97,C53 assist stability when remote sensing is used.

Voltage and Current Metering Points - Chain R17,R59,VR4,R211 attenuates the voltage sense p.d. to feed the multiplexed differential input ADC on the control/CPU board from PJ1-2 and PJ1-4. The current signal is taken directly from the current sense network to feed the ADC from PJ1-5 and PJ1-3.

Control Board Circuit Description
(non-programmable versions only)

The control pcb contains the voltage and current measurement system, the display, the controls for adjustment of the output voltage, current limit and over voltage protection, plus the output on/off switch connection. The pcb is connected to the main pcb by a 34-way flat cable. The control board also contains three preset adjustments.

The measurement system and display are controlled by a microcontroller IC1.

The measurement of output and preset values of voltage, current and OVP is performed by the 12 bit analog to digital converter IC2. The measurement rate is controlled by the 4.0MHz ceramic resonator XL1 connected between pins 22 and 23 and the buffered version of this 4MHz signal at pin 25 is used as the clock to the microcontroller IC1. The ADC, IC2, is a dual slope converter and provides just over 8 readings per second when clocked at 4MHz. The ADC is run in continuous mode and the status signal on pin 2 is read by the microcontroller every 6ms. When a reading is ready the microcontroller reads the 12 bit binary value and then converts it to 7 segment BCD and stores it ready to be sent to the display. After each reading the microcontroller switches the input multiplexers IC3 and IC4 to the next required input. In this way it is possible to read and display any of the following:

Preset Volts
Preset Current
OVP
Output Volts
Output Current

The multiplexers are controlled by the latch, IC6, which also drives the additional indicator LEDs, this latch is driven by the microcontroller.

The decision on what to measure and display at any time is taken by the microcontroller and in order to do this correctly a number of status signals and switches are monitored on a regular basis. These are:

VLIMD	from the main board
ILIMD	from the main board
TRIPPED	from the main board
PRKEY	the preset key signal
OVPKEY	the OVP key signal
DAMPING	the DMPGKEY signal
OPON	the output on/off switch signal

all these signals may be read by the microcontroller as required.

The +2.45V reference line VREF+ is derived from reference diode D35 on the main PCB, attenuated to about 188 mV by divider R206,207 and then connected to the control board as ADREF via PJ1-17. It is then applied to the reference input of analogue to digital converter IC2, yielding a sensitivity of about 92 uV per digit.

The set current signal ISET is taken from the VR4 wiper to feed the current control amplifier on the main PCB via PJ1-20; it is also fed to the ADC system via adjustable attenuating chain VR7,R34-36 for display of preset voltage level.

The voltage control signal VSET is derived from the wipers of the coarse and fine voltage controls VR1 and VR2 via weighting network R19,20 to feed the voltage control amplifier on the main PCB via PJ1-19; it is also fed to the ADC input via adjustable attenuating chain VR6,R26,28,33 for display of preset voltage level.

The over voltage protection user preset potentiometer VR3 is fed from the same +2.45V reference voltage as the other controls but connected from the main PCB via PJ1-15 as OVPREF+. The OVP set from VR3 wiper OVPSET is fed to the OVP trip comparator IC6-A on the main board via PJ1-18; it is also fed to the ADC input via divider R37,41 for display of preset over voltage trip level.

The output on-off switch connected at SW1 drives the output off-on control line OPON bar providing off-on control at the main PCB via PJ1-33.

The two 4-digit LED displays are driven by IC1 via the segment latch IC10 and the digit latch IC7. Digit current is provided by IC8 and individual segment current is limited to 50mA by the resistors R1 to R8. The digit multiplex rate is 2ms and is controlled by IC1 which also provides the inter digit blanking to prevent ghosting segments.

The power supply for all the above circuitry is provided by the main board.

CPU Board Circuit Description
(Programmable versions only)

OVERVIEW

The power supplies use a Z80 microprocessor to accept and process commands (from the keyboard, RS232 interface or GPIB interface) and to pass on the necessary command and control information to a microcontroller, located on the other side of an opto-isolated interface, which controls the setting of the values for voltage, current and OVP and the measurement of output voltage and current. The opto isolated interface is later referred to as the Inter-Processor-Interface or IPI.

The CPU board contains the Z80 microprocessor, program memory, data memory, RS232 interface, GPIB interface, keyboard scan circuitry and the interface to communicate with the microcontroller. The microcontroller is also on the CPU board together with its display control latches and drivers and the analog to digital converter which measures the output voltage and current. The Z80 and microcontroller are electrically isolated from each other by an opto-coupled interface. This allows the Z80 and its interfaces to operate at mains ground potential while the microcontroller and the output of the power supply may be up to 300 Volts away from ground. The circuitry on each side of the isolation interface is described below.

The Z80 uses a 4 digit LED display and 16 LEDS to communicate status information to the user, The microcontroller uses two 4 digit LED displays to show voltage and current values at the output. All LED displays are mounted on the keyboard pcb, see next section.

Z80 CIRCUIT

The 4.9152MHz clock for the Z80 is generated by IC13 which also provides the 1.6ms clock used as the NMI signal, the various clocks used to specify the RS232 interface baud rate and the 600Hz buzzer drive. The 1.6ms clock is used by the CPU as follows. Six ticks are used to generate the LED display and the 16 status LEDs. The seventh tick is used to read the continuously rotating pot and alternately to scan the keyboard and to generate timing delays for the slower parts of the system or to update the system status.

The memory map is divided into a 56k byte area at IC10, which contains the system code in ROM, and an 8k byte area at IC11 containing RAM which is battery backed and holds all the system parameters and power supply stores. IC10 is mapped in the address range 0000H to DFFFH (56k bytes) and IC11 is mapped in the address range E000H to FFFFH.

The input/output devices are selected by IC14 during IORQ cycles. Each output from IC14 selects a range of 8 ports as follows

00H to 07H	RS232 serial device IC5.
08H to 0FH	7210 GPIB controller IC3.
10H to 17H	Segment latch. Drives the LED display segment lines and scans the keyboard rows.
18H to 1FH	Digit latch. Drives the LED display digit lines. Also controls the buzzer and NMI enable signals.
20H to 27H	Status read. Reads from keyboard columns, the pot adc and the IPI.
28H to 2FH	Control port. Writes to the IPI, sets the baud rate and controls the pot adc.

When the power fail line (**PF bar** on PJ1 pin 5) goes low the system immediately enters a reset condition by Q6 turning on and discharging C2. This causes the reset lines, **MRST** and **MRST bar**, to assume their active states and all circuitry is held in the reset condition. The ram, IC11 is switched to battery power and disabled by pulling the chip select input high via the **RAMSAVE** line thus ensuring that the contents are retained until power is restored.

MICROCONTROLLER CIRCUIT

This section contains the voltage and current measurement system, the display drivers and the DACs which are used to set the output voltage, current limit and over voltage protection.

The measurement system and display is controlled by a microcontroller IC26.

The two 4-digit LED displays on the front panel board are driven by IC26 via the segment latch IC30 and the digit latch IC31. Digit current is provided by I32. The digit multiplex rate is 2ms and is controlled by IC30 which also provides the inter digit blanking to prevent ghosting segments.

The measurement of output and preset values of voltage, current and OVP is performed by the 12 bit analog to digital converter IC27. The measurement rate is controlled by the 4.0MHz ceramic resonator XL2 connected between pins 22 and 23 and the buffered version of this 4MHz signal at pin 25 is used as the clock to the microcontroller IC26. The ADC, IC27, is a dual slope converter and provides a little over 8 readings per second when clocked at 4MHz. The ADC is run in continuous mode and the status signal on pin 2 is read by the microcontroller every 6ms. When a reading is ready the microcontroller reads the 12 bit binary value and then converts it to 7 segment BCD and stores it ready to be sent to the display. After each reading the microcontroller switches the input multiplexer IC28 to the next required input. In this way it is possible to read and display output volts and output current

The multiplexer is controlled by the latch, IC29, which also drives the additional indicator LEDs CV and CI and some of the control lines to the DACs. This latch is driven by the microcontroller

The decision on what to measure and/or display at any time is taken by the microcontroller and in order to do this correctly a number of status signals are monitored on a regular basis. These are:

VLIMD	from the main board
ILIMD	from the main board
TRIPPED	from the main board

These signals are read by the microcontroller from the output circuitry of the instrument and are combined with commands from the Z80 via the IPI to determine what appears on the two 4 digit displays. In this way it is possible to show preset voltage, preset current, output voltage and output current.

The power supply for the microcontroller circuitry is provided by the main board.

Keyboard Circuit Description (Programmable Versions only)

The front panel pcb contains the key matrix, 16 indicator LED's and the 4 digit LED display which are controlled by the Z80,and the two 4 digit LED displays and 2 indicator LEDs which are controlled by the microcontroller.

The key matrix is scanned every 22ms by the Z80. All key coding, de-bounce and key repeat operations are controlled by the software. The 4 digit LED display is multiplexed along with the 16 LEDs, which are treated as 2 extra digits, at a rate of 1.6ms per digit. The Z80 also provides the inter digit blanking to prevent ghosting segments.

The continuously rotating pot, VR1, is connected to an 8 bit analog to digital converter, IC2, via a pair of analog gates in IC1. This allows the Z80 to select the required track of the pot from which to establish a pot rotational movement value. This is done by reading the adc every 22ms and calculating the difference in software.

The two 4-digit LED displays are driven by the microcontroller at a digit multiplex rate of 2ms. The microcontroller also provides the inter digit blanking to prevent ghosting segments.

Test and Calibration Procedure

IMPORTANT ELECTRICAL SAFETY CONSIDERATIONS

A substantial proportion of the power supply main PCB is occupied by primary side circuitry comprising tracks, terminals and components (including one of the large heat sinks) which normally operate at AC mains potential.

The incoming AC supply to the PCB or PSU under test must be isolated by means of a 1:1 isolation transformer of at least 700VA rating for safety and noise control.

High voltages (up to 400V peak) are always present in the primary side circuitry. Note that removing bridging connector PJ4 disconnects HV only from the power FETs.

Components at high voltage lie within a well defined area of the main PCB which includes the large heat sink SK1. The operator should familiarise himself with the boundaries of this area and avoid contact within it.

Primary side earthing - Earthing of the Y filter capacitor at GND3, at the hex spacer, is desirable to control noise effects.

HV Capacitor Discharging - Allow 6 mins for HV reservoirs C9,10 to discharge from 400V to 40V via R5,6. Alternatively discharge <u>both</u> capacitors with 100R 5W resistor.

TEMPORARY EARTHING FOR PRIMARY SIDE MEASUREMENTS

Voltage checks and CRO measurements on the main PCB primary side circuit are only carried out with 60 VDC maximum applied to the switching power FETs. Primary side node VRECT- must be well grounded (e.g. at Q1,2 mount bolts) to protect the user and the external PSU during these measurements. Not that this negates the protection normally provided by the isolation transformer and earths the particularly easily touched heat sink SK1.

ORDER OF CHECKS AND ADJUSTMENTS

The power supplies comprise a switchmode pre-regulator operating at mains (primary) potential which feeds a (secondary) linear regulator. The latter must be working properly for proper operation or testing of the former. Both regulators obtain their auxiliary supplies from 50Hz auxiliary transformer T1 the primary of which is fed from the mains potential (primary) section of the PCB which is therefore energised during all tests. The order of checks and adjustments reflects these dependencies and should be followed after any repair work.

DIRECTIONS FOR DIFFERENT TYPES

The directions are written as far as possible to cover normal (non-programmable) and programmable versions. Settings and other values which vary between 35V/10A and 18V/20A versions are respectively separated by an oblique stroke.

Figures referred to in the text appear on a fold-out sheet immediately before the Circuit Diagrams.

TEST EQUIPMENT REQUIRED FOR RECALIBRATION ONLY

Rheostat or other high power load arrangements to provide 3.5 & 2.75/0.9 & 0.6Ohms at 10/20A for 35V/10A and 18V/20A respectively at 400W dissipation.

10Ohm 10W wirewound resistance.

Common mode rejection test network according to Fig 3.

Digital voltmeter with 100uV resolution and 1mV accuracy.

Current meter 20A maximum, 2mA accuracy, or equivalent shunt and voltmeter arrangement.

TEST EQUIPMENT FOR MAIN PCB TESTING

100Ohm 5W wirewound resistance for discharging HV reservoirs.

Power supplies: 60VDC 2A limited, 5VDC 2A limited, 3VDC 1.5A limited. A single 60V 2A dual lab supply should meet all requirements. A 4700uF 63V electrolytic capacitor is required across the 60V output while checking over-current tripping.

A 4-pin 0.156" pitch socket with leads carefully wired for safe connection of external 60V PSU to header PJ4 according to Fig 1.

A 2 pin 0.156" pitch polarised socket for connection of output terminals to sense input header PJ3 according to Fig 2.

A lead for earthing node VRECT-.

A light lead with an EZ clip at each end.

A light lead with a clip and pointed probe for tripping.

Oscilloscope, 20 MHz bandwidth with x10 HV probes.

General purpose multimeter suitable for HV use.

REPAIRS FOLLOWING POWER FET FAILURE

Q1,Q2 must both be replaced. Survival of gate drive components, particularly R18,22 should be checked. Triac TC1 should be checked for short circuit failure.

PREPARATION FOR MAIN PCB TESTING

Set mains voltage selector switch to 230 or 115VAC position to suit local supply.

Visual Inspection. C9,10 electrolytic polarities; all power semiconductors properly mounted and correctly torqued.

Remove HV bridging connector from PJ4.

Earth primary side circuitry at Q1,2 mounting screws on SK1.

Link sense input from PJ3 to its corresponding output terminal using 2-pin polarised connector lead as shown in Fig 2.

Connect EZ clip lead to link from 0V to C69 +ve to inhibit apparent primary overtemp trip.

If preset potentiometer settings are suspect, centralise all presets except VR10 (fully CW) and VR9 (fully ACW).

Connect the Control Board via PJ1.

Connect the isolated AC supply to the main PCB pins P100,101.

Connect DVM to output terminals.

PRELIMINARY CHECKS

1. **Check Inrush Control and HV Rectification** - This should be carried out if this section is suspect. Adjust the Variac for about 15 percent of the voltage selector indication. Switch on. Check that voltage across C9 and C10 are both about 25/50VDC for selector on 230/115V and that voltage across PTC1 exceeds 3 VAC (meter on AC mains voltage range). Then increase Variac to about 60 and then 100 per cent of the voltage selector setting. At each voltage, check for equal DC voltage across C9 and C10 and that voltage across PTC1 is less than 1.5 VAC (meter on AC mains range).

2. **Check Auxiliary Supplies** - The voltages from 0V to IC4 pin 3 and IC3 pin 3 should be +5V and -5VDC within 0.25V. Note that the Control board draws approx 280 mA from the +5V rail. The primary side auxiliary voltage between VRECT- and IC2 pin 3 should be 12V within 0.6V.

LINEAR REGULATOR CHECKS

1. **Check/Preadjust Voltage Zero** - Connect an external +5VDC, 2A limited power supply between DCVOUT (+ve) and VOUT- (access top R55 and D37 respectively). Set Voltage control(s) to minimum and Current control to maximum. Switch Output on. Switch supplies on. CV LED should come on. Adjust VR3 for zero output voltage within 5 mV.

2. **Check/Preadjust Current Zero** - Connect 10Ohm 10W load to output terminals. Set Voltage control(s) to maximum and Current control to minimum. Adjust VR8 for zero output voltage within 20 mV. CI LED should be on. Note and avoid saturated region below about -20 mV.

3. **Check All Series Pass Transistors Active** - Short circuit output. Set current control to maximum. Check that voltage across each emitter resistor R38-39/R38-41 is at least 10mV.

4. **Check Linear Reg Shutdown** - Trip the supervisory logic trip by momentarily connecting 0V to IC9 pin 13 with pointed probe lead. The output voltage should fall below -20mV. Reset the logic by momentarily connecting 0V to PJ1-27.

5. **Check Output Off Level.** Switch Output off. Disconnect load. Output voltage should lie between -0.25V and -0.15V. Disconnect +5V external supply.

TESTING MAIN PCB WITH LV ON HF SWITCHING SECTION

1. **Preparation** - Allow time or discharge HV reservoirs C9,10 then connect external 60V 2A limited PSU to switchmode section via connector lead of Fig 1 to PJ4. Connect 3.75Ohm load. Switch PSU off.

2. **Check Switchmode Master/Clock Waveform** - Connect CRO via x10 probe between VRECT- (common) and IC1 pins 6,7. Check ramp waveform against Fig 4 observing:

(i) Basically saw tooth of period of 5.9 to 6.7 usec.
(ii) Downward stroke duration approx 0.7 usec.
(iii) Voltage swinging between approx +0.9V and +2.8V.
(iv) Fast rising section over first approx 0.7 usec of ramp.

3. **Check Power On Soft Start** - Connect CRO via X10 probe to IC1 pin 8. Turn mains supply to board off and on. The soft-start voltage should fall immediately to less than +1V then rise slowly (about 0.5 sec) to about +4.5V.

4. **Check Demand and Gate Waveforms** - Turn voltage and current controls to maximum. Q1 gate drive waveform should be an almost square, approximately 20V pk-pk waveform swinging symmetrically about 0V. Q2 drive waveform may also be checked if node HF is **momentarily** linked to VRECT-. Switch off.

5. **Check Power FETs Blocking** - Connect CRO between VRECT- and switchmode output point HF. Set Voltage control(s) to minimum, Current control to maximum and Output off. Switch 60V PSU on. No current should be drawn.

6. **Check Switchmode Idling Waveforms and Pre-regulator Overhead** - Switch on. Current from 60V supply should still be less than 10 mA. Waveform at point HF should show narrow symmetrical alternating pulses and very slow no-load ringing. At R10/22 junction the positive gate drive pulse should exceed +6V for 100-200ns. Linear regulator overhead voltage between 0V and DCVOUT should be 1.7 to 1.9VDC.

7. **Check Switchmode Waveforms** - Switch Output on. Waveform at point HF should not change. If Voltage control is advanced PWM duty cycle at point HF should increase with rectangular PWM pulses of about 60V pk-pk amplitude separated by a plateau at 30V as shown in Fig 5. Maximum duty cycle should occur at about 10V/5V DC output. Storage spikes at point HF are then typically 20V pk and 100ns base width.The PWM waveform edges should be stable; however instability or lack of output may be cured in the next section.Remove all instrument connections from the primary side circuitry.

8. **Check/Set Pre-regulator Gain** - Connect CRO between 0V and OPTPO1B. Reduce Voltage controls for 5.0/3.2V *? DC output. The voltage across R128 (generated by the optocoupler input current) should be 175 to 200mV; otherwise switch off, discharge HV reservoirs C9,10 and fit E12 0.25W resistor in R128 to bring the voltage into range on retest. When the Voltage control(s) are adjusted just to reach maximum duty cycle, the voltage across R128 should be +200 to 250mV.

9. **Check HF rectifier waveforms** - Connect CRO probe to DCT (D14 tab). The 160kHz rectified rectangular PWM pulses typically exhibit similarly sized ringing recovery spikes of 20V peak and 1us half cycle basewidth decaying within 2 ring cycles as shown in Fig 6.

10. **Check Switchmode Supervisory Shutdown** - Connect 0V momentarily to IC9 pin

13 (sense miswire input). Switchmode activity should cease, trip LED1 on PCB come on and the display indicate "TRIP". Reset the supervisory logic by momentarily connecting 0V to PJ1-27. Check the secondary thermostat input by momentarily connecting +5V to IC8 pin 5 which should give the same result.

11. **Check Overcurrent Trip Action** - 4700uF is needed across the output of the 60V supply to provide the necessary current surge. Set the Voltage control(s) to maximum then connect a 0.47Ohm 5W resistor **momentarily** between VOUT- and DCVOUT (access top leads of R55). PWM output should cease immediately and then soft-restart. Switch off. Remove earthing link to VRECT-.

TESTING OF MAIN PCBS AT FULL VOLTAGE

1. **Preparation** - Remove VRECT- earthing link. Allow time or discharge HV reservoirs C9,10. Refit leadless bridging connector to PJ4. Connect DVM between filter output at top of R55(+ve) and D37 (VOUT-). Set the Voltage and Current controls to minimum. Switch Output off. Switch AC on. The CV and CI LEDs should be off, the Output LED on and both displays reading zero.

2. **Control Board Adjustments (non-programmable versions)** - If the control board is suspect carry out this stage as described under Calibration stage 2.

3. **Check Voltage Zero** - Set Voltage control(s) to minimum and Current control for about 0.2A. Switch Output on. The CV LED should be on and the Output LED off. The Current and Voltage displays should both read zero. Adjust VR3 until the DVM reads within 5mV of zero. Set the Current control to minimum. The DVM should read between -0.7V and -0.15V. Switch Output off. The DVM should read between -0.15 and -0.25V.

4. **Check Current Zero** - Connect 10Ohm 10W load to output terminals. Set Voltage control(s) to display about 4V and Current control to minimum. The CI LED should come on. Adjust VR8 for zero DVM reading within 20mV. Note and avoid saturated region below about -20mV. Disconnect load after test.

5. **Check Maximum Voltage** - Set Voltage control(s) to maximum. Switch Output on. The CV LED should be on. The Voltage display should read 35.3/18.15V. Adjust VR2 until the DVM reading matches the Voltage display. Switch Output off.

6. **Check Measured Current Display** - Connect 3.75/0.9Ohm load in series with the current meter. Set preset VR9 fully ACW. Set the Current control to maximum. Switch Output on. Adjust VR9 until the current display reading matches the current meter. The CV LED should remain on. Switch output off.

7. **Check HF Power Filtering** - CRO check that 160 kHz ripple voltage between 0V and DCVOUT (top R55) is less than 50 mV pk-pk. Switch Output off.

8. **Check Measured Voltage Display** - Connect 2.75/0.6Ohm load in series with the current meter. Switch Output on. The CI LED should be on. Adjust VR4 until the Voltage display matches the DVM reading. Switch Output off. Disconnect the load.

9. **Check OVP Trip** - Set preset VR10 fully CW. Set Current control to about 0.5A display. Set Voltage control(s) for about 34V display. Set the user OVP preset (VR3 on the control board) for about 34V OVP display. Rotate VR10 fully ACW. The display should indicate "TRIP". Switch off. Allow time or discharge HV reservoirs C9,10.

RECALIBRATION OF ASSEMBLED POWER SUPPLIES

1. **Preparation** - Ensure voltage selector is in the appropriate position and HV bridging connector present. Connect common mode test network to rear terminal block as shown in Fig 3. Close the test network switch. Set the Voltage and Current controls to minimum. Switch Output off. Switch on. The CV and CI LEDs should be off, the Output LED on and both displays reading zero. Switch Output off.

2. **Control Board Adjustments (non-programmable versions only)** - Connect the DVM between 0V and IC7-A on the main PCB pin 13. Note the DVM reading which should be within 3 mV of zero. Switch Output on. If necessary adjust VR5 on the control board to maintain the same DVM reading. SWITCH OUTPUT OFF to avoid destroying test network. Advance Voltage and Current controls to maximum. Adjust VR6 on the control board for a Voltage display of 35.3/18.15V. Adjust VR7 on the control board for a Current display of 10.2/20.2A.

3. **Set Voltage Zero** - Move DVM to rear sense terminals. Set Voltage control(s) to minimum and Current control for about 0.2A. Switch Output on. The CV LED should be on and the Output LED off. The Current and Voltage displays should both read zero. Adjust VR3 until the DVM reads within 5mV of zero. Set the Current control to minimum. The DVM should read between -0.7V and -0.15V. Switch Output off. The DVM should read between -0.15 and -0.25V.

4. **Set Current Zero** - Connect 10Ohm 10W load to output terminals. Set Voltage control(s) to display about 4V and Current control to minimum. The CI LED should come on. Adjust VR8 for zero DVM reading within 20mV. Note and avoid saturated region below about -20mV. Disconnect load after test.

5. **Adjust CMRR** - Set the Current control for about 0.2A. Note the DVM reading. Open the switch on the test network and if necessary adjust VR1 to remove about half the difference. Close the switch and repeat the process until the DVM reading is the same for both switch positions. Switch Output off. Disconnect the test network and link adjacent sense and output terminals.

6. **Set Maximum Voltage** - Set Voltage control(s) to maximum. Switch Output on. The CV LED should be on. The Voltage display should read 35.3/18.15V. Adjust VR2 until the DVM reading matches the Voltage display. Switch Output off.

7. **Adjust Measured Current Display** - Connect 3.75/0.90hm load in series with the current meter. Set preset VR9 fully ACW. Set the Current control to maximum. Switch Output on. Adjust VR9 until the current display reading matches the current meter. The CV LED must remain on. Switch output off.

8. **Adjust Measured Voltage Display** - Connect 2.75/0.60hm load in series with the current meter. Switch Output on. The CI LED must remain on. Adjust VR4 until the Voltage display matches the DVM reading. Switch Output off. Disconnect the load.

9. **Adjust OVP Trip** - Set preset VR10 fully CW. Set Current control to about 0.5A display. Set Voltage control(s) for 34.00V display. Set the user OVP preset (VR3 on the control board) for near 34V OVP display. Now slowly adjust preset VR10 ACW until the display indicates "TRIP". Reduce the Voltage control(s) by about 5 per cent and turn the supply off briefly to reset the supervisory logic. Then recheck the trip point by increasing the Voltage control(s) gradually until OVP trip occurs.

Parts Lists

PCB ASSY MAIN (10A) - (44115-0350) - COMMON PARTS
PCB ASSY MAIN (20A) - (44115-0300) - COMMON PARTS

Part Number	Description	Position
20030-0240	WASHER 4BA ZPST	FOR SK1,2
20030-0263	WASHER M3 ZPST FOR T1,TC1,Q1,2,TS1,2,IC4,PCB	
20038-9501	WASHER M3 Spring FOR T1,TC1,Q1,2,TS1,2,IC4,PCB	
20038-9503	WASHER M3.5 SPRING	FOR SK1,2
20062-9303	SCREW NO 6 X 0.5" PNHDPZ ST/AB	FOR SK1,2
20062-9304	SCREW No.6x5/8" Pozi. Pan	FOR SK1,2
20205-0610	STUD M3 X 10 KFH-M3-10ET	
20210-0101	NUT M3 ZPST FOR TC1,Q1,2,TS1,IC4	
20234-0011	SCREW M3 X 10 PNHDPZ NPST FOR TC1,TS1,TS2,IC4	
20234-0012	SCREW M3 X 8 PNHDPZ ZPST	FOR T1
20234-0024	SCREW M3 X 16 PNHDPZ ZPST	FOR Q1,Q2
20234-0027	SCREW M3 X 6 PNHDPZ ZPST	PCB/SPACER
20234-0033	SCREW M3 X 20 PNHDPZ ZPST	FOR D14/Q4
20234-0038	SCREW M3 X 40 PNHDPZ ZPST	FOR T1
20611-0003	BUSH POLYESTER TO220 J22-5006	FOR Q4,IC4
20613-0012	WASHER NON-INSULATING	FOR Q1,Q2
20613-0013	WASHER MICA T03P	FOR D14
20613-9401	WASHER TO220 Adhesive	FOR Q4,IC4
20613-9402	WASHER T0220 Adh. (Plain)	FOR TC1
20661-0222	SPACER Hex M3 x 10 NPBR	FOR PCB
20661-0225	SPACER Hex M3 x 12 ZPST	FOR T1
20661-0800	SPACER transistor mtg TO18	FOR D35,D36
20661-9403	SPACER Rnd/Hex/ST 1"L Plas	FOR SK1,2
20670-0170	HEATSINK DRILLED	SK1,2
22109-0030	TRANSFORMER HF DRIVE	T3
22109-0040	TRANSFORMER HF CURRENT	T4
22115-0170	TRANSFORMER 20VA - AUX	T1
22154-0020	INDUCTOR EMI	L1
22218-0211	SWITCH 115/230V RT ANG PCB MTG	SW2
22312-0250	FUSE CLIP 0.25" PCB MTG	FOR F1
22316-0205	FUSE 10A TL HRC CER 1.25"X0.25	F1
22320-0010	THERMOSTAT 100 DEG C T0220	TS1
22455-0030	TAB 0.25" STR PCB MTG	P100,101
22482-0020	BEAD, CERAMIC 11-54-3557-0	FOR R38,39
22573-0202	HEADER 2 WAY STRAIGHT .156P	PJ2,3
22573-0204	HEADER 4 WAY STRAIGHT .156P	PJ4
22575-0100	HEADER 34 WAY (2X17) STR SKELN	PJ1
23183-1220	RES 220RJ 1W CF	R1
23183-4100	RES 100KJ 1W CF	R5,6 Vert
23185-0000	RES ZERO OHM	LK2
23185-0047	RES 4R7J W25 CF RD25S B/R	R13
23185-0120	RES 12RJ W25 CF RD25S B/R	R155
23185-0220	RES 22RJ W25 CF RD25S B/R	R12
23185-0470	RES 47RJ W25 CF RD25S B/R	R18,22,37,83

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PCB ASSY MAIN (10A) - COMMON PARTS CONTINUED
PCB ASSY MAIN (20A) - COMMON PARTS CONTINUED

Part Number	Description	Position
23185-0820	RES 82RJ W25 CF RD25S B/R	R76
23185-1100	RES 100RJ W25 CF RD25S B/R	R9,10,57,58
23185-1220	RES 220RJ W25 CF RD25S B/R	R96,97
23185-1330	RES 330RJ W25 CF RD25S B/R	R19
23185-1390	RES 390RJ W25 CF RD25S B/R	R3
23185-1470	RES 470RJ W25 CF RD25S B/R	R30,31,121,134
23185-1560	RES 560RJ W25 CF RD25S B/R	R47,48
23185-2100	RES 1K0J W25 CF RD25S B/R	R2,33,49,51,78
23185-2120	RES 1K2J W25 CF RD25S B/R	R24
23185-2150	RES 1K5J W25 CF RD25S B/R	R27,34
23185-2180	RES 1K8J W25 CF RD25S B/R	R42
23185-2220	RES 2K2J W25 CF RD25S B/R	R77,92,157
23185-2330	RES 3K3J W25 CF RD25S B/R	R14
23185-2390	RES 3K9J W25 CF RD25S B/R	R91
23185-2470	RES 4K7J W25 CF RD25S B/R	
	R25,28,36,70,71,122,125,138,148,150,156,203,205	
23185-2680	RES 6K8J W25 CF RD25S B/R	
	R11,129,130,131,149,151	
23185-3100	RES 10KJ W25 CF RD25S B/R	
	R26,29,35,53,60,86,124,133,141,202,204	
23185-3220	RES 22KJ W25 CF RD25S B/R	R152,153
23185-3330	RES 33KJ W25 CF RD25S B/R	R123
23185-3470	RES 47KJ W25 CF RD25S B/R	R20,43,45,50,146
23185-3560	RES 56KJ W25 CF RD25S B/R	R59
23185-4100	RES 100KJ W25 CF RD25S B/R	R72,82,136,139
23185-4120	RES 120KJ W25 CF RD25S B/R	R126
23185-4220	RES 220KJ W25 CF RD25S B/R	R52,147
23185-4270	RES 270KJ W25 CF RD25S B/R	R127
23185-4330	RES 330KJ W25 CF RD25S B/R	R132
23185-5100	RES 1M0J W25 CF RD25S B/R	R140
23185-5220	RES 2M2J W25 CF RD25S B/R	R212
23185-5680	RES 6M8J W25 CF RD25S B/R	R46
23202-0470	RES 47R0F W25 MF 50PPM	R115
23202-1510	RES 510RF W25 MF 50PPM	R98
23202-1750	RES 750RF W25 MF 50PPM	R90
23202-2100	RES 1K00F W25 MF 50PPM	R89,209
23202-3100	RES 10K0F W25 MF 50PPM	R87,114,207,208,211
23202-3470	RES 47K0F W25 MF 50PPM	R16
23202-3680	RES 68K0F W25 MF 50PPM	R61,95
23202-4120	RES 120KF W25 MF 50PPM	R206
23202-4220	RES 220KF W25 MF 50PPM	R64,68,88
23202-5100	RES 1M00F W25 MF 50PPM	R17
23202-5120	RES 1M20F W25 MF 50PPM	R56
23202-5220	RES 2M20F W25 MF 50PPM	R69
23202-5330	RES 3M30F W25 MF 50PPM	R84
23202-5470	RES 4M70F W25 MF 50PPM	R85
23202-5680	RES 6M80F W25 MF 50PPM	R74

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PCB ASSY MAIN (10A) - COMMON PARTS CONTINUED
PCB ASSY MAIN (20A) - COMMON PARTS CONTINUED

Part Number	Description	Position
23271-0010	RES 0R047J 4W MR KN350-8	R38,39
23271-0011	RES 100RJ 6W WW VERT VTM 308-3	R7
23274-0035	RES 0R33K 2W5 WW	R44
23296-0020	RES 0R01D 4 TERM 30PPM PBV	R54
23379-1100	RES PS/H 100R Cermet 10mm skel	VR9
23379-2470	RES PS/H 4K7 Cermet 10mm skel	VR2,10
23379-3470	RES PS/H 47K Cermet 10mm skel	VR6
23379-4100	RES PS/H 100K Cermet 10mm skel	VR3,8
23386-0010	VARISTOR V275LA20A	VDR1
23388-0020	THERMISTOR PTC 2322.661.11013	PTC
23424-0459	CAP 4N7 250V AC CER STR/LNG	C3,4,7,8
23427-0322	CAP 100PG 100V CER N150 P5	C36,46
23427-0325	CAP 10NZ 63V CER HI K P5	C5,23
23427-0329	CAP 47PG 63V CER N150 P5	C47
23427-0331	CAP 1N0K 63V CER RD870-6B102	C14,15,29
23427-0334	CAP 470PK 100V MED K P5	C50
23427-0353	CAP 220PG 100V CER N750 P5T	C37,40,62
23438-0007	CAP 100NS 63V CER P5	
	CD1,2,3, C17,24,31,34,51,53	
23556-0220	CAP 1200UM 200V ELEC MXR	C9,10
23557-0612	CAP 1U0 50V ELEC RE2 P2	
	C18,30,44,45,48,57	
23557-0647	CAP 10U 35V ELEC RE2 P2	CD4,C20,21,63
23557-0655	CAP 470U 35V ELEC RE2 P5	C25,28
23557-0660	CAP 2200U 16V ELEC RE2 P5	C27
23557-0664	CAP 1000U 35V ELEC RE2 P5	C6
23557-0673	CAP 22U 35V ELEC RE2 P2	C69
23557-0676	CAP 470U 63V ELEC RE2 P5	C16
23557-9122	CAP 4700U 16V ELEC RE2 P7.5	C26
23620-0236	CAP 1N0K 100V P/E 435/1 P5	C43
23620-0246	CAP 100NK 63V P/E P5	C35
23620-0252	CAP 2N2K 63V P/E P5	C68,70,71
23620-0255	CAP 3N3K 63V P/E P5	C19,22,49
23620-0256	CAP 1U0K 63V P/E P5	C33
23620-0259	CAP 15NK 63V P/E P5	C38
23620-0260	CAP 1N5K 63V P/E P5	C39
23620-0261	CAP 100NK 400V P/E	C54
23620-0806	CAP 100NG 2%	C41,42
23620-9007	CAP 10NK 100V P/E P5	C32
23621-0314	CAP 1UO 400V P/E P27.5	C11,12
23684-0010	CAP 470NK 250VAC X2 P/P P27.5	C1,2
23686-0010	CAP 680PJ 630V P/P FPC/SE	C13
25021-0901	DIO 1N4148 B/R	
	D6,7,11,12,16,17,21-26,28-32,39,40,49,50,52,60,62	
25031-0040	DIO BAX16	D3,4,15
25061-0200	LED - T1 ROUND (3mm) - RED	LED1
25115-0700	DIO 11DQ03	D8,9 Vert
25115-0907	DIO 1N4002 B/R	D1,2

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PCB ASSY MAIN (10A) - COMMON PARTS CONTINUED
PCB ASSY MAIN (20A) - COMMON PARTS CONTINUED

Part Number	Description	Position
25117-0020	DIO 1N5401	D18,37,42,61
25118-0100	DIO DUAL S20LC40	D14
25130-0903	DIO ZEN 5V1 W4	D10
25130-0906	DIO ZEN 4V3 W4	D51
25210-0030	TRIAC TAG T0805MH	TC1
25211-0301	RECTIFIER BRIDGE D20XB60	BR3
25211-9302	RECTIFIER BRIDGE W02G	BR1,2
25341-0214	TRAN PNP ZTX214L/BC559	Q3,5,25,26,28
25380-0229	TRAN NPN BC549 Q6,7,13,19,20,21,22,23,24	
25380-0230	TRAN NPN MPS2369	Q27,30
25383-0505	TRAN NPN BC338	Q8,29
25383-0507	TRAN NPN BC546	Q16,17
25386-0020	TRAN NPN MJE3055-T	Q4
25386-9901	TRAN Mounting Clamp	FOR TC1
25601-0430	TRAN MOSFET N CHAN 2SK1524	Q1,2
27001-0020	OPTO-COUPLER CNY17-3	OPTO 1
27106-0506	IC LM324N	IC5
27106-0513	IC LM358N	IC6
27160-0009	IC V/REG 7805 TO220	IC4
27160-0012	IC V/REG 79L05 TO92	IC3
27160-0017	IC V/REG 7812 TO220	IC2
27161-0120	IC V/REF W/DIO ZN404 2.45V	D35,36
27168-0010	IC UC3825N	IC1
27169-0010	IC ICL7667CPA	IC11
27230-0530	IC 74HC4053	IC7
27231-0020	IC 74HC02	IC8
27231-0140	IC 74HC14	IC12
27231-0210	IC 74HC21	IC9
35555-1910	PCB MAIN	

PCB ASSY MAIN (10A) - (44115-0350) - UNIQUE PARTS

Part Number	Description	Position
20030-0263	WASHER M3 ZPST	FOR Q14,15
20038-9501	WASHER M3 Spring	FOR Q14,15
20210-0101	NUT M3 ZPST	FOR Q14,15,TS2
20234-0024	SCREW M3 X 16 PNHDPZ ZPST	FOR Q15
20611-0003	BUSH POLYESTER TO220 J22-5006	FOR Q14,15
20613-9401	WASHER TO220 Adhesive	FOR Q14,15
22109-0020	TRANSFORMER HF POWER (10A)	T2
22154-0040	CHOKE HF POWER (10A)	L3
22320-0010	THERMOSTAT 100 DEG C TO220	TS2
23184-0470	RES 47RJ 2W CF	R66,75 Vert
23184-2100	RES 1K0J 2W CF	R55 Vert
23184-2470	RES 4K7J 2W CF	R80 Vert

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PCB ASSY MAIN (10A) - UNIQUE PARTS CONTINUED

Part Number	Description	Position
23185-1470	RES 470RJ W25 CF RD25S B/R	R73
23185-3560	RES 56KJ W25 CF RD25S B/R	R59
23202-1510	RES 510RF W25 MF 50PPM	R98
23202-3100	RES 10K0F W25 MF 50PPM	R81
23202-3140	RES 14K0F W25 MF 50PPM	R65
23202-3174	RES 17K4F W25 MF 50PPM	R63,67
23202-4220	RES 220KF W25 MF 50PPM	R79
23202-5100	RES 1M00F W25 MF 50PPM	R62,93
23202-5120	RES 1M20F W25 MF 50PPM	R56
23379-2100	RES PS/H 1K0 Cermet 10mm skel	VR1
23379-3470	RES PS/H 47K Cermet 10mm skel	VR4
23424-0461	CAP 680PK 250VDC CER (H/TEMP)	C64,65
23557-0654	CAP 1000U 63V ELEC RE2 P7.5	C74
23557-0664	CAP 470U 63V ELEC RE2 P5	C16
23620-9007	CAP 10NK 100V P/E P5	C52
25386-0020	TRAN NPN MJE3055-T	Q14,15

PCB ASSY MAIN (20A) - (44115-0300) - UNIQUE PARTS

Part Number	Description	Position
20030-0240	WASHER 4BA ZPST	FOR SK3
20030-0263	WASHER M3 ZPST	FOR Q9,10,11,12
20038-9501	WASHER M3 Spring	FOR Q9,10,11,12
20038-9503	WASHER M3.5 SPRING	FOR SK3
20062-9303	SCREW NO 6 X 0.5" PNHDPZ ST/AB	FOR SK3 (2)
20062-9304	SCREW No.6x5/8" Pozi. Pan	FOR SK3
20210-0101	NUT M3 ZPST	FOR Q9,10,11,12,TS3
20234-0024	SCREW M3 X 16 PNHDPZ ZPST	FOR Q9,11
20611-0003	BUSH POLYESTER TO220 J22-5006	FOR Q9,10,11,12
20613-9401	WASHER TO220 Adhesive	FOR Q9,11
20661-9403	SPACER Rnd/Hex/ST 1"L Plas	FOR SK3
20670-0170	HEATSINK DRILLED	SK3
20670-0230	HEATSINK V4-3-190F	FOR R54
20670-0235	CLIP W936	SK4 (FOR R54)
22109-0010	TRANSFORMER HF POWER (20A)	T2
22154-0030	CHOKE HF POWER (20A)	L3
22320-0010	THERMOSTAT 100 DEG C TO220	TS3
22482-0020	BEAD, CERAMIC 11-54-3557-0	FOR R40,41 (2 EACH)
23184-0100	RES 10RJ 2W CF	R66,75 Vert
23184-1470	RES 470RJ 2W CF	R55 Vert
23184-2220	RES 2K2J 2W CF	R80 Vert
23185-2100	RES 1K0J W25 CF RD25S B/R	R73
23185-3330	RES 33KJ W25 CF RD25S B/R	R59
23202-2120	RES 1K20F W25 MF 50PPM	R98
23202-2680	RES 6K80F W25 MF 50PPM	R65
23202-3180	RES 18K0F W25 MF 50PPM	R81
23202-3316	RES 31K6F W25 MF 50PPM	R63,67

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PCB ASSY MAIN (20A) - UNIQUE PARTS CONTINUED

Part Number	Description	Position
23202-4100	RES 100KF W25 MF 50PPM	R79
23202-4430	RES 430KF W25 MF 50PPM	R56
23202-4560	RES 560KF W25 MF 50PPM	R62,93
23271-0010	RES 0R047J 4W MR KN350-8	R40,41
23379-2220	RES PS/H 2K2 Cermet 10mm skel	VR1
23379-4100	RES PS/H 100K Cermet 10mm skel	VR4
23424-0460	CAP 2N2K 250VDC CER (H/TEMP)	C64,65
23557-0664	CAP 1000U 35V ELEC RE2 P5	C16
23557-0669	CAP 2200U 35V ELEC RE2 P7.5	C73,74
23620-0248	CAP 22NJ 100V P/E	C52
25386-0020	TRAN NPN MJE3055-T	Q9,10,11,12

PCB ASSY CPU - (44115-0330)

Part Number	Description	Position
10366-9701	Adhesive Mtg Pads 25 x 12mm	FOR BATTERY
20030-0263	WASHER M3 ZPST	FOR IC36
20038-9501	WASHER M3 Spring	FOR IC36
20210-0101	NUT M3 ZPST	IC36,PJ2
20234-0011	SCREW M3 X 10 PNHDPZ NPST	IC36,PJ1,PJ2
20611-0003	BUSH POLYESTER TO220 J22-5006	IC36/HEATSINK
20613-0006	WASHER (SIL-PAD) TO220	IC36/HEATSINK
20670-0150	HEATSINK PCB MTG 38MM HIGH	FOR IC36
22010-0610	BATTERY 3V LITH 20MM BUTTON	BATT
22573-0041	HEADER 2 WAY STRAIGHT	LK1,2,TP1
22573-0048	HEADER 3 WAY STRAIGHT	LK3
22573-0202	HEADER 2 WAY STRAIGHT .156P	PJ5
22574-0400	SKT 9W R/A D-TYPE (RS232)	PJ2
22574-0430	SKT 24W RA IEEE RC10-24R-LNA	PJ1
22575-0009	SHORTING BLOCK RED	FOR LK2,3
22575-0064	HEADER 26 WAY (2X13) STR SKEL	PJ3
22575-0065	HEADER 20 WAY (2X10) STR SKELN	PJ6
22575-0100	HEADER 34 WAY (2X17) STR SKELN	PJ4
23185-0220	RES 22RJ W25 CF RD25S B/R	R2
23185-0470	RES 47RJ W25 CF RD25S B/R	R15
23185-1100	RES 100RJ W25 CF RD25S B/R	R20,37
23185-1220	RES 220RJ W25 CF RD25S B/R	R12-14,25-28
23185-1390	RES 390RJ W25 CF RD25S B/R	R8
23185-2150	RES 1K5J W25 CF RD25S B/R	R21,23,29,31
23185-2220	RES 2K2J W25 CF RD25S B/R	R18
23185-2470	RES 4K7J W25 CF RD25S B/R	R34
23185-3100	RES 10KJ W25 CF RD25S B/R	R17,33,39-46
23185-3470	RES 47KJ W25 CF RD25S B/R	R1,4,5,7,16
23185-4100	RES 100KJ W25 CF RD25S B/R R9,10,11,22,24,30,32,35,36	
23185-5100	RES 1M0J W25 CF RD25S B/R	R19,38
23202-3300	RES 30K0F W25 MF 50PPM	R3

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PCB ASSY CPU - CONTINUED

Part Number	Description	Position
23427-0324	CAP 56PG 100V CER N150 P5T	C22,23
23557-0611	CAP 47U 10V ELEC RE2 P2	C7,8
23557-0612	CAP 1U0 50V ELEC RE2 P2	C1
23557-0634	CAP 4U7 63V ELEC P2	C12
23557-0647	CAP 10U 35V ELEC RE2 P2	C3,10,11,13,14,24
23557-0657	CAP 100U 10V ELEC RE2 P2	C5,6,9,61
23557-0660	CAP 2200U 16V ELEC RE2 P5	C4
23557-0673	CAP 22U 35V ELEC RE2 P2	C2
23620-0246	CAP 100NK 63V P/E P5	C16,18,25,26,28-48,50-60
23620-0249	CAP 330NK 63V P/E P5	C17
23620-0256	CAP 1U0K 63V P/E P5	C19,20,21
23621-0310	CAP 10NJ 400V P/E 435/1 P7.5	C15
25021-0901	DIO 1N4148 B/R	D8,9
25115-0907	DIO 1N4002 B/R	D1-4
25130-0903	DIO ZEN 5V1 W4	D7
25341-0214	TRAN PNP ZTX214L/BC559	Q3
25380-0229	TRAN NPN BC549	Q1,2,4,5,6,7
27001-0020	OPTO-COUPLER CNY17-3	IC21,22,23,24
27106-0530	IC OP297	IC35
27153-0030	IC ICL7109B	IC27
27153-0150	IC DAC8248HP	IC33
27153-0160	IC ZN559E/ZN558E	IC34
27160-0440	IC V/REG LM2940CT5 TO220	IC36
27162-0010	IC SI7660CJ	IC38
27163-1600	IC 75160	IC2
27163-1620	IC 75162	IC1
27164-0506	IC ULN-2803A	IC7,32
27223-3740	IC 74LS374	IC20
27226-0510	IC 4051B	IC12
27226-0520	IC 4052B	IC28
27230-0600	IC 74HC4060	IC13
27231-0000	IC 74HC00	IC9
27231-0040	IC 74HC04	IC6
27231-0320	IC 74HC32	IC4,15
27231-1380	IC 74HC138	IC14
27231-2440	IC 74HC244	IC19
27231-2730	IC 74HC273	IC18,29,31
27234-5730	IC 74AC573	IC17,30,37,39
27250-0050	IC 14C88	IC16
27250-0060	IC 14C89	IC25
27250-0200	IC Z80B CMOS CPU	IC8
27250-0410	IC UPD7210C GPIB CONT	IC3
27250-0450	IC UPD71051C	IC5
27250-2000	IC MCU8 PIC16C55XT-P	IC26
27400-0080	IC 27C256 32Kx8 EPRM 200ns	IC10
27410-0420	IC 32Kx8 CMOS RAM 120ns	IC11
28151-0010	BUZZER C & D TRANSDUCER 40TGPC	BUZZ
28500-0800	XTAL - 4.9152MHZ - MICROPROCSR	XL1
28502-0010	RESONATOR CER 4MHZ CSA4.00MG	XL2
35555-1920	PCB - CPU	

PCB ASSY CONTROL (10A) (44115-0310) - COMMON PARTS
PCB ASSY CONTROL (20A) (44115-0320) - COMMON PARTS

Part Number	Description	Position
22226-0140	KEYSWITCH DARK GREY	K1,2,3
22573-0056	HEADER 16 WAY STR SIL (6.8MM)	FOR DISPLAYS
22575-0100	HEADER 34 WAY (2X17) STR SKELN	PJ1
23185-0220	RES 22RJ W25 CF RD25S B/R	R25
23185-0270	RES 27RJ W25 CF RD25S B/R	R1-8
23185-1100	RES 100RJ W25 CF RD25S B/R	R42
23185-1680	RES 680RJ W25 CF RD25S B/R	R21
23185-2150	RES 1K5J W25 CF RD25S B/R	R17,18,38,39
23185-3100	RES 10KJ W25 CF RD25S B/R	R23,31,32,40
23185-3470	RES 47KJ W25 CF RD25S B/R	R9-16,22
23185-4100	RES 100KJ W25 CF RD25S B/R	R27,29,30
23185-4470	RES 470KJ W25 CF RD25S B/R	R20
23202-3100	RES 10K0F W25 MF 50PPM	R19,33,36,41
23202-3300	RES 30K0F W25 MF 50PPM	R24
23347-0140	POT 10K LIN VO12L-PV25F-B10K	VR1,2
23347-0150	POT 10K LOG VO12L-PV25F-15A10K	VR4
23380-4220	RES PS/V 220K Cermet 10mm skel	VR5
23382-3100	RES PS/H 10K CERMET MIN	VR3
23557-0611	CAP 47U 10V ELEC RE2 P2	C7,8
23557-0657	CAP 100U 10V ELEC RE2 P2	C13
23620-0246	CAP 100NK 63V P/E P5	C2,4,6,14-21
23620-0249	CAP 330NK 63V P/E P5	C5
23620-0256	CAP 1U0K 63V P/E P5	C3,22,23
23621-0310	CAP 10NJ 400V P/E 435/1 P7.5*	C1
25061-0200	LED - T1 ROUND (3mm) - RED	LED1-4
25061-9503	DISPLAY - 4 DIGIT LED	DISP1,2
27153-0030	IC ICL7109B	IC2
27164-0506	IC ULN-2803A	IC8
27230-0510	IC 74HC4051	IC3,4
27231-2730	IC 74HC273	IC6,7
27234-5730	IC 74AC573	IC5,10
27250-2000	IC MCU8 PIC16C55XT-P	IC1
28502-0010	RESONATOR CER 4MHZ CSA4.00MG	XL1
35555-1900	PCB CONTROL	

CB ASSY CONTROL (10A) - UNIQUE PARTS

Part Number	Description	Position
23202-2680	RES 6K80F W25 MF 50ppm	R28
23202-3220	RES 22K0F W25 MF 50PPM	R35
23202-3470	RES 47K0F W25 MF 50PPM	R26
23202-3560	RES 56K0F W25 MF 50PPM	R37
23202-4220	RES 220KF W25 MF 50PPM	R34
23380-2470	RES PS/V 4K7 Cermet 10mm skelt	VR6
23380-3220	RES PS/V 22K Cermet 10mm skelt	VR7

PCB ASSY CONTROL (20A) - UNIQUE PARTS

Part Number	Description	Position
23202-3220	RES 22K0F W25 MF 50PPM	R28
23202-3180	RES 18K0F W25 MF 50PPM	R35
23202-4100	RES 100KF W25 MF 50PPM	R26,34,37
23380-3100	RES PS/V 10K Cermet 10mm skelt	VR6,7

PCB ASSY KEYBOARD - (44115-0340)

Part Number	Description	Position
10148-0005	CABLE 26W IDC FLAT GREY AWG-28	
22226-0140	KEYSWITCH DARK GREY	K0-26
22573-0056	HEADER 16 WAY STR SIL (6.8MM)	FOR DISPLAYS
22575-0046	CONN TRANSITION 26W IDC	PJ1
22575-0050	CONN TRANSITION 20W IDC	PJ2
22575-0051	SKT 20W IDC HIF3BA-20D-2.54R	
22575-0102	SKT 26W IDC HIF3BA-26D-2.54R	
23185-0270	RES 27RJ W25 CF RD25S B/R	R13-20
23185-0470	RES 47RJ W25 CF RD25S B/R	R25
23185-0560	RES 56RJ W25 CF RD25S B/R	R5-12
23185-1270	RES 270RJ W25 CF RD25S B/R	R26-33
23185-2120	RES 1K2J W25 CF RD25S B/R	R21,22
23185-3100	RES 10KJ W25 CF RD25S B/R	R24
23185-3470	RES 47KJ W25 CF RD25S B/R	R1,2,3,4
23185-4100	RES 100KJ W25 CF RD25S B/R	R23
23347-0510	POT 10KAX10KA OW2G20BU SPECIAL	VR1A,B
23557-0611	CAP 47U 10V ELEC RE2 P2	C1
23620-0246	CAP 100NK 63V P/E P5	C2,3
25021-0901	DIO 1N4148 B/R	D1-7
25061-0200	LED - T1 ROUND (3mm) - RED	LED 1-18
25061-0500	DISPLAY - 4 DIG 0.3" LED	DISP1
25061-9503	DISPLAY - 4 DIGIT LED	DISP2,3
27153-0050	IC TLC549IP	IC2
27226-0660	IC 4066B	IC1
35555-1940	PCB KEYBOARD	

REAR PANEL ASSY - (46912-0400)

Part Number	Description	Position
20030-0263	WASHER M3 ZPST	
	IEC INLET, EARTH, BLANKING PIECES	
20030-0266	WASHER M4 ZPST	
	TERMINAL BARRIER, EARTHING TAG	
20037-0401	SOLDER TAG SHAKEPROOF - 4BA	
20038-9501	WASHER M3 Spring	
	IEC INLET, EARTH, BLANKING PIECES	
20038-9502	WASHER M4 Spring	
	TERMINAL BARRIER, EARTHING TAG	
20210-0101	NUT M3 ZPST	
	IEC INLET, BLANKING PIECES	
20210-0102	NUT M4 ZPST	
	TERMINAL BARRIER, EARTHING TAG	
20213-0010	CAPTIVE NUT SNU-1219-17-00	
20234-0025	SCREW M3 X 12 PNHDPZ ZPST	IEC INLET
20234-0027	SCREW M3 X 6 PNHDPZ ZPST	EARTH
20234-0029	SCREW M4 X 12 PNHDPZ ZPST	TERMINAL BARRIER
20234-0034	SCREW M4 X 6 PNHDPZ ZPST	EARTH TAG
22458-0004	SHROUD INSULATING (MS1 BOOT)	
22467-0030	TERMINAL BARRIER BLOCK 4W 15A	
22467-0040	FANNING STRIP 4WAY 15AMP	
22520-0150	AC MAINS RECEP 10AMP 0707-1	
33331-1620	REAR PANEL - SERIES	

FRONT PANEL ASSY - (10A) (46912-0410)
FRONT PANEL ASSY - (20A) (46912-0420)

Part Number	Description	Position
20030-0263	WASHER M3 ZPST	PCB FIXING
20038-9501	WASHER M3 Spring	PCB FIXING
20038-9503	WASHER M3.5 SPRING	TERMINALS
20100-9401	NUT 4BA Half - Steel	TERMINALS
20234-0027	SCREW M3 X 6 PNHDPZ ZPST	PCB FIXING
22040-0030	FERRITE SLEEVE ID 7.87 H 14.27	
22219-0060	SWITCH PADDLE DPST SOLDER LUGS	
22450-0020	EYELET M3.5 (4BA) SHRD BLUE	
22451-0200	SOLDER TAG 4BA	TERMINALS
22571-0691	WASHER ALUMINIUM FOR TP2E TERM	EARTH TERMINAL
22571-0700	TERMINAL BLACK 4mm 30AMP INS	
22571-0710	TERMINAL GREEN 4mm 30AMP INS	
22571-0720	TERMINAL RED 4mm 30AMP INS	
23424-0454	CAP 10NZ 1KV CER P10	TERMINALS
33331-1910	FRONT PANEL PNCHD - 10A/20A	
33331-1920	OVERLAY FRONT PANEL - 10A	
	OR	
33331-1970	OVERLAY FRONT PANEL - 20A	

FRONT PANEL ASSY - (10A) PROG (46912-0430)
FRONT PANEL ASSY - (20A) PROG (46912-0440)

Part Number	Description	Position
20030-0263	WASHER M3 ZPST	PCB FIXING
20038-9501	WASHER M3 Spring	PCB FIXING
20038-9503	WASHER M3.5 SPRING	TERMINALS
20100-9401	NUT 4BA Half - Steel	TERMINALS
20234-0027	SCREW M3 X 6 PNHDPZ ZPST	PCB FIXING
20657-0060	KNOB KX6621761 LIGHT GREY	FOR VR1
20657-0061	CAP, KNOB, LIGHT GREY 21MM	FOR VR1
22040-0030	FERRITE SLEEVE ID 7.87 H 14.27	
22219-0050	SWITCH ROCKER DPST SOLDER LUGS	MAINS
22450-0020	EYELET M3.5 (4BA) SHRD BLUE	O/P FILTER HARNESS
22451-0200	SOLDER TAG 4BA	TERMINALS
22571-0691	WASHER ALUMINIUM FOR TP2E TERM	EARTH TERMINAL
22571-0700	TERMINAL BLACK 4mm 30AMP INS	
22571-0710	TERMINAL GREEN 4mm 30AMP INS	
22571-0720	TERMINAL RED 4mm 30AMP INS	
23424-0454	CAP 10NZ 1KV CER P10	TERMINALS
33331-1930	FRONT PANEL - PROG	
33331-1940	OVERLAY FRONT PANEL (10A PROG)	
	OR	
33331-1980	OVERLAY FRONT PANEL (20A PROG)	
43171-1100	CONNECTOR ASSY KEYBOARD/CPU 20W	
43171-1110	CONNECTOR ASSY KEYBOARD/CPU 26W	

35V/10A - CASE PARTS (51153-0601))
18V/20A - CASE PARTS (51153-0701)) - COMMON
35V/10A PROG - CASE PARTS (51153-0651))
18V/20A PROG - CASE PARTS (51153-0751))

Part Number	Description	Position
20030-0266	WASHER M4 ZPST	FEET, CPU PILLARS
20030-0267	WASHER M5 ZPST	RUBBER FEET
20037-0247	WASHER 4BA SHK/PROOF I/T ZPST	CASE UPPER
20037-0301	WASHER M3 SHK/PROOF I/T ZPST	CHASSIS/FRONT PANEL
20038-9501	WASHER M3 Spring	
	CHASSIS PILLARS, PCB STUDS, BLANKING PIECES	
20038-9502	WASHER M4 Spring	FEET, CPU PILLARS
20062-0700	SCREW NO 6 X 3/8 RFLNGPZ ST/AB	
	REAR PANEL TO CHASSIS, CASE UPPER	
20062-9308	SCREW No.6x3/8" Pozi Pan	
	HEATSINK AND CPU PILLARS	
20210-0101	NUT M3 ZPST	
	FRONT PANEL, PCB STUDS, BLANKING PIECES	
20210-0102	NUT M4 ZPST	FEET
20213-0010	CAPTIVE NUT SNU-1219-17-00	CASE UPPER TO LOWER
20234-0027	SCREW M3 X 6 PNHDPZ ZPST	CHASSIS PILLARS
20234-0028	SCREW M4 X 10 PNHDPZ ZPST	

CONTINUED....

CASE PARTS - COMMON CONTINUED

Part Number	Description	Position
20662-0201	BRACKET PLAS FOOT 3786-7001	
20662-0530	FOOT POLY/E BLACK P2629	
22491-0010	MAINS LEAD 2M (UK)	
	OR	
22491-0020	MAINS LEAD 2M (EUROPE)	
	OR	
22491-0010	MAINS LEAD 2M (USA)	
22575-0202	SKT 2W .156 20AWG (YELLOW) IDT	SENSE LEADS
22575-0204	SKT 4W .156 20AWG (Yellow)IDT	
	MAIN/CPU POWER, SHORTING LINK	
31711-0080	BEZEL	
33171-0130	SPRING FOOT	
33537-0640	CASE UPPER	
33537-0650	CASE LOWER	
37511-0500	LABEL - O/P TERMINALS REAR PANEL	
37522-0160	LABEL SERIAL NO	
37558-0970	LABEL REAR PANEL	

35V/10A - CASE PARTS - UNIQUE
18V/20A - CASE PARTS - UNIQUE

Part Number	Description	Position
20030-0263	WASHER M3 ZPST	BLANKING PIECES
20234-0012	SCREW M3 X 8 PNHDPZ ZPST	BLANKING PIECES
20657-0072	CAP BLK LINE C211 GREY 99	
20657-0070	KNOB 21MM DA217 180 GREY 99	
31334-0100	BLANKING PIECE - 9WAY "D"	
31334-0110	BLANKING PIECE - 24WAY "IEEE"	
43171-1120	CONNECTOR CONTROL/MAIN	
48511-0120	INSTRUCTION SHT	

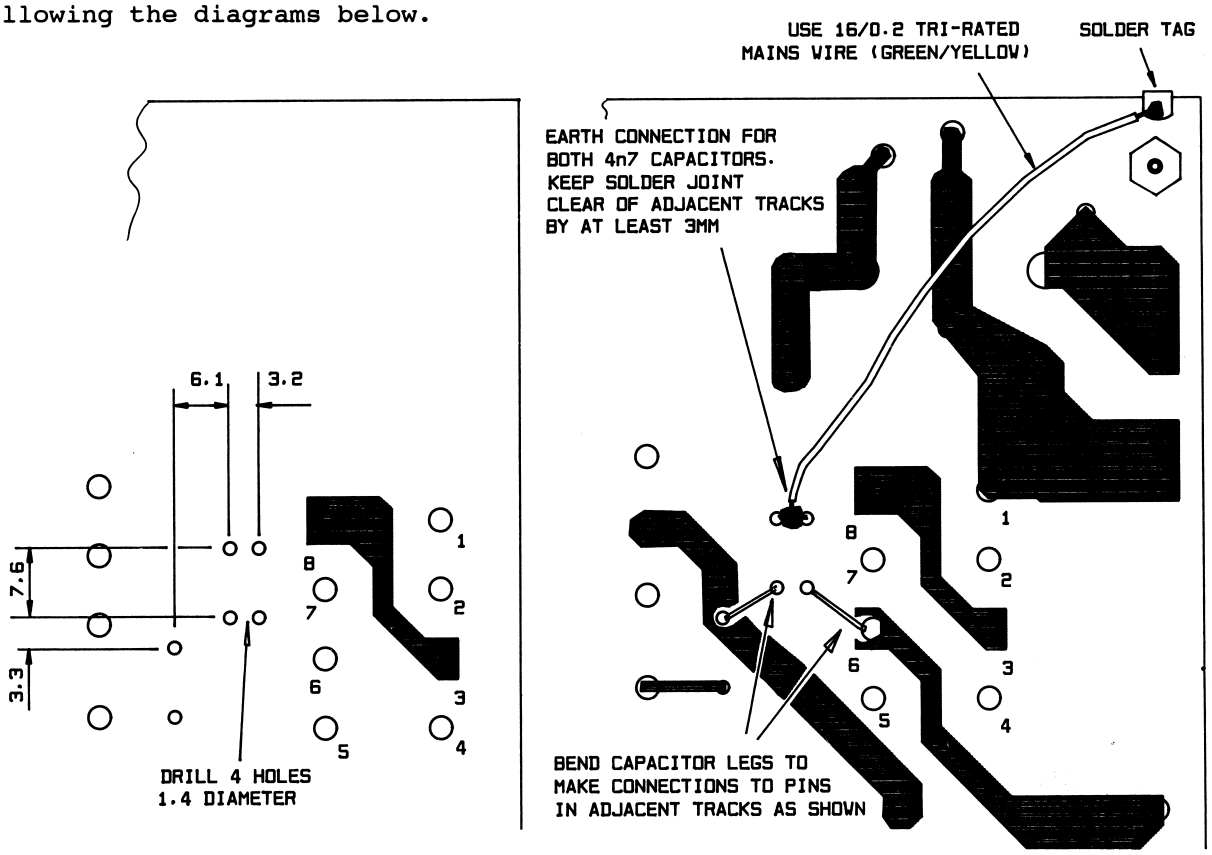
35V/10A PROG - CASE PARTS - UNIQUE
18V/20A PROG - CASE PARTS - UNIQUE

Part Number	Description	Position
20038-9503	WASHER M3.5 SPRING	CPU PILLARS
20062-9305	SCREW No.6x3/4" Pozi. Pan	CPU PILLARS
20661-0408	SPACER Rnd/Hex/ST 2.5"L Plas	
37511-0480	LABEL - GPIB	
37511-0490	LABEL - RS232	
43171-1130	CONNECTOR CPU/MAIN	
48511-0130	INSTRUCTION BOOK	

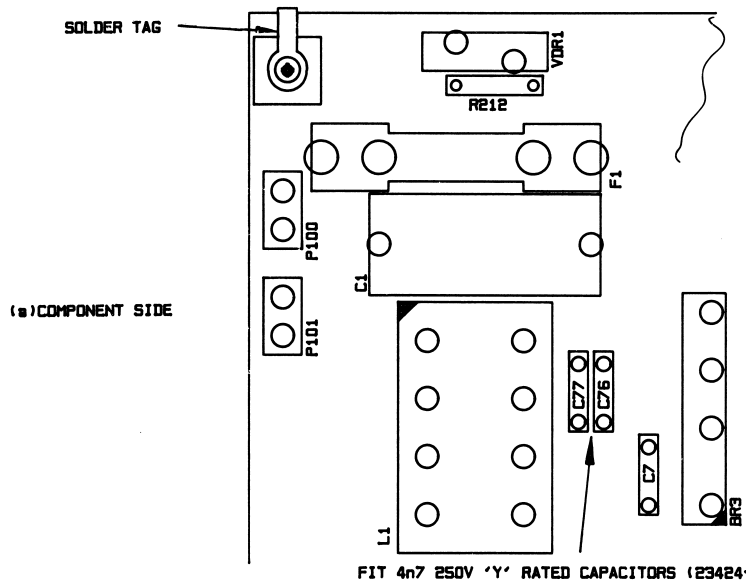
Manufacturing Changes

From March 1993 additional 4N7 'Y' rated (250V) capacitors (Part no. 23424-0459) were added to the main board in positions C76 and C77, see Main Board circuit diagram sheet 1. These improve the rejection of large line-borne transients which in extreme circumstances could otherwise damage any or all of TC1, BR3, Q1, and Q2.

The components can be retrofitted to an earlier board (Iss. 2 or earlier) following the diagrams below.



(b) SOLDER SIDE



(a)COMPONENT SIDE

FIT 4n7 250V 'Y' RATED CAPACITORS (23424-0459) INTO NEW PCB HOLES (SEE DIAGRAM (b) FOR DIMENSIONS

From **May 94** OPTO1 became an HCPL-4503 (Part No. 27001-0030), R133 became 3k3 and R128 a S.O.T. (typically 680hm); the main pcb became Iss 5 to accommodate this 8-pin device. The high C.M.M.R. of this opto improved immunity to conducted interference from both AC input and DC output terminals. At the same time the collector of Q3 was returned to VRECT- via link LK4, instead of to the base of Q7, to eliminate the long soft-start after primary overcurrent trip caused by certain unusual load conditions. Refer to schematic for Iss 5 Main onwards.

From **October 95** the main pcb was modified (Iss 6) to add a 22uH choke, L2 (22154-0130), in the VRECT+ line to reduce conducted emissions, and pcb fuses F2 to F8 to ensure safety in "single fault" conditions. At the same time, 10N decoupling capacitors were added across the rear panel terminals and to ground to improve EMC RF immunity.

Fuse values are as follows:

F2, 4	375mAT	22315-0440
F3, 5, 6, 7	3AT	22315-0457
F8	100mAT	22315-0402

Refer to schematic for Iss 5 Main onwards for fuse positions.

From **December 95** the main pcb was further modified (Iss 7) to add C78 (220pF, 23427-0384), R213 and R214 (both 1kOhm, 23202-2100) to IC5-D to improve EMC RF immunity when in Constant Current mode.

TSX SERVICE TEST CONNECTIONS ETC

FIG 1
60V SUPPLY
INJECTION

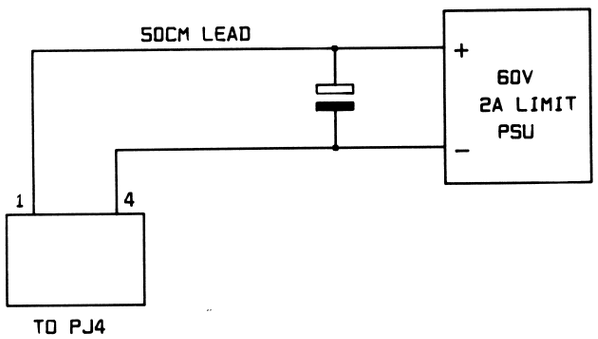


FIG 2
SENSE-OUTPUT
CONNECTION

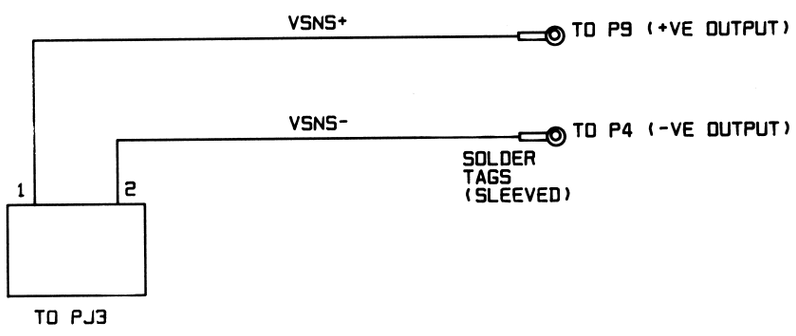
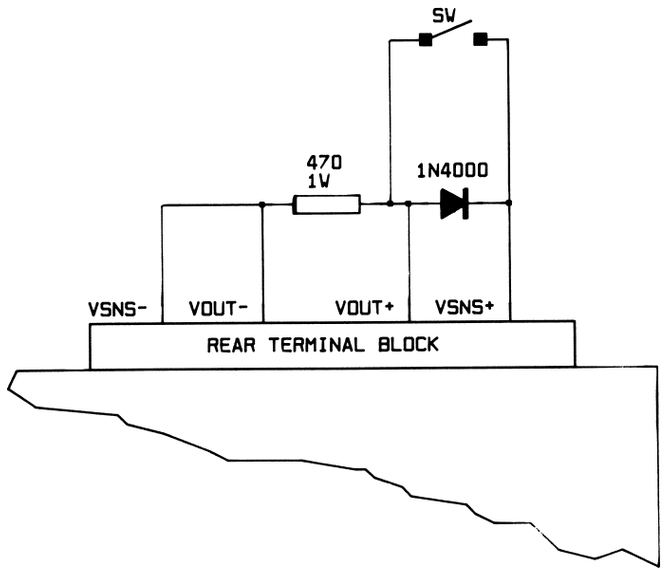


FIG 3
CMRR
ADJUST
NETWORK



PRIMARY SIDE SWITCHMODE WAVEFORMS WITH 60V SUPPLY TO PJ4 SCOPE COMMON TO VRECT-

FIG 4
TYPICAL
RAMP
WAVEFORM

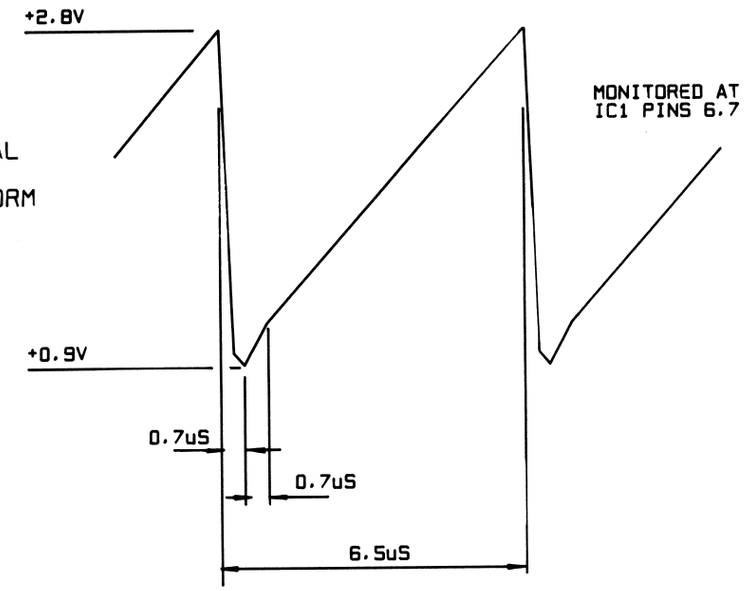


FIG 5
TYPICAL PWM
WAVEFORM AT
POINT HF

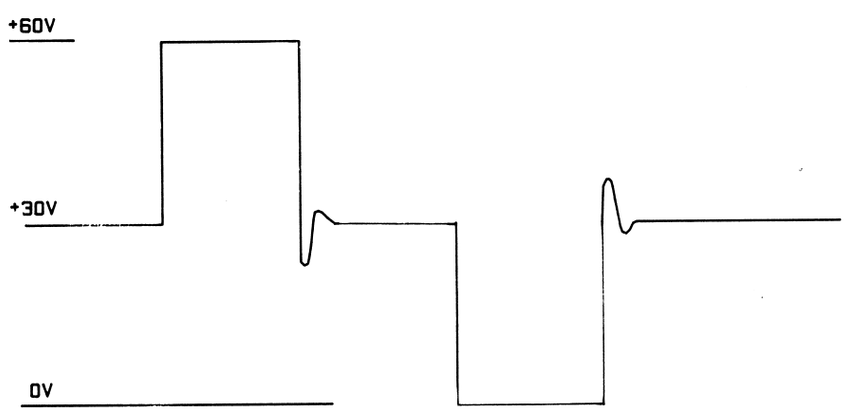
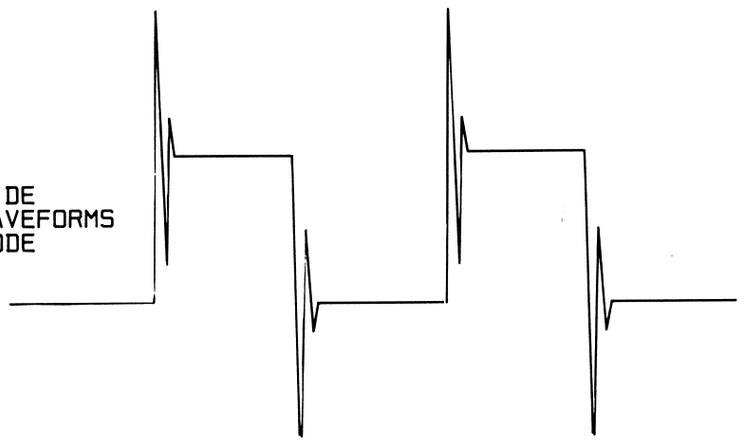
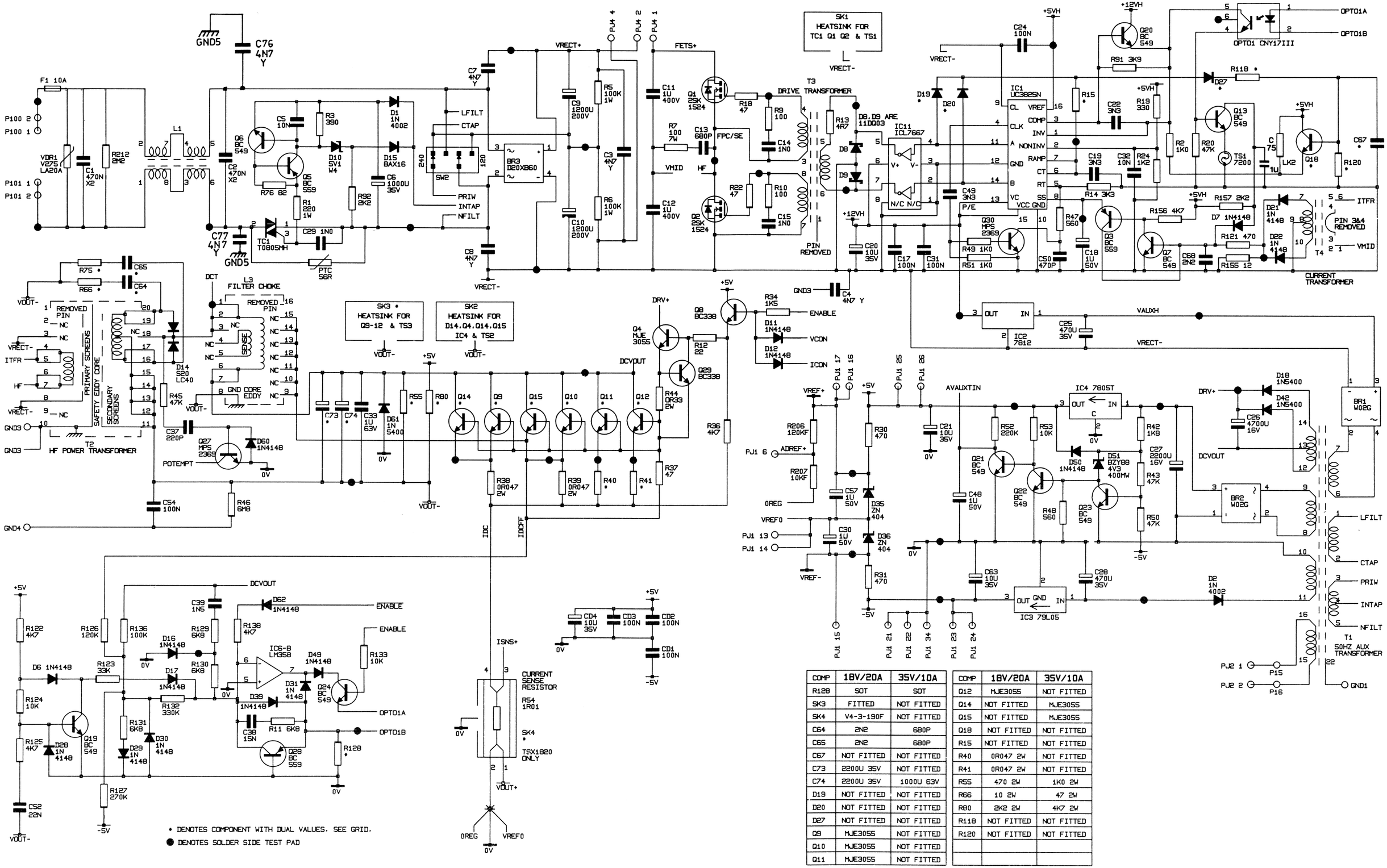


FIG 6
SECONDARY SIDE
RECTIFIER WAVEFORMS
AT D14 CATHODE





COMP	18V/20A	35V/10A
R128	SOT	SOT
SK3	FITTED	NOT FITTED
SK4	V4-3-190F	NOT FITTED
C64	2N2	680P
C65	2N2	680P
C67	NOT FITTED	NOT FITTED
C73	2200U 35V	NOT FITTED
C74	2200U 35V	1000U 63V
D19	NOT FITTED	NOT FITTED
D20	NOT FITTED	NOT FITTED
D27	NOT FITTED	NOT FITTED
Q9	MJE3055	NOT FITTED
Q10	MJE3055	NOT FITTED
Q11	MJE3055	NOT FITTED

COMP	18V/20A	35V/10A
Q12	MJE3055	NOT FITTED
Q14	NOT FITTED	MJE3055
Q15	NOT FITTED	MJE3055
Q18	NOT FITTED	NOT FITTED
R15	NOT FITTED	NOT FITTED
R40	0R047 2W	NOT FITTED
R41	0R047 2W	NOT FITTED
R55	470 2W	1K0 2W
R66	10 2W	47 2W
R80	2K2 2W	4K7 2W
R118	NOT FITTED	NOT FITTED
R120	NOT FITTED	NOT FITTED

Main Board Circuit Diagram - Sheet 1
Upto Iss. 4

COMP	18V/20A	35V/10A
RA	SOT	SOT
RB	SOT	SOT
R56	430KF	1M2F
R59	33K	56K
R62	560KF	1M0
R63	31K6	17K4
R65	6K8	14K
R67	31K6	17K4
R73	1K0	470
R79	100KF	220KF
R81	18K	10K
R93	560KF	1M0
TS2	NOT FITTED	FITTED
TS3	FITTED	NOT FITTED
VR4	100K	47K
VR6	10K	47K
VDR2	NOT FITTED	NOT FITTED
C16	1000U 35V	470U 63V
R80	2K2 2W	4K7 2W
R98	1K2	510
VR1	2K2	1K
R70	31K6	17K4

• DENOTES COMPONENT WITH DUAL VALUES. SEE GRID

● DENOTES SOLDER SIDE TEST PAD

NON-PCB OUTPUT FILTER

Main Board Circuit Diagram - Sheet 2
Upto Iss. 4

ISS 16

SK1 HEATSINK FOR TC1 Q1 Q2 & TS1

SK3 * HEATSINK FOR Q9-12 & TS3

SK2 HEATSINK FOR D14.D4.Q14.Q15 IC4 & TS2

T2 HF POWER TRANSFORMER

T3 DRIVE TRANSFORMER

T4 CURRENT TRANSFORMER

T1 50HZ AUX TRANSFORMER

L1

L2 22uH

L3 FILTER CHOKE

IC1 UC3825N

IC11 ICL7667

IC2 7812

IC3 79L05

IC4 7805T

IC6-8 LM358

BR1 V02G

BR2 V02G

BR3 D20X860

TS1 7200

OPTO1 HCPL-4503

CURRENT SENSE RESISTOR RS4 1R01

TSX1820 ONLY

PIN REMOVED

PIN 3&4 REMOVED

LK4

LK9 (NOT FITTED)

* DENOTES COMPONENT WITH DUAL VALUES. SEE GRID.

● DENOTES SOLDER SIDE TEST PAD

COMP	TSX1820	TSX3510
SK3	FITTED	NOT FITTED
SK4	FITTED	NOT FITTED
C64	2N2	680P
C65	2N2	680P
C67	NOT FITTED	NOT FITTED
C73	2200U 35V	NOT FITTED
C74	2200U 35V	1000U 68V
D19	NOT FITTED	NOT FITTED
D20	NOT FITTED	NOT FITTED
D27	NOT FITTED	NOT FITTED
Q9	MJE3055	NOT FITTED
Q10	MJE3055	NOT FITTED
Q11	MJE3055	NOT FITTED

COMP	TSX1820	TSX3510
Q12	MJE3055	NOT FITTED
Q14	NOT FITTED	MJE3055
Q15	NOT FITTED	MJE3055
Q18	NOT FITTED	NOT FITTED
R15	NOT FITTED	NOT FITTED
R40	OR047 2W	NOT FITTED
R41	OR047 2W	NOT FITTED
R55	470 2W	1K0 2W
R66	10 2W	47 2W
R80	2K2 2W	4K7 2W
R118	NOT FITTED	NOT FITTED
R120	NOT FITTED	NOT FITTED
D33	NOT FITTED	NOT FITTED
D34	NOT FITTED	NOT FITTED

Main Board Circuit Diagram - Sheet 1
Iss. 5 onwards

ISS 16

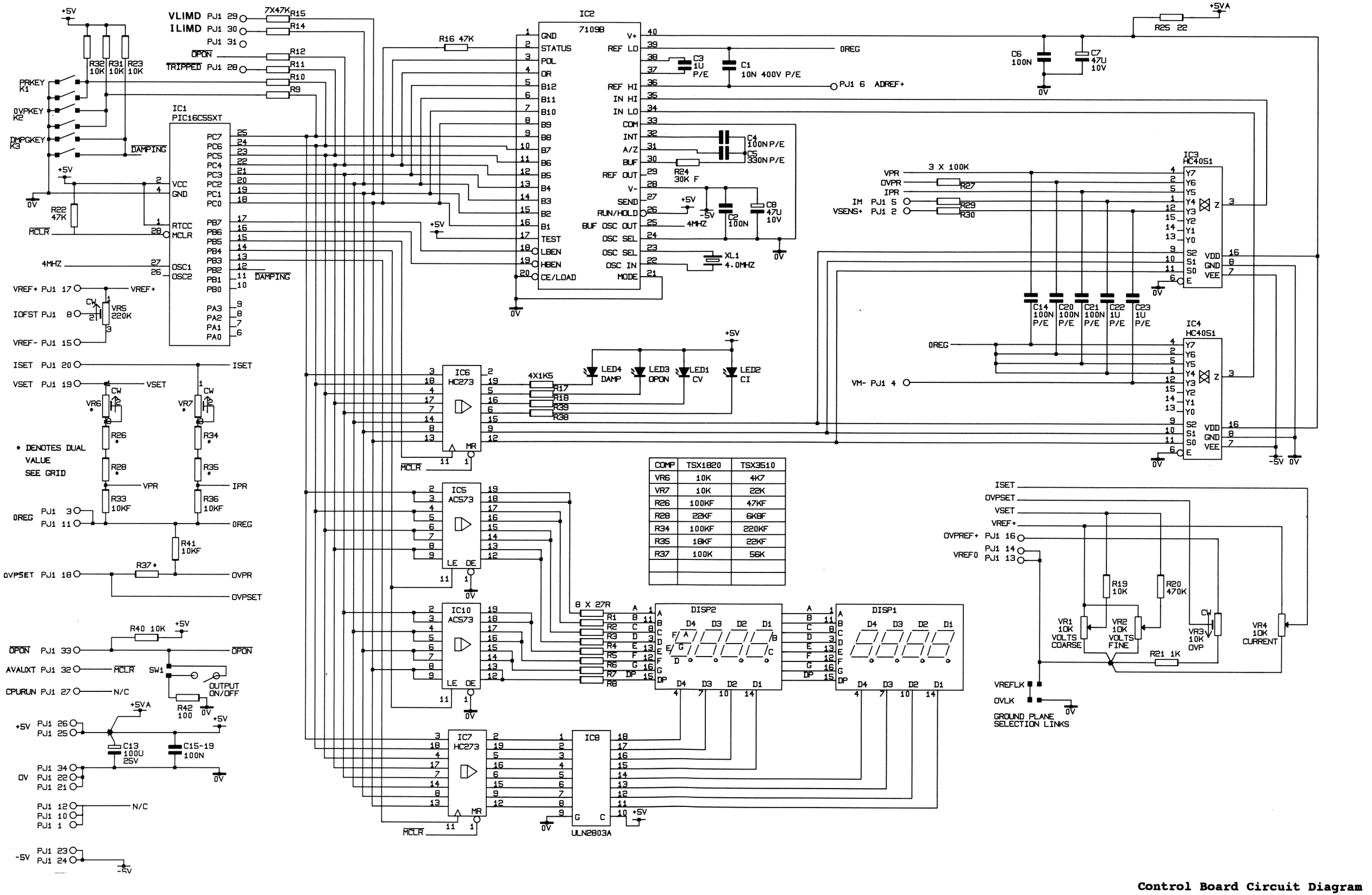
COMP	TSX1820	TSX3510
RS6	430KF	1MEF
RS8	33K	56K
RS2	560KF	1M0
RS3	31K6	17K4
RS5	6K8	14K
RS7	31K6	17K4
R73	1K0	470
R79	100KF	220KF
R81	18K	10K
R83	560KF	1M0
TS2	NOT FITTED	FITTED
TS3	FITTED	NOT FITTED
VR4	100K	47K
VR6	10K	47K
VDR2	NOT FITTED	NOT FITTED
C16	1000U 35V	470U 63V
R80	2K2 2W	4K7 2W
R98	1K2	510
VR1	2K2	1K
R70	31K6	17K4

• DENOTES COMPONENT WITH DUAL VALUES. SEE GRID

● DENOTES SOLDER SIDE TEST PAD

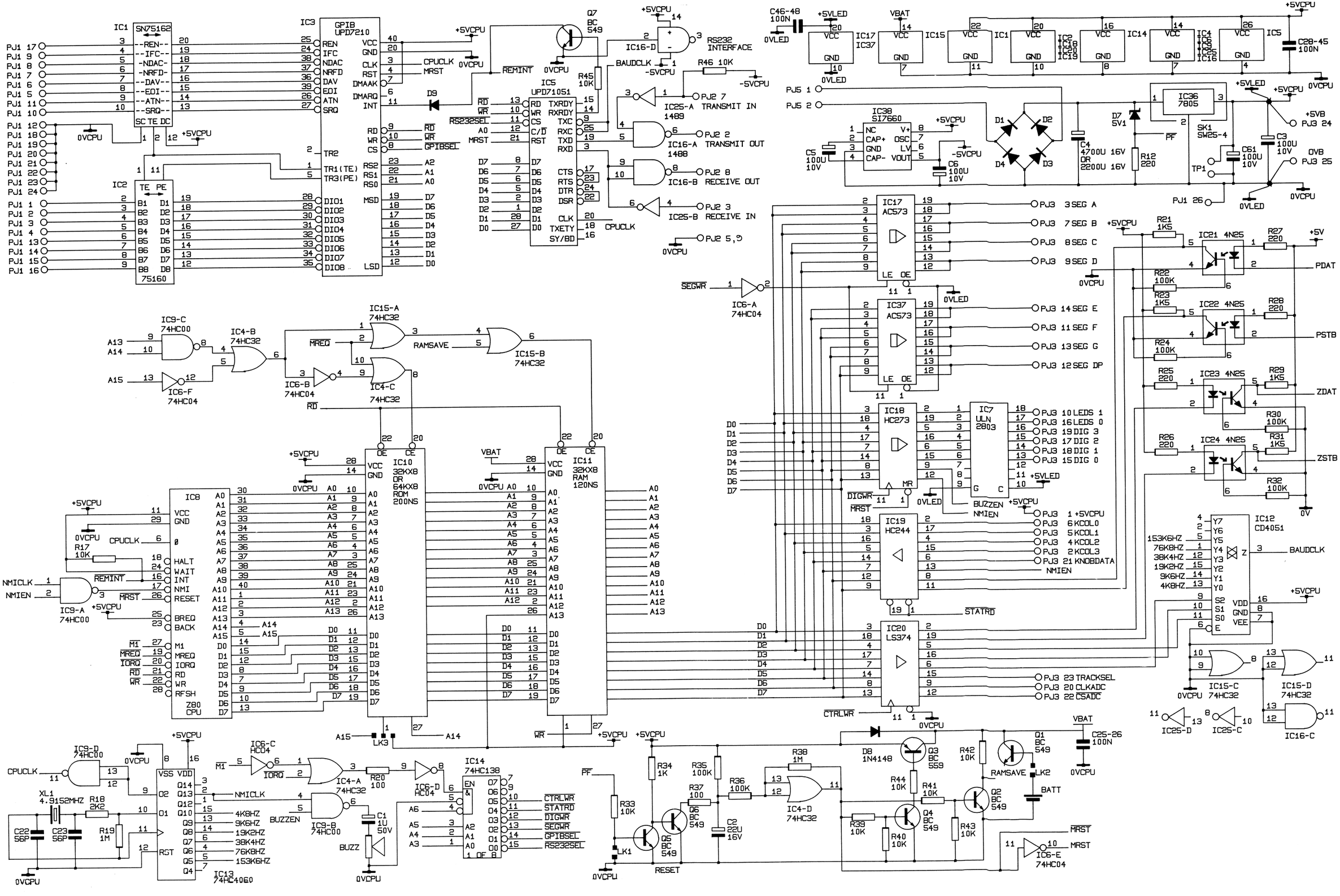
NON-PCB OUTPUT FILTER

Main Board Circuit Diagram - Sheet 2
Iss. 5 onwards

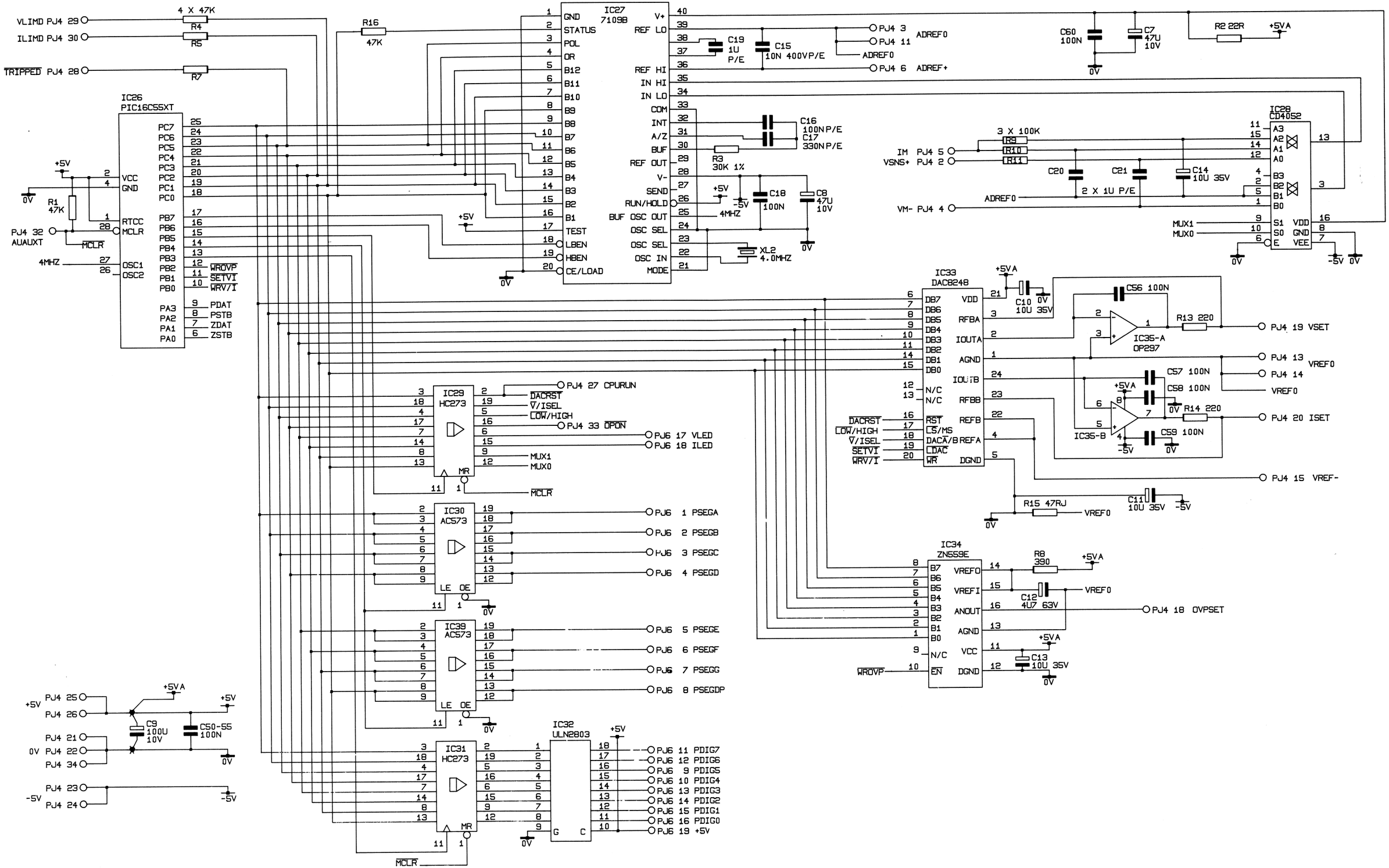


COMP	TSX1820	TSX3510
VR6	10K	4K7
VR7	10K	22K
R26	100KF	47KF
R28	22KF	6K8F
R34	100KF	220KF
R35	18KF	22KF
R37	100K	56K

Control Board Circuit Diagram



CPU Board Circuit Diagram - Sheet 1



CPU Board Circuit Diagram - Sheet 2

+5VKP1 PJ1 1
4 X 47K
R1 R2 R3 R4
KBCOL0 PJ1 6
KBCOL1 PJ1 5
KBCOL2 PJ1 4
KBCOL3 PJ1 2
ROW0 ROW1 ROW2 ROW3 ROW4 ROW5 ROW6
K3 K7 K11 K15 K19 K23
9 8 7 DVP AMPS VOLTS
K2 K6 K10 K14 K18 K22 K26
6 5 4 DAMPING △A △V OUTPUT
K1 K5 K9 K13 K17 K21 K25
3 2 1 LOCAL BAUD/ ADDRESS I/F ▽
K0 K4 K8 K12 K16 K20 K24
CONFIRM . 0 ESCAPE RECALL STORE △
COL3 COL2 COL1 COL0
SEGA PJ1 3
SEGB PJ1 7
SEGC PJ1 8
SEGD PJ1 9
SEGE PJ1 14
SEGF PJ1 11
SEGG PJ1 13
SEGDP PJ1 12
D1 D2 D3 D4 D5 D6 D7 8X1N4148
ROW7
8 X 56
R5 R6 R7 R8 R9 R10 R11 R12
DISP1
D4 D3 D2 D1
A B C D E F G DP
12 11 16 7 2 13 8 15
D4 D3 D2 D1
3 6 10 14
8 X 270
R26 R27 R28 R29 R30 R31 R32 R33
LED8 △A LED7 AMPS LED6 OVP LED5 BAUD LED4 ADDR LED3 VOLTS LED2 △V LED1 I/F
LED16 OPP LED15 ON LED14 REMOTE LED13 DAMPED LED12 ADJ VOLTS LED11 ADJ AMPS LED10 STORE LED9 RECALL
LEDS1 PJ1 10
LEDS0 PJ1 16
DIG3 PJ1 19
DIG2 PJ1 17
DIG1 PJ1 18
DIG0 PJ1 15
V+ K1 K2 V-
VR1 10K
C2 100N C3 100N
IC1-A 4066 IC1-B IC1-C
R23 100K R24 10K
REF+ AIN REF- VCC CLK DATA CS GND
IC2 TLC549
PJ1 20 CLKADC
PJ1 21 KNOBDATA
PJ1 22 CSADC
IC1-D
C1 47U 10V
VCC IC1 GND
R25 47R
PJ1 24 +5VB
PJ1 25 0VB
PJ1 23 TRACKSEL
8 X 27R
PSEGA PJ2 1
PSEGB PJ2 2
PSEGC PJ2 3
PSEGD PJ2 4
PSEGE PJ2 5
PSEGF PJ2 6
PSEGG PJ2 7
PSEGDP PJ2 8
R13 R14 R15 R16 R17 R18 R19 R20
A 1 B 11 C 8 D 3 E 13 F 12 G 16 DP 15
VOLTAGE
DISP2
CURRENT
DISP3
PDIG7 PJ2 11
PDIG6 PJ2 12
PDIG5 PJ2 9
PDIG4 PJ2 10
PDIG3 PJ2 13
PDIG2 PJ2 14
PDIG1 PJ2 15
PDIG0 PJ2 16
VLED PJ2 17
ILED PJ2 18
+5V PJ2 19
R21 1K2
R22 1K2
LED17 CV
LED18 CI

Keyboard Circuit Diagram