LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

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Prototype Electrostatic Driver —User Guide

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This is an internal working note
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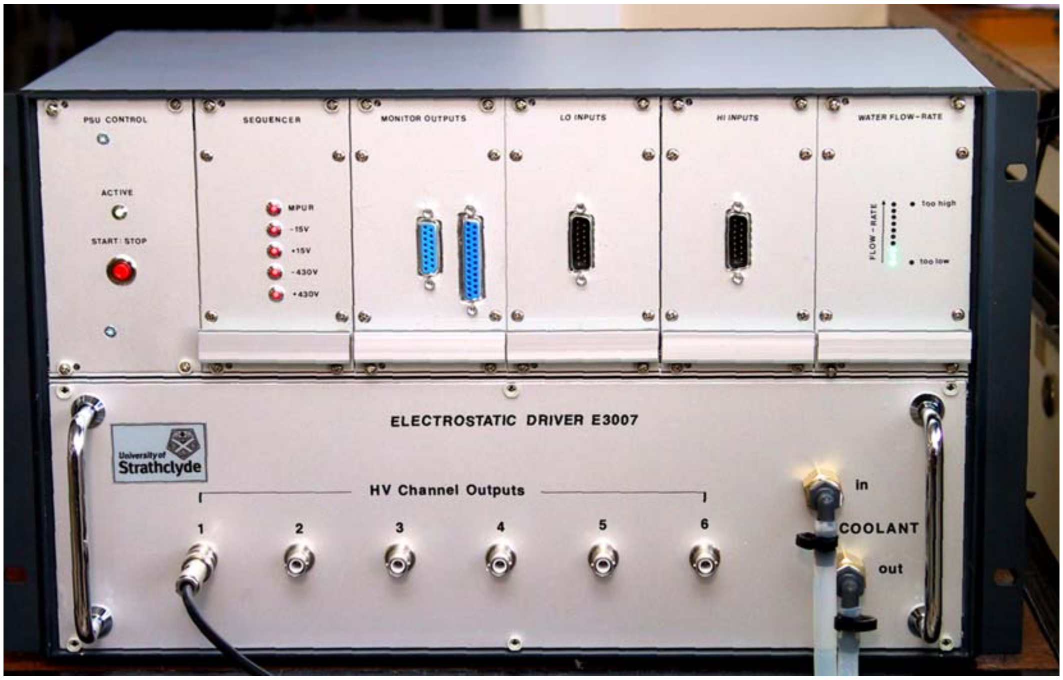
Prototype Electrostatic Driver E3007—User Guide

NOTE: PLEASE EXERCISE EXTREME CAUTION WHEN USING THIS PIECE OF EQUIPMENT—IT IS CAPABLE OF PRODUCING LETHAL VOLTAGES AT ITS HIGH VOLTAGE (HV) OUTPUTS.

IN PARTICULAR: WITH ZERO VOLTS APPLIED TO THE 'Hi' AND 'Lo' INPUTS OF THE E3007 THE OUTPUTS OF ITS HV CHANNELS SIT WITHIN A FEW MILLIVOLTS OF ZERO VOLTS. THEREFORE, AT SOME REMOVE FROM THE INSTRUMENT IT MIGHT BE CONCLUDED, MISTAKENLY, THAT THE INSTRUMENT WAS POWERED-OFF, AND INERT.

1. Features of the E3007

- Six-channel independent High Voltage (HV) outputs, all with with DC capability and exceptionally low (millivolt-level) zero voltage offsets. Modular unit, weighing 17 kg. wt., is designed to mount in a 19″ rack.
- All Channels can source voltages in the range ±404 V DC.
- Low noise: all Channels < 66 nV/√Hz @ 1 Hz, and ≤ 25 nV/√Hz @ 16384 Hz (noise levels referred to inputs).
- Designed to be stable when driving capacitive loads at AC.
- Channels' full-scale DC output range is < 2% down at 20 kHz AC, when HV outputs are loaded by 1.25nF.
- Greater than 101 dB separation between Channels 2–3 and 4–5 (> 109 dB between all other Channel pairs), at 20 kHz.



- All channels can source/sink currents of up to ±70 mA.
- Dual inputs for each Channel, their effects being summed at the corresponding HV output: a 'Hi' (coarse) level input, with a voltage gain of ×40, and a 'Lo' (fine) level input, with a voltage gain of ×0.4—this latter optional input allowing precise trimming of each Channel's HV output voltage, if required.

- Water-cooled for very low acoustic noise—with a flow-rate display via a front-panel LED bargraph.
- Seven remote-monitoring 'readback' analog outputs, monitoring all six actual HV output voltages, as well as monitoring the cooling-water flow-rate.
- Twelve (open-collector) remote-monitoring digital outputs, signalling the presence of the four external power rails to the unit, the temperature state of the unit's six HV power amplifiers, the adequacy of the cooling water's flow-rate, and the status (active or inactive) of the E3007's microcontroller.
- All analog inputs and monitored analog outputs are differential, with a nominal full-scale (differential) input range of ±10 V, and (differential) output range of ±20 V; all digital outputs are open-collector types, each with a current-return to an internal +12 V supply.
- The E3007 has automatic internal sequencing for power-up and power-down—interlocked, for reliable operation.

2. Supply Requirements

■ Low Voltage supply rails: $\begin{cases} +18\text{ V}(\pm 0.5\text{ V})\text{ at } 500\text{ mA} \\ -18\text{ V}(\pm 0.5\text{ V})\text{ at } -300\text{ mA} \end{cases}$ ...plus Ground.

■ High Voltage supply rails: $\begin{cases} +430\text{ V}(\pm 5\text{ V})\text{ at } 400\text{ mA} \\ -430\text{ V}(\pm 5\text{ V})\text{ at } -400\text{ mA} \end{cases}$ ...plus Ground.

■ Coolant: a water supply at a temperature of less than 86°F (30°C), at a (modest) flow-rate of just 1.2 pts (0.5–0.6 litres) per minute—equivalent to 3–4 bars on the front-panel LED bargraph flow-rate display.

➢ The E3007 is interlocked with the four externally provided power rails, and the water-cooling supply. It cannot be fully powered-up unless (i) all four power rails are present and at satisfactory voltage levels, and (ii) the cooling water's flow-rate is adequate (please refer to the sections below: *'Applying the four external power rails (entering the 'idle' state)'*, and *'Setting an adequate coolant flow-rate'*).

3. Connection of the Supplies

Connecting the ±18 V supplies

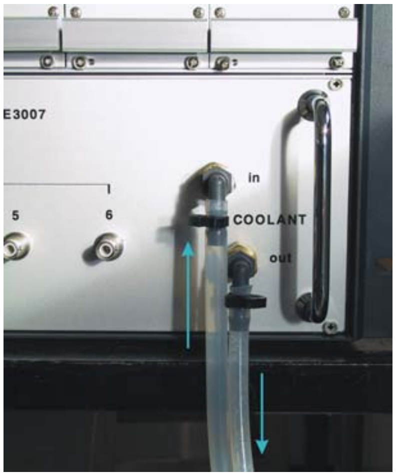
At the rear of the E3007 is a 3-pin socket to take (Left to Right) the +18 V, Ground, and −18 V supply inputs, respectively. A mating (latching) XLR plug for these inputs has been supplied fully wired with the unit.

- Please note that of the four power rails the +18 V supply has a special significance, since this supply powers the E3007's internal microcontroller, as well as its coolant flow-rate monitor and the front-panel LED bargraph display. With this supply in place the microcontroller, flow-rate monitor, and front-panel bargraph display, will all function properly, even when the instrument has not been fully powered-up.

Connecting the ±430 V supplies

Also at the rear of the E3007 are two colour-coded sockets to take (Red) the +430 V supply input, and (Black) the −430 V supply input. Two mating colour-coded Safe High Voltage locking plugs have been supplied with the unit. A braided-copper strap must be used to connect the Safety Ground terminal on the instrument's rear panel to a good local Earth point.

Connecting the Coolant supply



Internally, the E3007's six HV drivers have a high *static* thermal dissipation (14.6 W, each) when the unit is fully powered-up. This level of dissipation rises significantly when driving large capacitive loads at high frequency AC. Consequently, forced-cooling of the physically small HV drivers is essential in the unit's powered-up state. This has been accomplished in the E3007—with very low consequential acoustic noise—by water-cooling three internal heatsinks, a pair of HV drivers being mounted on each heatsink.

Flexible tubing for the E3007's cooling-water inlet and outlet should be attached to the instrument's two front panel-mounted spigots, as shown in the figure above, 1/4" inside-diameter tubing being ideal. Care must be taken in the choice of tubing to ensure that it is sufficiently robust, so that it does not rupture when the water pressure is applied. Note that the water inlet is the upper of the two spigots, and that this choice of connection must be respected—to avoid damage to the unit.

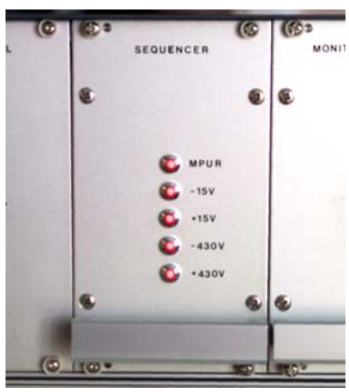
Internally, the instrument's flexible water tubing has a 1/10" inside-diameter, and so an upstream water filter should be employed if particulate matter in the cooling water is present such that the internal tubing might become blocked. Please note that high-pressure gases must not be used to clear the cooling-water path within the instrument, should it ever become blocked (the internal water flow-rate monitoring transducer would be damaged irreperably).

4. Operation

As mentioned above, the E3007 cannot be powered-up fully unless (i) all four externally supplied voltage rails are present at satisfactory voltage levels, and (ii) the coolant water supply is flowing through the E3007 at an adequate rate. In addition, if the E3007 has been caused to power-down due to a thermal over-temperature fault having occurred on any of its six HV amplifiers, the E3007 will not power-up again until this condition has been cleared—please see below.

Applying the four external power rail voltages (entering the 'idle' state)

Once the four power rails have been connected to the unit they may be powered-up in any order to the proper supply levels of ±18 V and ±430 V. Correct application of these external power rails is indicated by the corresponding red LED being lit on the Sequencer module's front-panel.



The ±430 V LED indicators are lit, respectively, when the ±430 V supply rails are present and at a satisfactory voltage level, and the ±15 V 'internally regulated supply' LEDs are lit, respectively, when the external ±18 V supply rails are present and at a satisfactory voltage level. These 'satisfactory voltage level' indicators change in the following way: -

+18 V rail: '+15 V' front panel LED lights when external supply = +17.5 V; goes out at +16.4 V,

–18 V rail: '–15 V' front panel LED lights when external supply = –17.4 V; goes out at –15.8 V,

+430 V rail: '+430 V' front panel LED lights at +428 V, goes out at +400 V, and

–430 V rail: '–430 V' front panel LED lights at –427 V, goes out at –391V.

- Please note that once supply voltage levels have been adjusted to the correct voltage levels for the E3007 on the external Power Supply Units, these PSUs can subsequently be switched on abruptly at full voltage to the E3007, without risk of damage to the instrument.

When the +18 V supply rail is present the MPUR LED on the Sequencer module will normally be lit, and the flow-rate bargraph will be powered. The MPUR status LED being lit indicates that the E3007's internal Microcontroller Power sequencer Unit is Running. Post power-up this LED indicates—by remaining lit—that no fault has occurred.

Once all four power rails are present the E3007 enters its 'idle' state, waiting for its front-panel Start : Stop push-button to be pressed: no power has been applied yet to the HV drivers or their low-voltage peamplifiers.

Setting an adequate Coolant flow-rate

The E3007 cannot be powered-up (i.e., be made to leave its 'idle' state) by pressing the Start : Stop pushbotton without the prior establishment of an adequate water flow-rate. The cooling-water flow-rate is indicated by a front-panel LED bargraph on the E3007's Water Flow-Rate module's front panel—once the external +18 V rail has been applied to the instrument—as shown in the figure above. An adequate flow-rate is present when the lower amber 'too low' LED goes out. This happens at a very modest cooling-water flow-rate of approximately 1.2 pts, or 0.5–0.6 litres, per minute (when 3–4 LEDs are lit on the Flow-Rate bargraph)—requiring a differential pressure between water inlet and outlet of just under 1 bar. There is a hysteresis of approximately 1 'LED' on the flow-rate sensor, and the flow-rate 'too low' state will not be entered unless the flow-rate falls below (effectively) ~ 2.5 LEDs. Note that the water flow-sensor has a time-constant of ~ 4 s, so that it is unaffected by small air bubbles in the inlet water tube.

Should the indicated flow-rate rise to full-scale on the bargraph, or above, the amber 'too high' LED will light, and the flow-rate must be reduced.

Connecting to the HV outputs

Six Safe High Voltage (SHV) BNC-like connectors have been supplied with the E3007.

First of all, the external wiring intended for connection to the E3007's Output(s) must be made safe, and then one, or more, of the terminating SHV connectors should be plugged into the appropriate Channel Output(s), as shown in the figure above. Only then should the E3007 be powering-up, i.e., be made to leave the idle state by pressing the Start : Stop pushbutton.

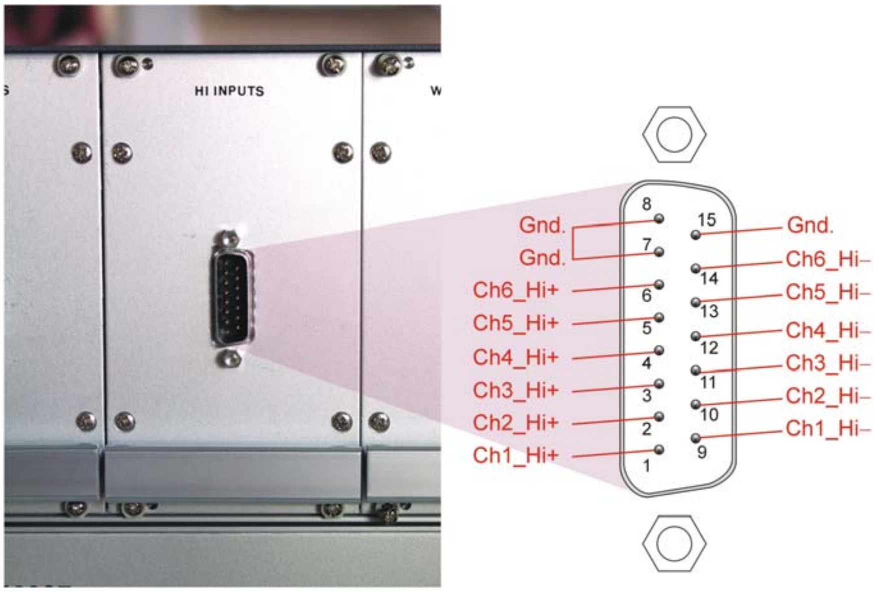
5. Powering-up the E3007

When the voltage rails and coolant have been supplied correctly to the E3007, the instrument can be powered-up by pressing the Start : Stop button, located on the PSU Control module.

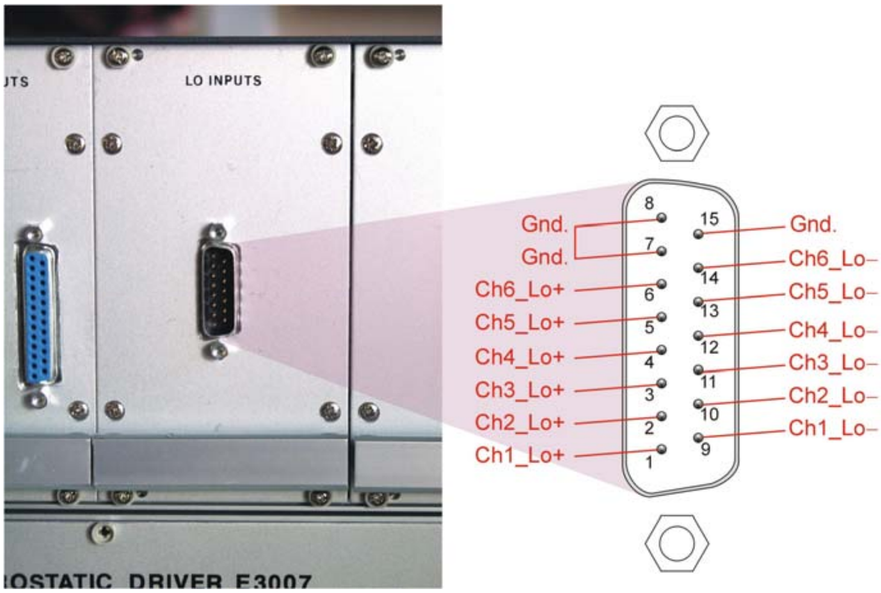
As soon as this button has been pressed the green Active LED on the module lights, in order to show that the instrument is now 'live'. The E3007 now enters, sequentially, its 'powered-up' state—it being the function of the instrument's Sequencer module to power-up the E3007 as a whole in an orderly way. First of all the ±15 V internally regulated voltage rails are switched to the unit's internal electronics, followed by the external ±430 V rails, these being applied initially through current-inrush limiting resistors to the internal HV driver boards, before these resistors are shorted-out and the ±430 V are applied to the HV driver boards directly. This whole power-up sequencing process takes a little over 3 seconds to complete after the green 'Active' LED is lit.

6. Applying inputs to the E3007

Although the Hi inputs and Lo inputs preamplifier modules are interchangeable, in principle, for best performance they should be maintained in their respective positions within the Schroff case (Lo module to the left of Hi). All inputs to the E3007 are assumed to be differential, and should be brought to the E3007 via screened twinax cable.



The controlling voltages fed to the Hi inputs of the E3007 Electrostatic Driver should be in the (differential) range ±10 V, and the leads should be connected to the 15-way male D-sub connector on the Hi preamplifier module as shown in the figure above. For example, +5 V connected to pin 1, and −5 V connected to pin 9, of the 15-way connector on the 'Hi inputs' module will generate a voltage of 40*(5 – (–5)) = +400 V at the Channel 1 HV output. Equally, if the side of the differential input connected to pin 9 of the connector were to be grounded (to pins 7, 8, or 15 on the connector), then a single-ended voltage of +10 V applied to pin 1 of this connector would also generate a voltage of 40*10 = +400 V at the Channel 1 HV output, whilst an input of –10 V would generate an output voltage of –400 V.



Connections to the Lo inputs module mirror those of the Hi inputs module, with the same differential input range of ±10 V. However, the contribution to the HV output of the selected Channel is 100× smaller than is the case for the Hi inputs. For example, +5 V connected to pin 1, and −5 V connected to pin 9, of the 15-way connector on the 'Lo inputs' module will generate a voltage of 0.4*(5 – (−5)) = +4 V at the Channel 1 HV output.

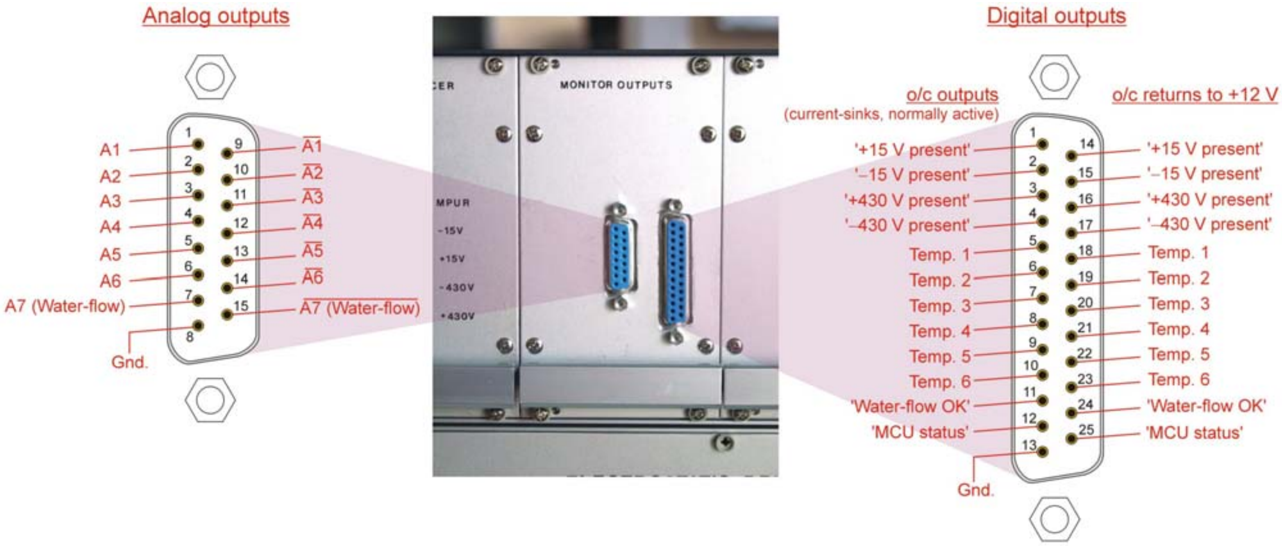
In general, when both Hi and Lo inputs are used, the output voltage produced by any channel is a weighted sum of its 'Hi' and 'Lo' input voltages, denoted by Hi_input and Lo_input in the following equation: -

Channel output voltage = 40*Hi_input + 0.4*Lo_input.

This feature greatly simplifies the setting of, e.g., a steady, high value, DC output voltage (via the 'Hi' input for that channel), with a superimposed, and finely controllable, low value AC modulation (via the 'Lo' input). Or, to take another example, the output voltage contribution from the 'Lo' input could be used as a very fine DC trim—both positively and negatively—about a steady high value DC output due to the voltage applied to that channel's 'Hi' input.

All the inputs on the Hi inputs and Lo inputs modules of the E3007 are tied to ground internally through 10 kΩ resistors, so that an unconnected input will not float. However, for best noise performance unused inputs should be connected to the instrument's ground at the respective 15-way connector.

7. Remote monitoring



Analog outputs A1, A2, ..., A6 on the Monitor Outputs module correspond to Channels 1, 2, ..., 6, respectively. Outputs A1—A6 give divided-down (by a factor of 40) versions of the actual voltages output by the HV drivers, in the low voltage range −10.1 to +10.1 V. In addition, output A7 gives a voltage analog of the cooling-water flow rate, this being in the range zero to +10.0 V. All seven analog Monitor outputs are differential: for example, when output A1 is at +10 V, output $\overline{\text{A1}}$ is its mirror image at −10 V, etc.

All 12 digital outputs on the Monitor Outputs module are normally active (open-collector outputs sinking current). A fault is signalled by the corresponding open-collector output switching off. It is anticipated that these outputs will be connected to the inputs of opto-isolators **via current-limiting resistors** (note: the open-collector returns to +12 V in the Monitor Outputs module only have protective 51 Ω series resistors. In order to reduce dissipation in the E3007's internal +12 V regulator it is recommended that low input-current (e.g., $I_F \leq 5$ mA) opto isolators be used, since a current of 12* I_F normally must be sourced continuously by this regulator (which also powers the instrument's internal relays).

8. Powering-down the E3007

If the Start : Stop button is pressed whilst the instrument is in its powered-up state it will enter immediately its power-down sequence. First of all the E3007 disconnects itself internally from the external ±430 V rails, after which it connects its internal, disconnected, ±430 V rails to two internal dump resistors, so as to discharge rapidly the high voltage capacitors on its HV boards. After a short delay the E3007 then disconnects its internal electronics from the internally regulated ±15 V supplies. This whole sequence has a duration of a little over 3 seconds, and it leaves the instrument in its idle state—from where it may be re-started by pressing the Start : Stop pushbutton again.

Should any one (or more) of the eleven 'fault' conditions listed below present itself after power-up, i.e., during active operation, the instrument will switch itself off in the aforementioned controlled manner—but with the difference that it will not re-enter the 'idle' state. Instead it will turn off the MPUR LED on the Sequencer module, and turn off the microcontroller's digital Status output, in order to show that a fault has occurred. The instrument's microcontroller will then shut itself down.

- The system's microcontroller may be re-started subsequently by removing just the external +18 V supply rail from the instrument for at least 3 seconds, and then reconnecting it. The E3007 will then enter its 'idle' state—but it will not leave the idle state to power-up (on pressing the Start : Stop pushbutton) until the condition that caused the fault has been cleared.

<u>Fault Conditions that will cause a power-down (and will prevent power-up from the 'idle' state)</u>

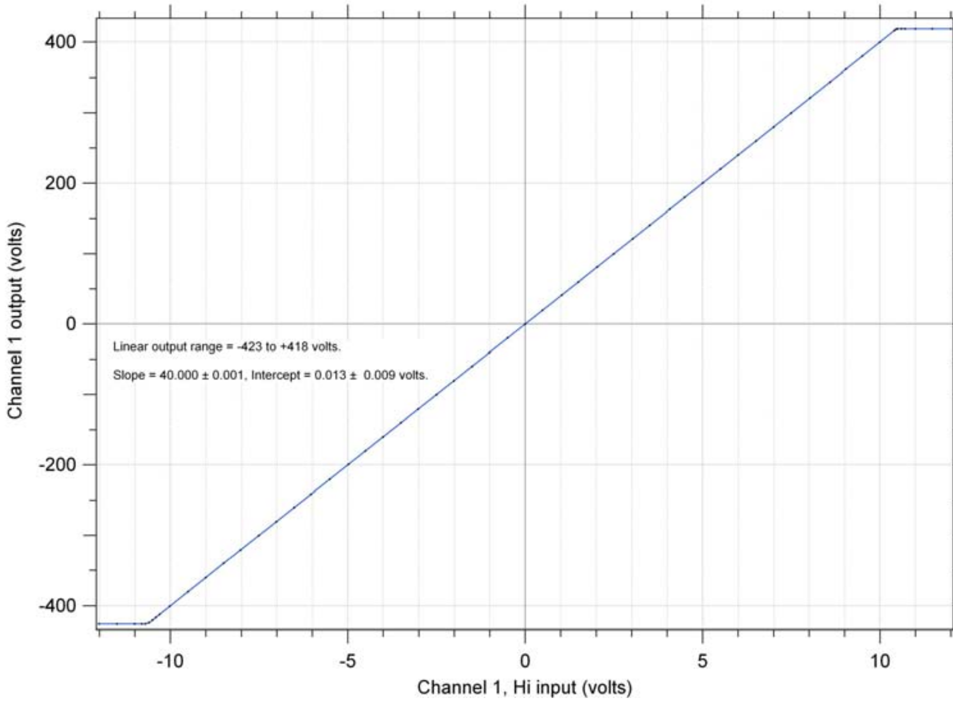
- +18 V absent, or too low.
- −18 V absent, or too low.
- +430 V absent, or too low.
- −430 V absent, or too low.
- Cooling-water flow-rate too low.
- Channel 1 HV amplifier's temperature sensor reading > 150°F (> 66°C).
- Channel 2 HV amplifier's temperature sensor reading > 150°F (> 66°C).
- Channel 3 HV amplifier's temperature sensor reading > 150°F (> 66°C).
- Channel 4 HV amplifier's temperature sensor reading > 150°F (> 66°C).
- Channel 5 HV amplifier's temperature sensor reading > 150°F (> 66°C).
- Channel 6 HV amplifier's temperature sensor reading > 150°F (> 66°C).

All of these potential fault conditions are available for remote-monitoring at the open-collector digital outputs on the Monitor Outputs module. In the absence of faults these open-collector outputs are individually in their ON states (sinking current)—switching OFF, should their respective fault occur.

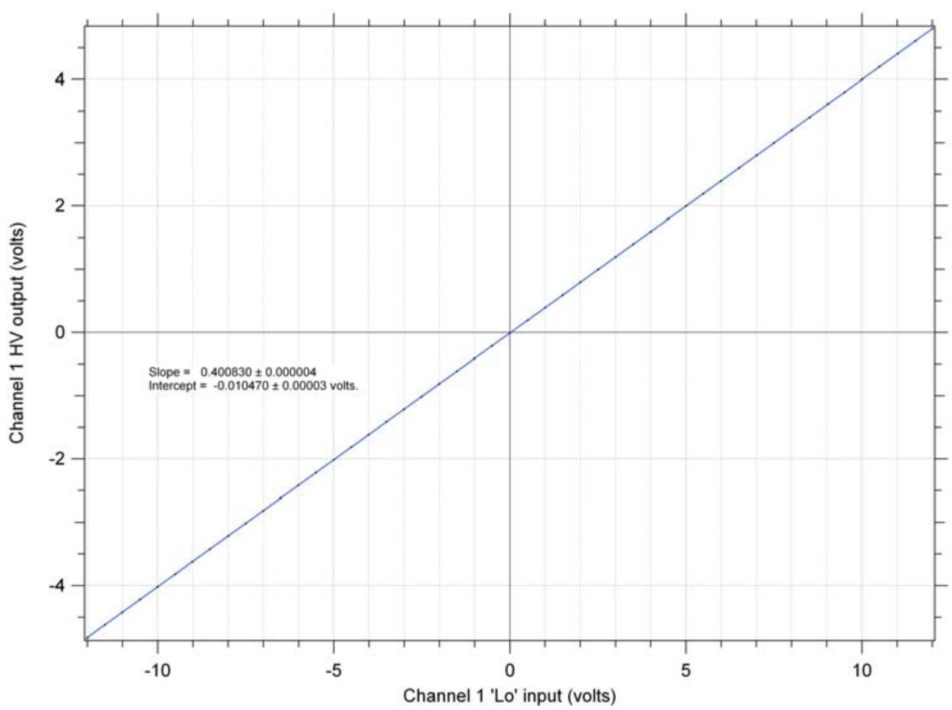
9. Appendices

Performance (Channel 1 used as an example—all 6 Channels give similar performances)

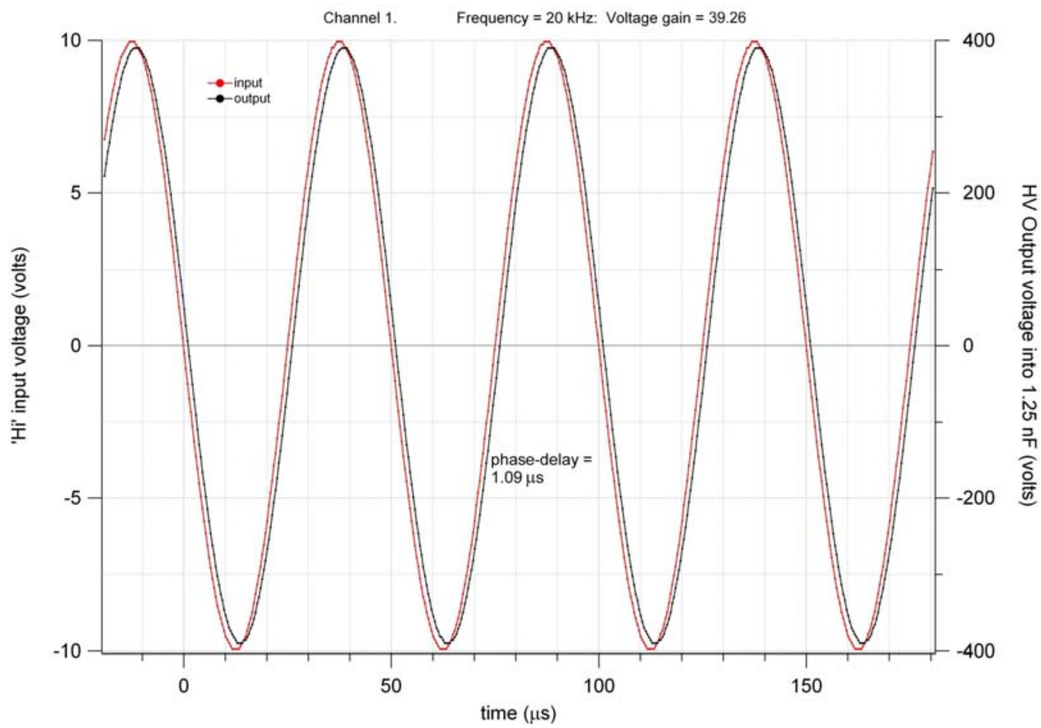
DC ('Hi' input).



DC ('Lo' input).



20 kHz AC ('Hi' input) into a load of 1.25 nF.

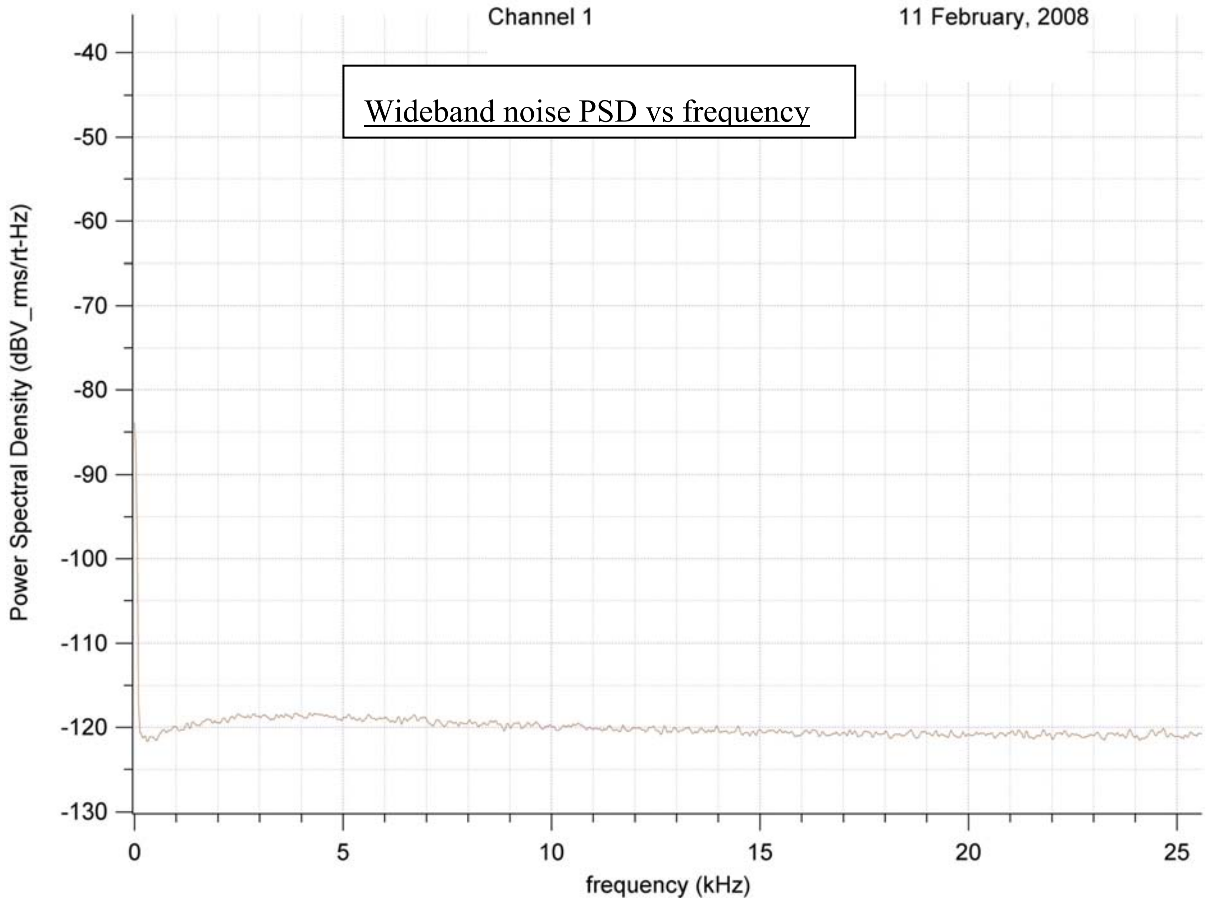


Although the AC output voltage swing is close to 800 V p-p for a 20 V p-p 'Hi' input, even at a frequency of 20 kHz, the mean DC level of the HV output was found to remain very close to zero volts (≤ 1.5 V, the limiting resolution of the digital 'scope used for the measurement).

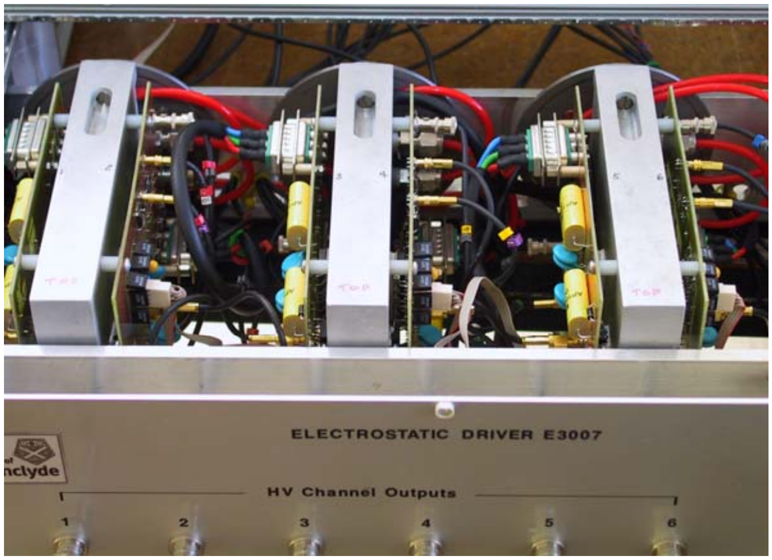
Noise and Offset performance (Noise referred to 'Hi' inputs: Noise Gain = 40).

Frequency (Hz): Channel #	Power Spectral Density ($nV/\sqrt{Hz}$) @ 1	10	100	1024	4096	10000	16384	20000	DC offset at the HV output with zero input (mV)
1	62.4	25.3	21.7	24.7	28.4	25.7	23.5	23.7	0.9
2	55.9	23.7	20.3	24.5	29.2	25.9	23.3	22.7	−3.3
3	65.6	23.9	26.5	24.3	28.6	26.9	23.3	22.9	−1.8
4	63.2	23.5	24.1	24.3	29.0	24.3	23.3	20.9	−2.8
5	65.0	24.5	23.3	25.5	29.8	27.5	24.3	23.3	−6.1
6	46.2	25.5	21.9	25.5	31.6	27.3	22.9	23.9	−5.2

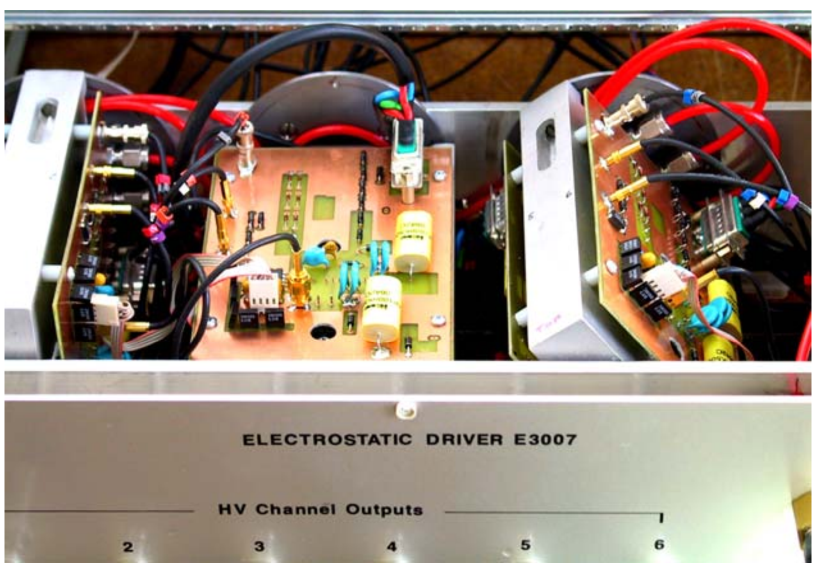
Despite its high voltage output capability the E3007 is a very low noise instrument, uniformly across its six output Channels, as the Table above shows. The measurements in the Table were made with both the 'Hi' and 'Lo' inputs of all 6 Channels shorted to ground.



Servicing: replacement of HV driver boards (if needed)



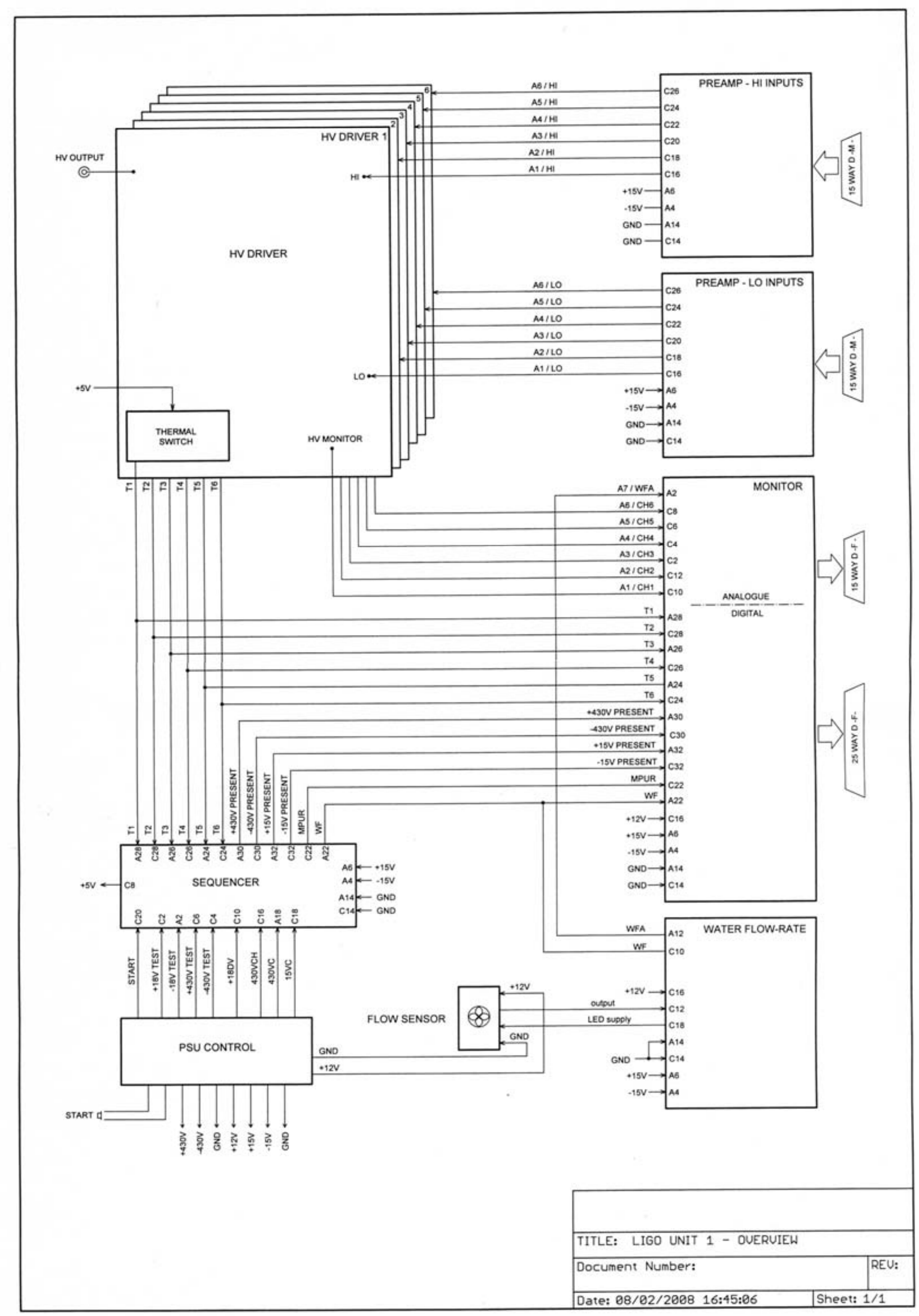
The E3007's three water-cooled heatsinks are normally orientated vertically, as shown in the figure above. Here, the 6 retaining screws have been disengaged, and the lower 3U drawer of the Schroff case has been withdrawn by approximately 8″ (200 mm), in order to access the HV driver boards. The heatsinks are each held in the vertical plane by a pair of sprung detents, and the six HV driver boards are mounted two to each heatsink, one on each side. However, each heatsink may be rotated (carefully!) by ±90°, in order to bring one or other of its two HV driver boards uppermost—for easy access. This procedure is aided considerably by rotating slightly one of the adjacent heatsinks as well, in order to free-up the wiring for rotation, as shown in the figure below.



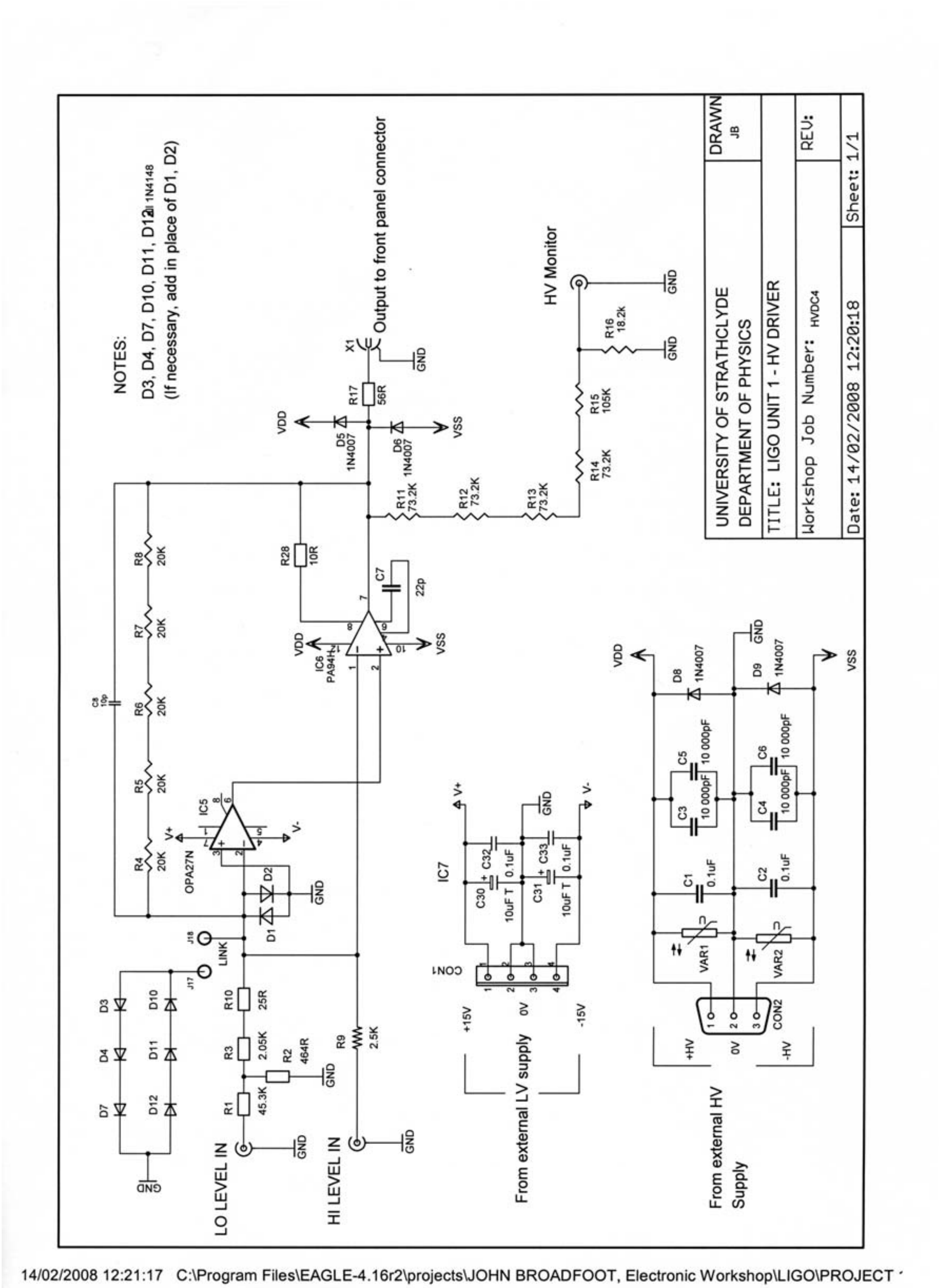
In this new orientation the detents will hold the heatsinks firmly in the horizontal plane, allowing, should it ever become necessary, the topmost HV driver board to be unplugged from the ±15 V supplies, the ±430 V supplies, the 'Hi' preamplifier input, the 'Lo' preamplifier input, and the HV output. These five connectors are not interchangeable, and re-connection is therefore straightforward. The HV boards are held to each heatsink by 4 screws mounted through 8 mm insulating PCB spacers, a single screw clamping the PA94 HV op-amp down onto its heatsink, and a second screw holding the series-connected short-circuit protection resistor to the heatsink. These last two screws are accessed through apertures in the HV driver's PCB. Please note that a Thermal switch is clamped to the upper face of the PA94's tab by the PA94's clamping screw. This should be repositioned with the heatswitch's legend 'TOP' uppermost when it is remounted on the PA94's tab of any replacement HV driver board.

Circuit Diagrams

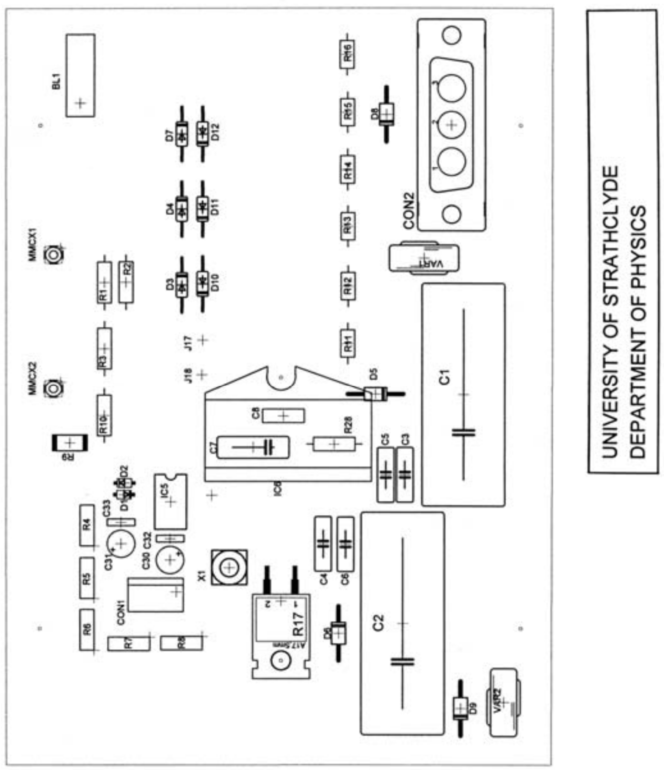
Overview of the instrument.



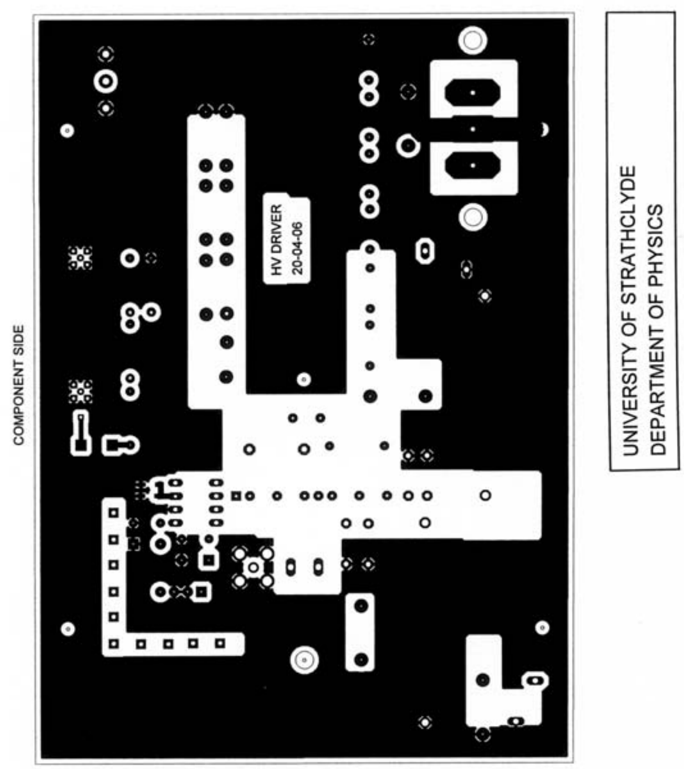
HV Driver boards (× 6)



Circuit diagram of HV Drivers.



HV Driver board component overlay.



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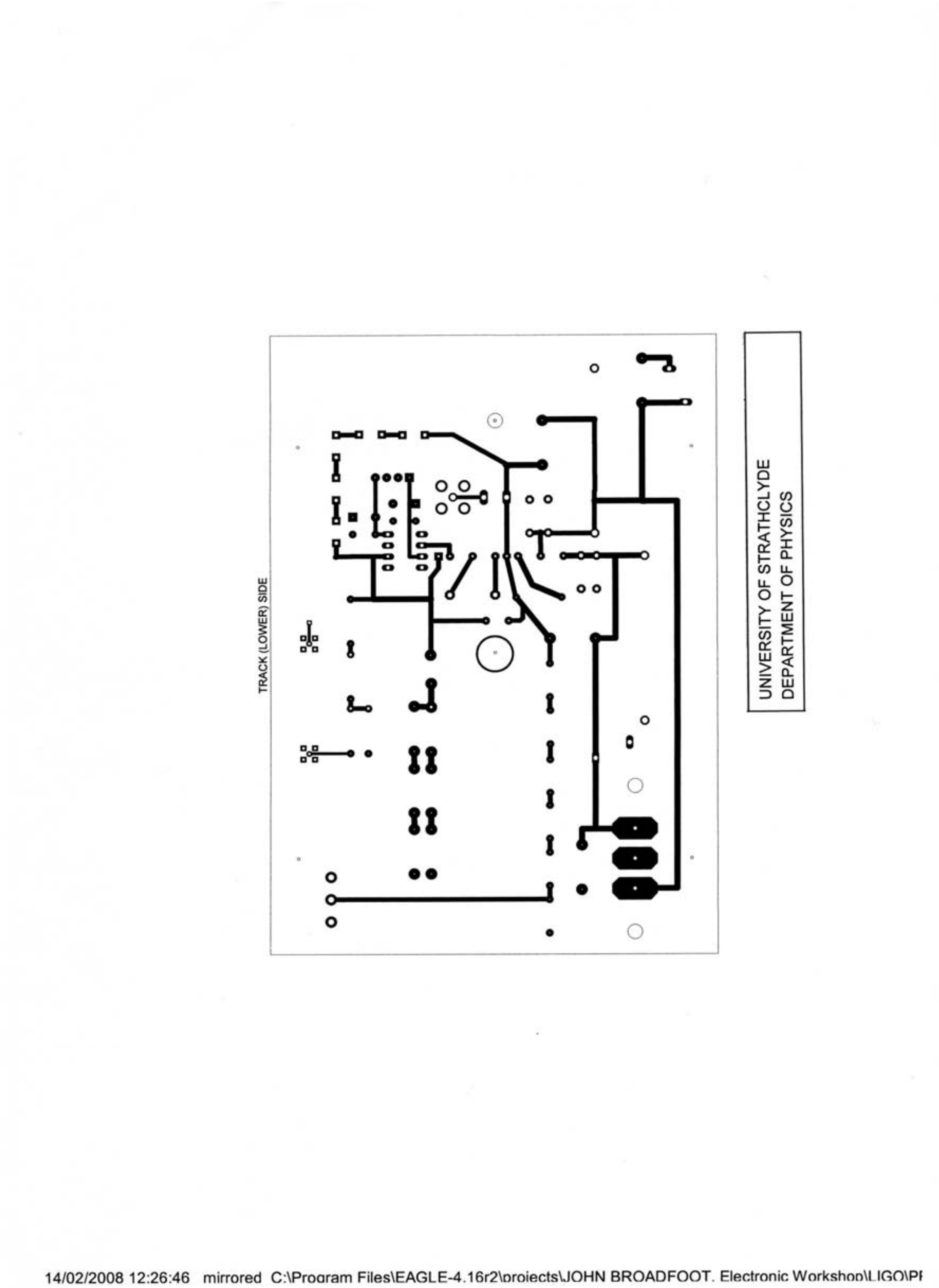
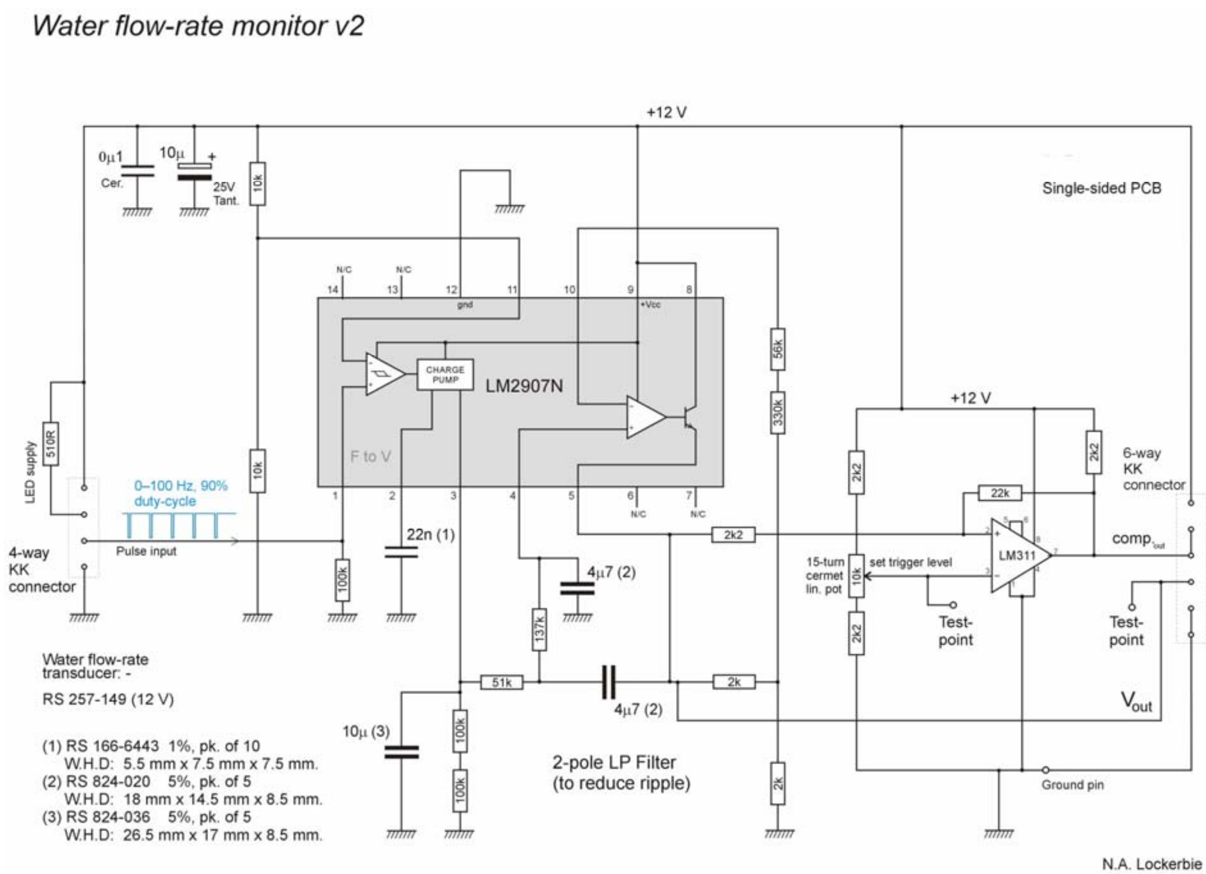
Top (component) side of HV Driver PCB.



Track (underside) of HV Driver PCB.

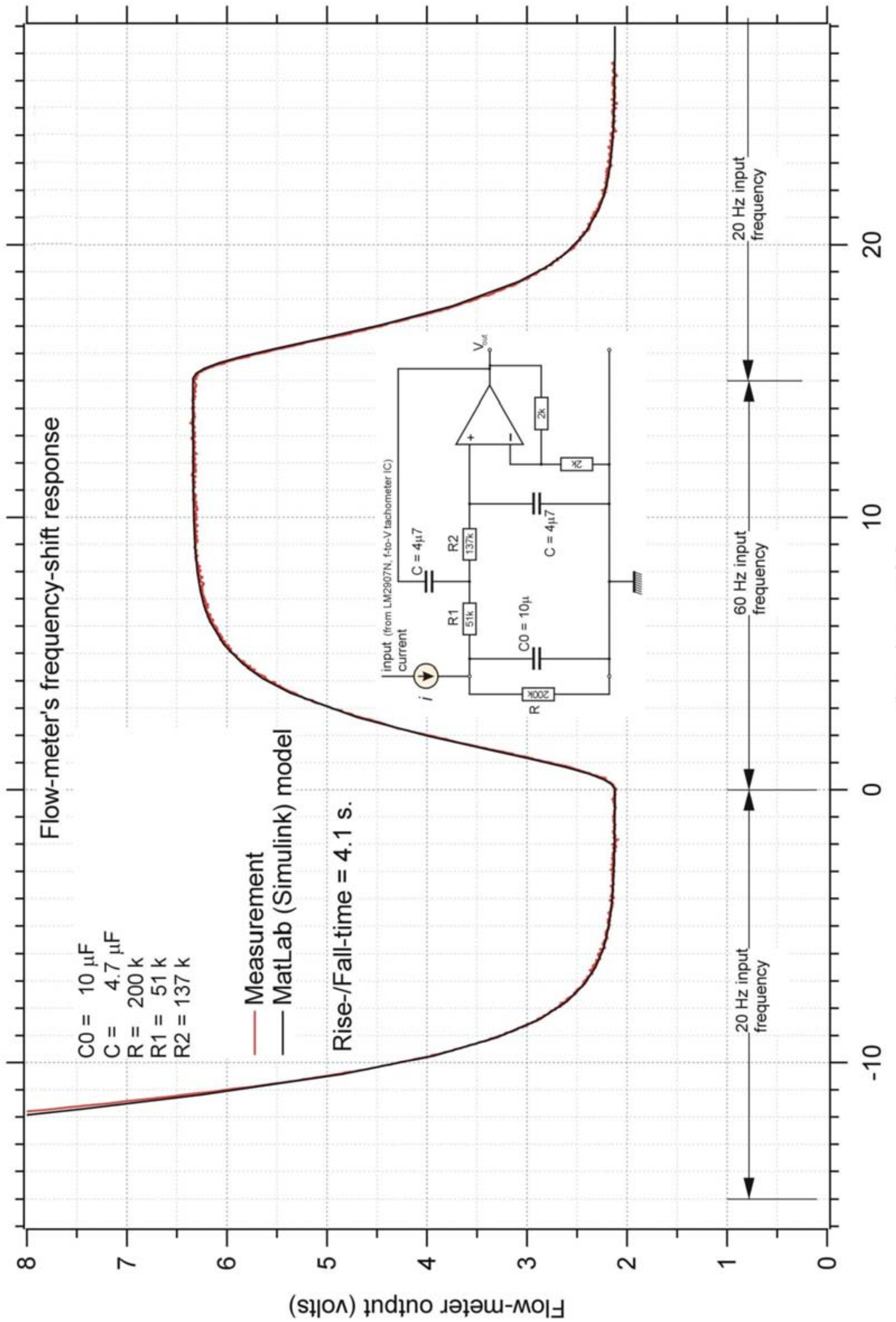
Water Flow-rate module

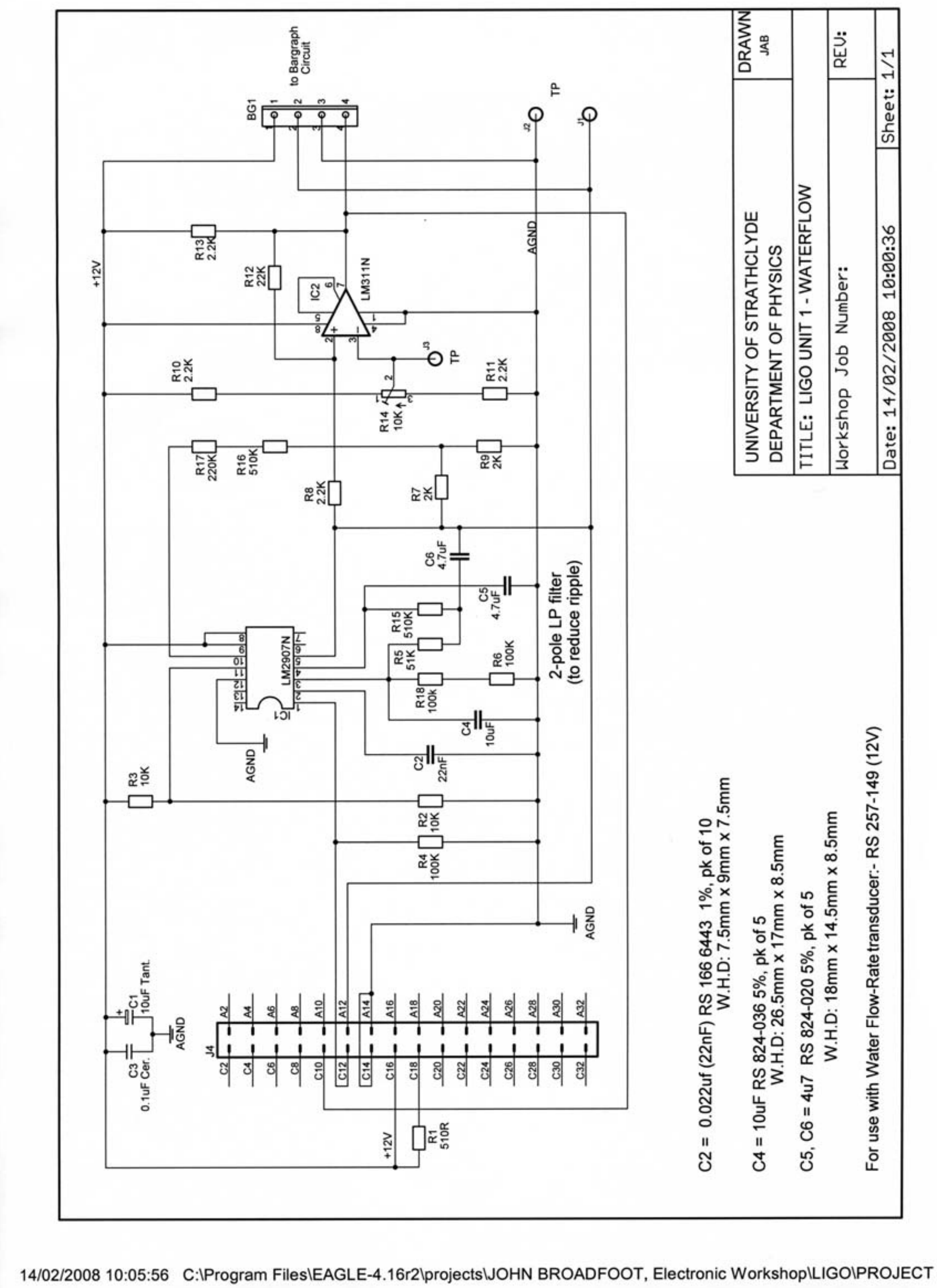
The water flow-rate transducer comprises a small flow-driven turbine flow-sensor that interrupts an infrared beam, producing a stream of pulses (with a 90% duty-cycle), at a frequency proportional to flow-rate. The output frequency of the transducer is approximately 67 Hz per litre/minute water flow-rate. The flow-rate sensing electronics has therefore been designed around a frequency-to-voltage IC (LM2907N), and a buffered version of the analog voltage output (V_{out} in the figure below) is available at one of the analog Monitor outputs (A7, $\overline{A7}$). The voltage V_{out} also drives a 10-LED bargraph on the Flow-rate module's front panel, so as to give direct visual feedback on the cooling water flow-rate during flow-rate adjustments. The bargraph is described below.



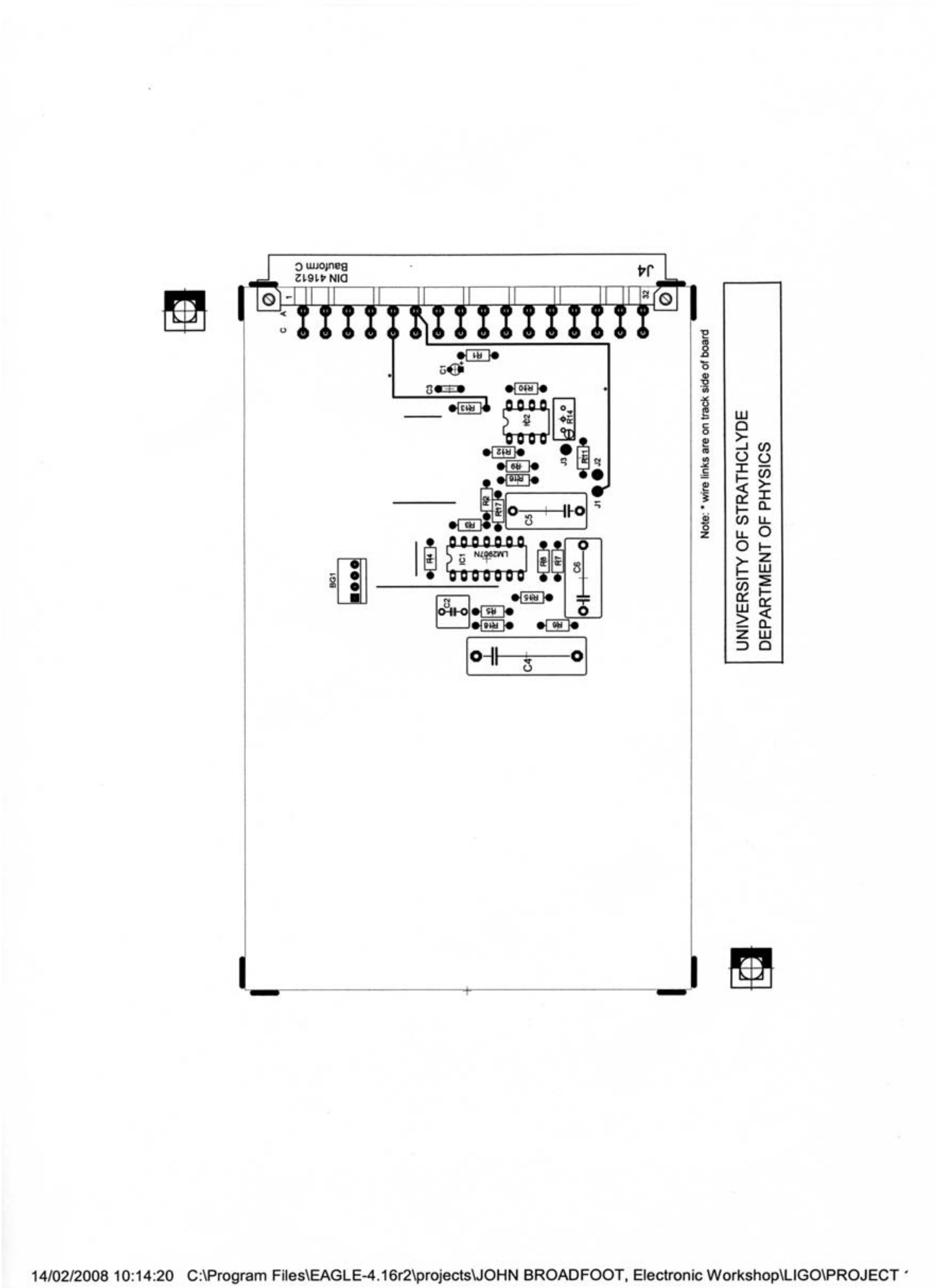
In addition, provided the voltage V_{out} remains greater than the trigger level set at the input to the LM311 comparator in the circuit above, the output of the comparator will remain high (close to +12 V). In this way, a high digital output signals that the cooling water flow-rate is adequate. The high comparator output level switches on an open-collector digital output on the Monitor module (pins 11 and 24), so that this normally sinks current. However, if V_{out} should fall approximately 1 volt below the set level, then this change will be signalled on the front panel of the Water flow-rate module by lighting the amber 'too low' LED, and the digital Monitor 'Flow-rate adequate' output will switch off. In addition, the E3007 will be caused to power-down and enter the 'idle' state.

In order to prevent the instrument switching off because of a few small air bubbles in the cooling-water line, the step-response of the flow-sensor has been modelled and adjusted so as to give a slightly sluggish single-pole-like response, with a time-constant of approximately 4 seconds. Both the model and actual responses due to step changes in input frequency are shown in the figure below.

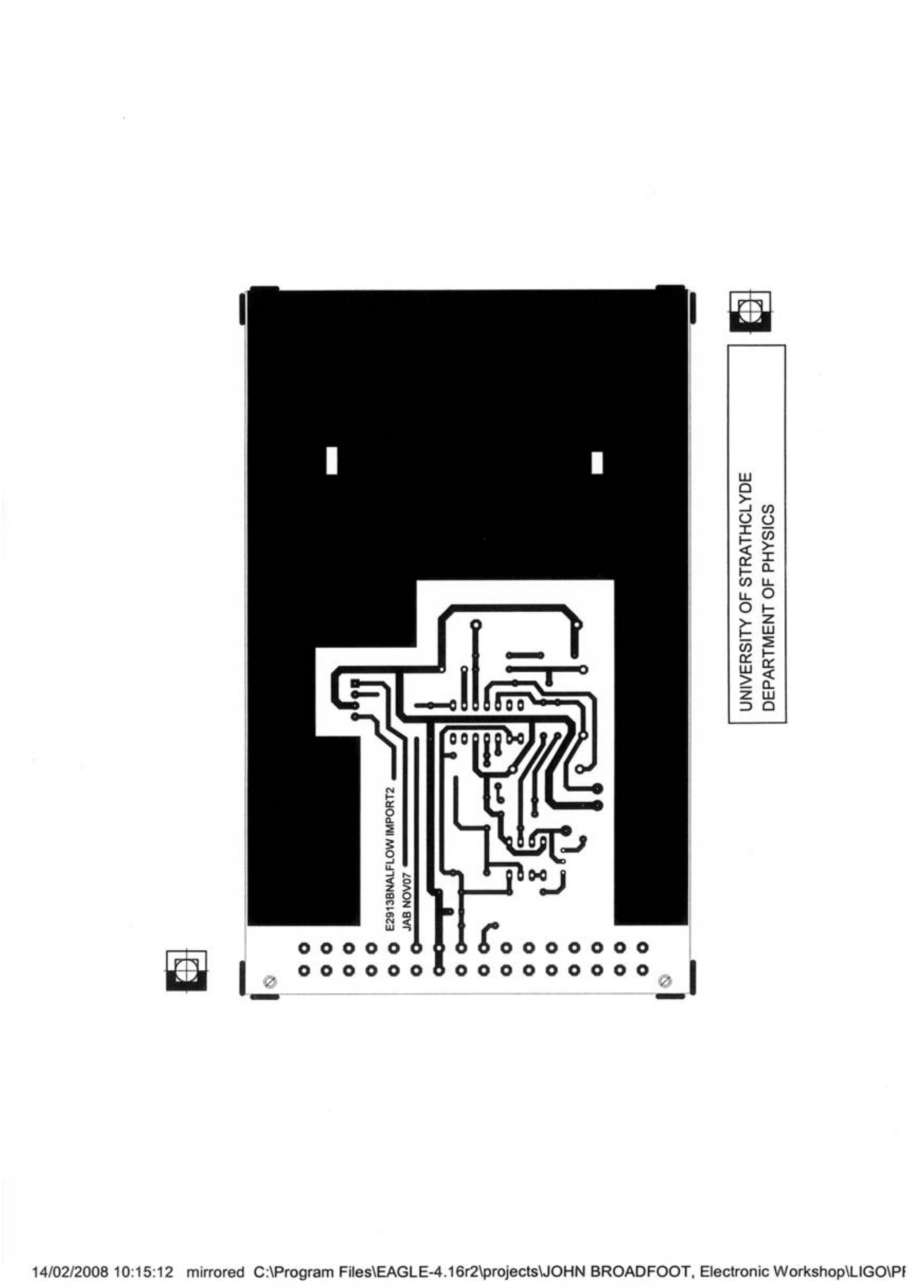




Water flow-rate sensor circuit—as constructed.



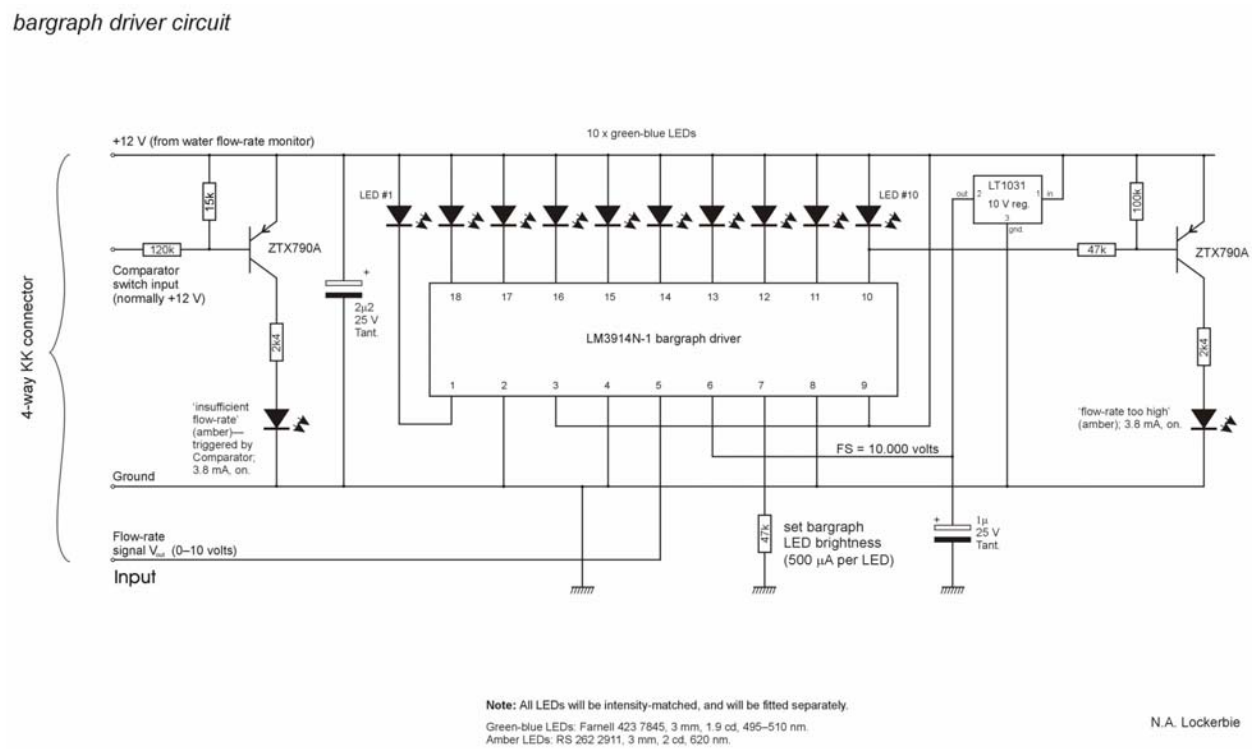
Water flow-rate sensor circuit—component overlay (topside) of PCB.

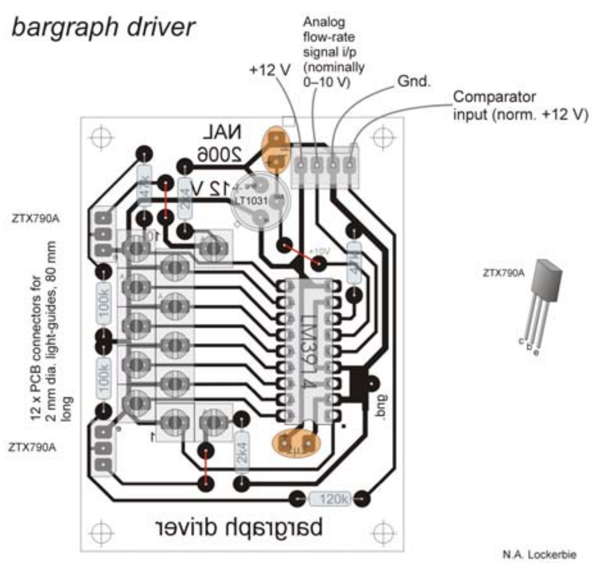


Water flow-rate sensor circuit—track (underside) of PCB.

The front-panel bargraph that is associated with the flow-rate sensor is powered by the E3007's +12 V supply, and employs a 10.000 V reference to set its full scale. Therefore, successive LED 'bars' light closely at voltages of V_{out} = 1.0 V, 2.0 V, ..., etc.

The 10 high-brightness/low-current green-blue bargraph LEDs each draw a current of only 500 μA, when lit. They are connected to the front panel of the Water Flow-rate module by 2 mm diameter, 80 mm long, flexible light-guides—as are the 'flow-rate too low' and 'flow-rate too high' amber LEDs. These latter LEDs each draw a current of 3.8 mA, when lit.

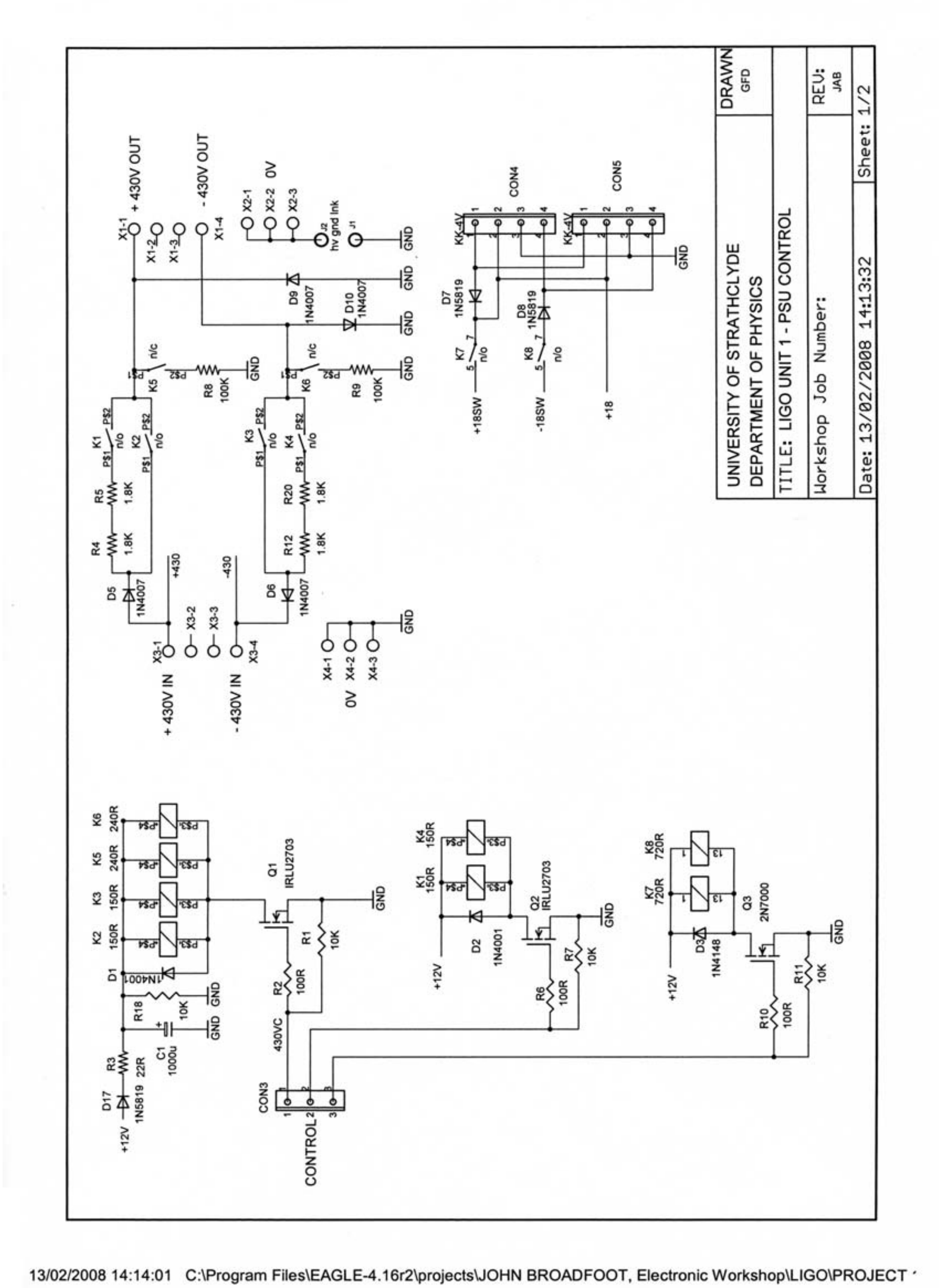




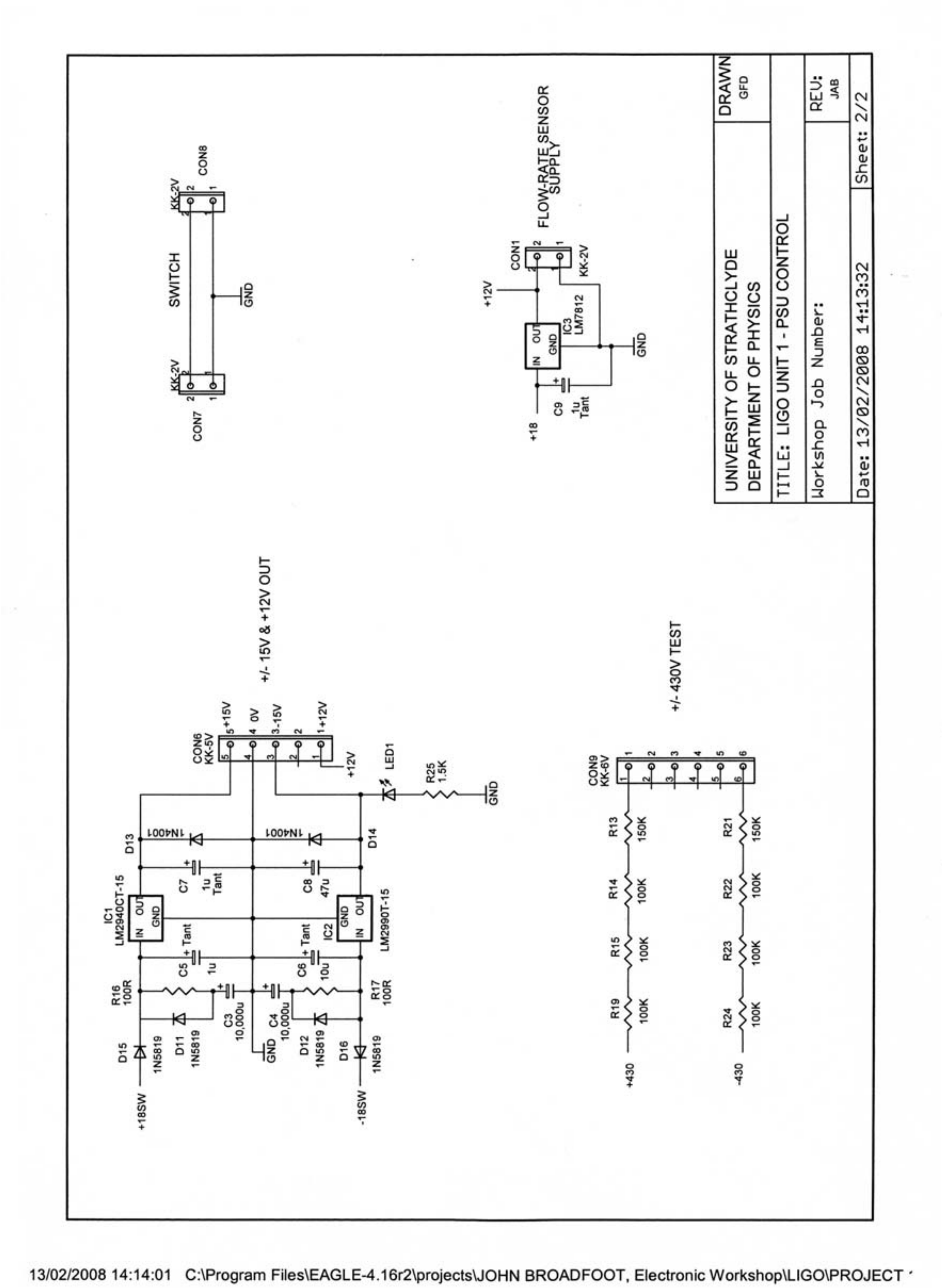
LED bargraph driver component overlay, also showing track (underside) PCB layout.

PSU Control

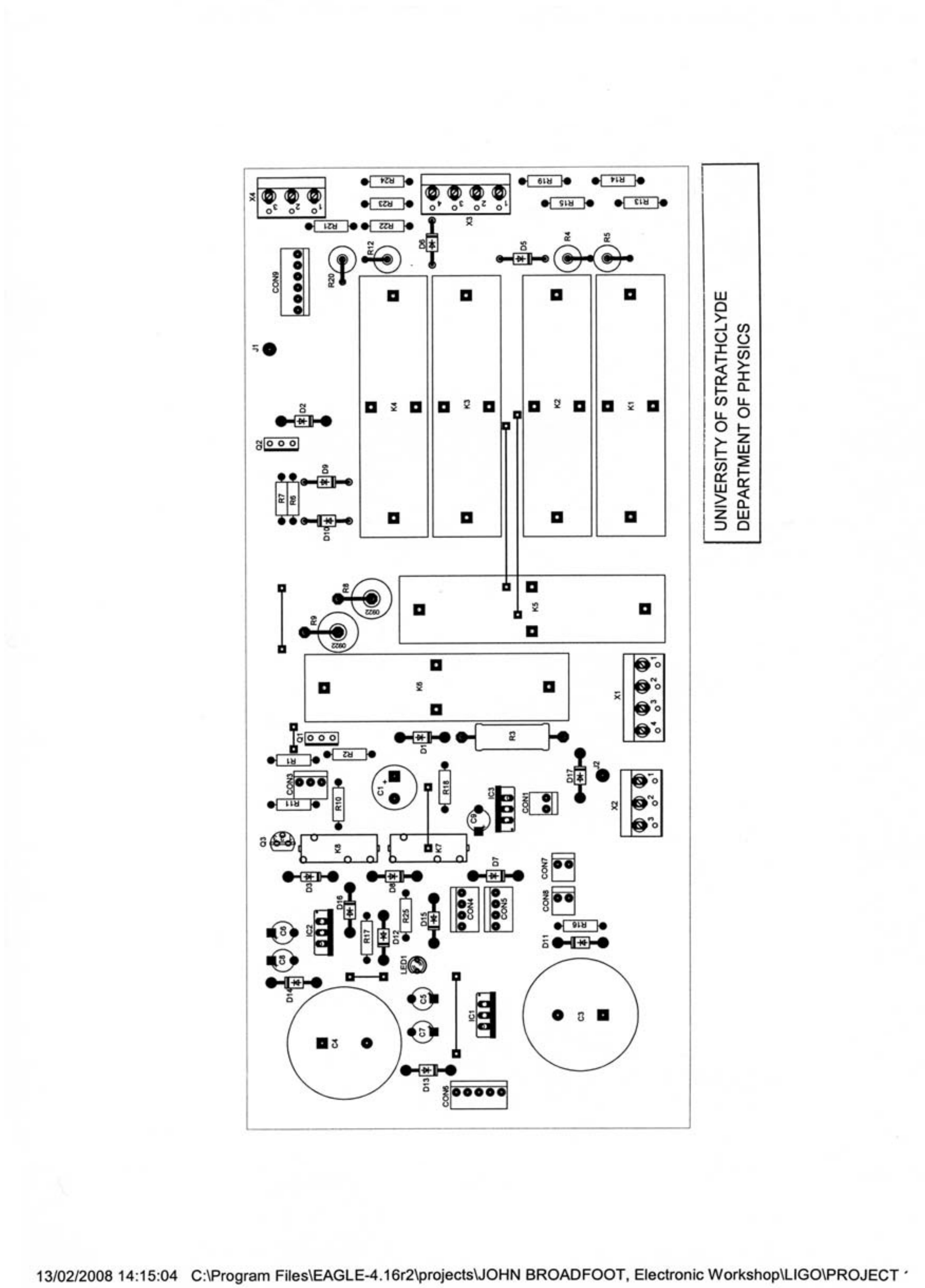
This unit provides regulated ±15 V and +12 V rails, and handles the ON/OFF switching (via relays) of the ±15 V and ±430 V power rails to the Channel preamplifiers and the HV output



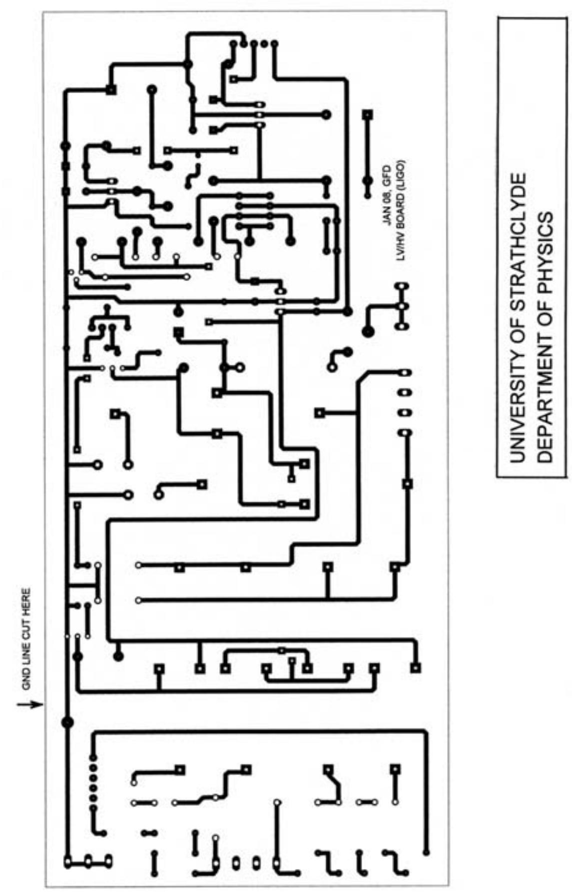
stages. The +5 V regulator is in the Sequencer module.



Note: the LDO voltage regulators shown in this Figure were found to be excessively noisy. They were replaced by conventional (non-LDO) low-noise types (µA7815C and MC7915CT).



PSU control board component overlay.



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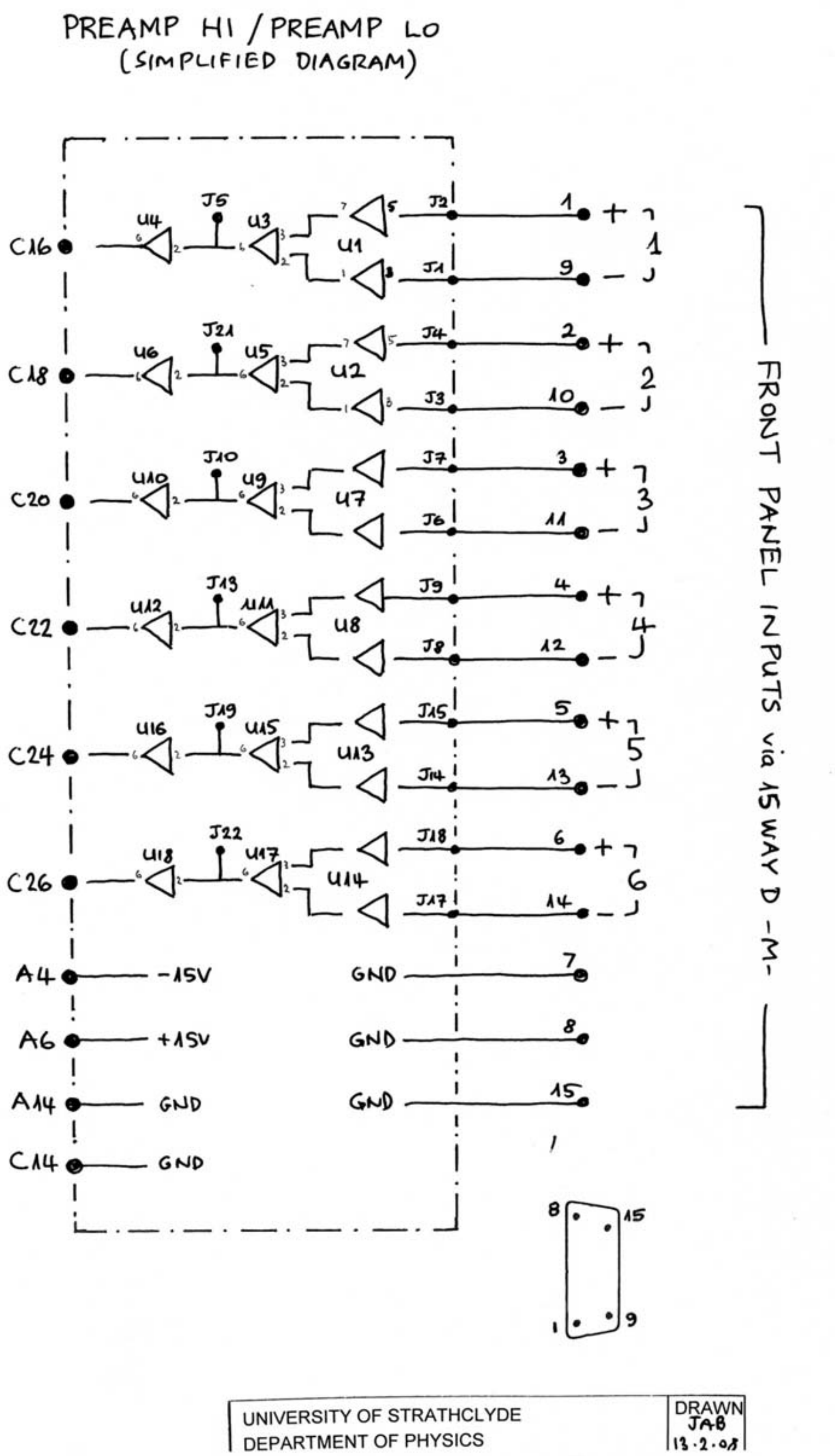
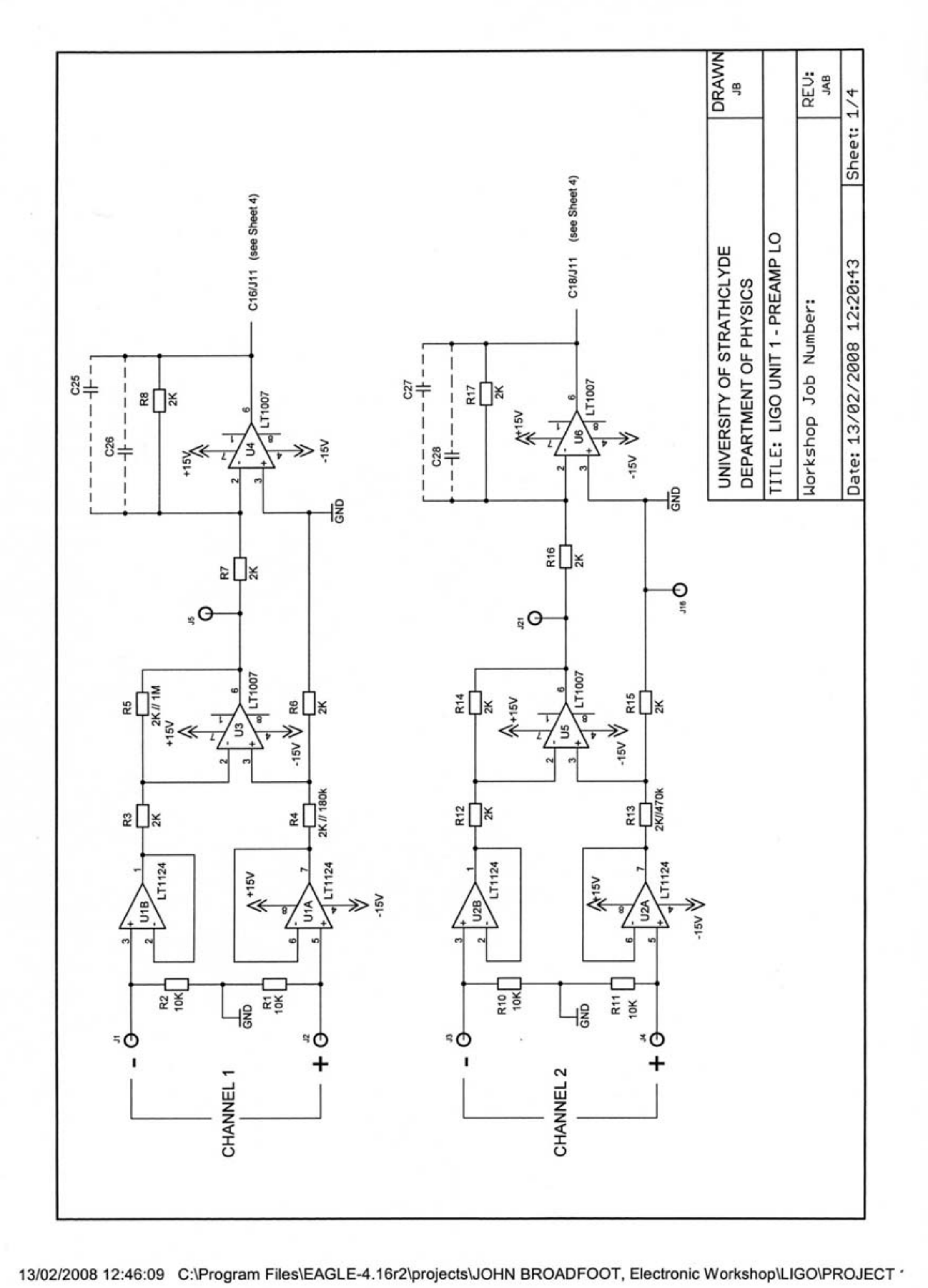
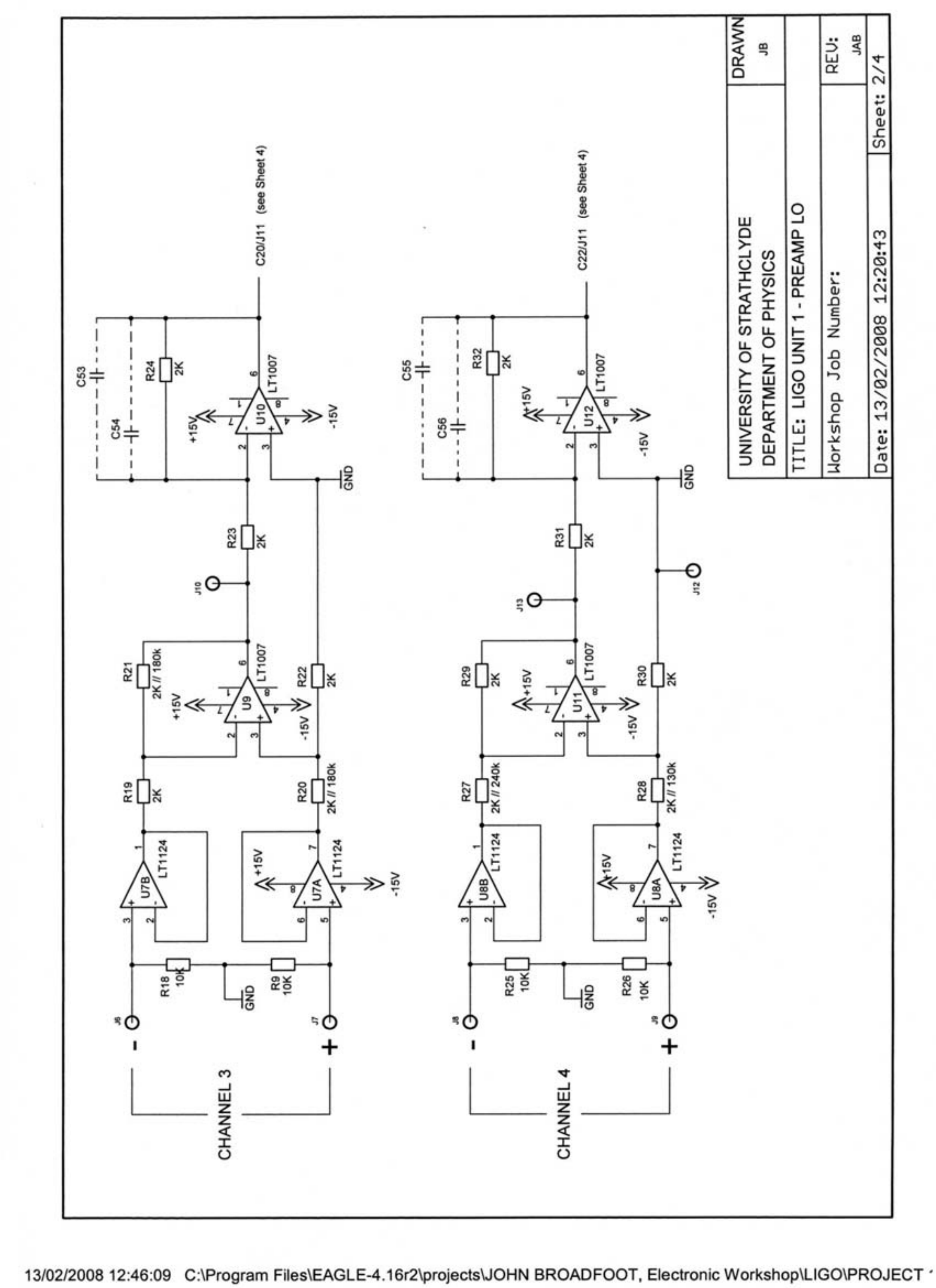
Preamplifier modules

The ‘Hi and ‘Lo’ preamplifier modules are nominally identical.

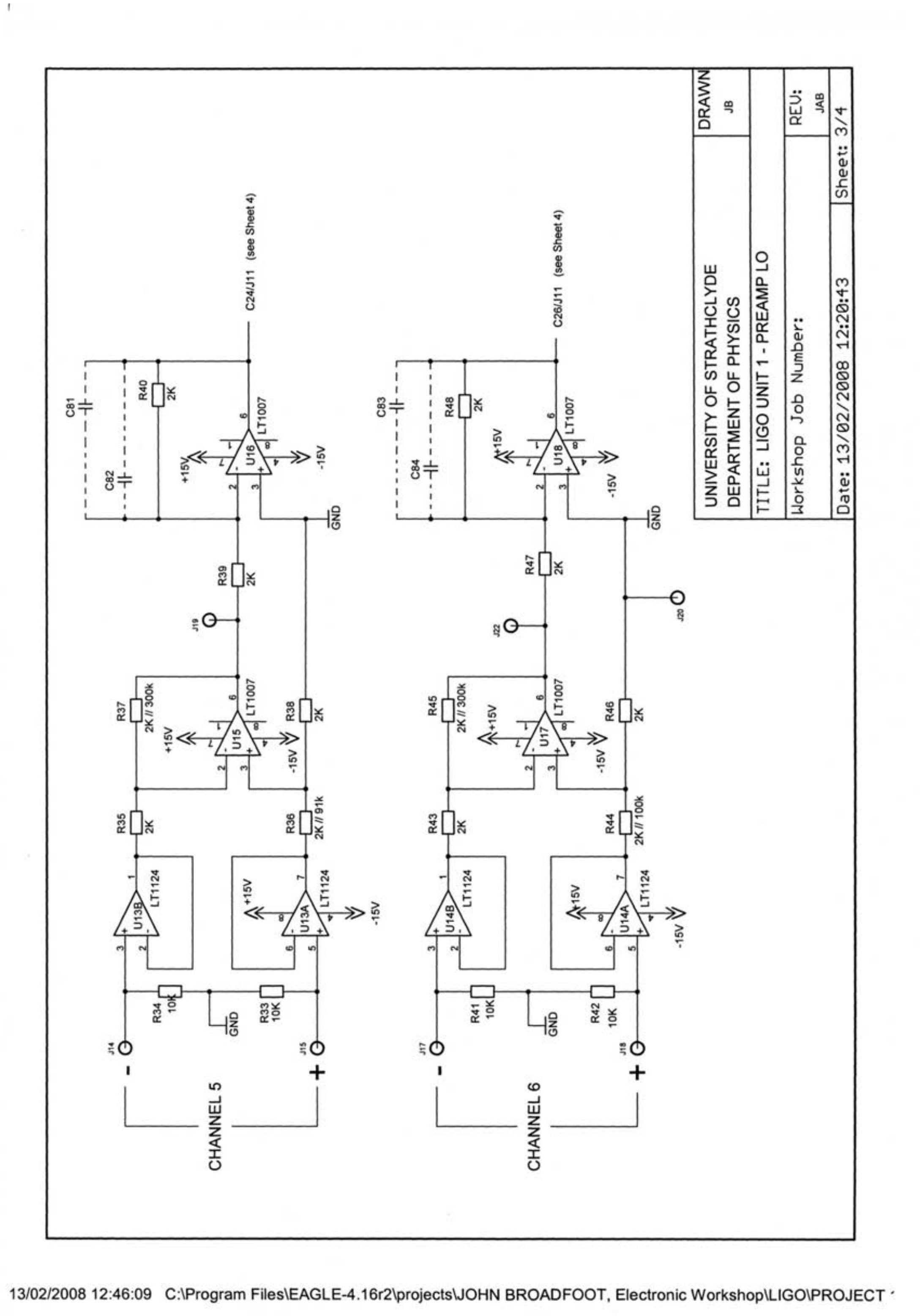




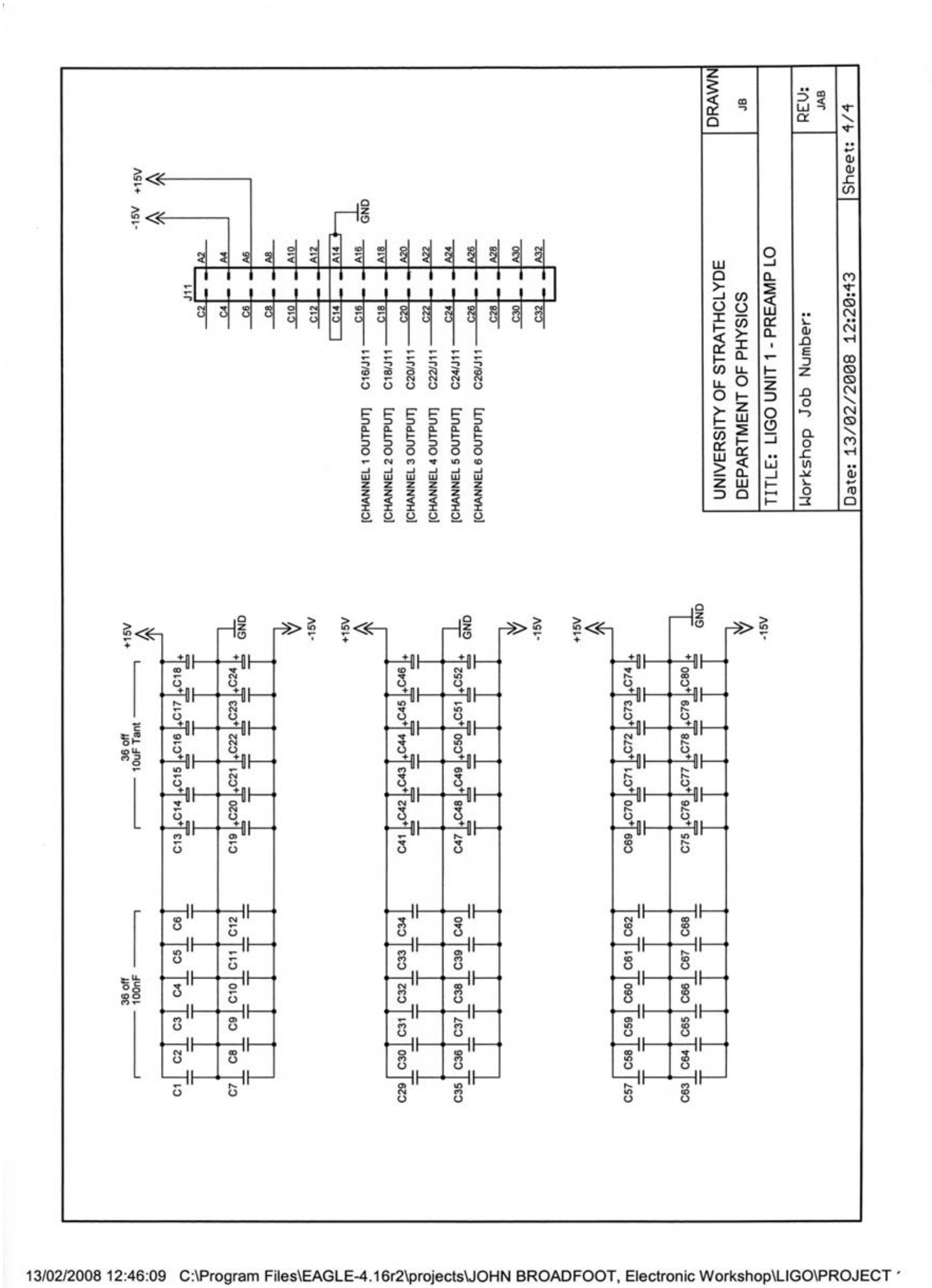
Circuit diagram of Lo preamp, Channels 1 and 2. The capacitors shown dashed could be added for (possible, future) bandwidth limiting.



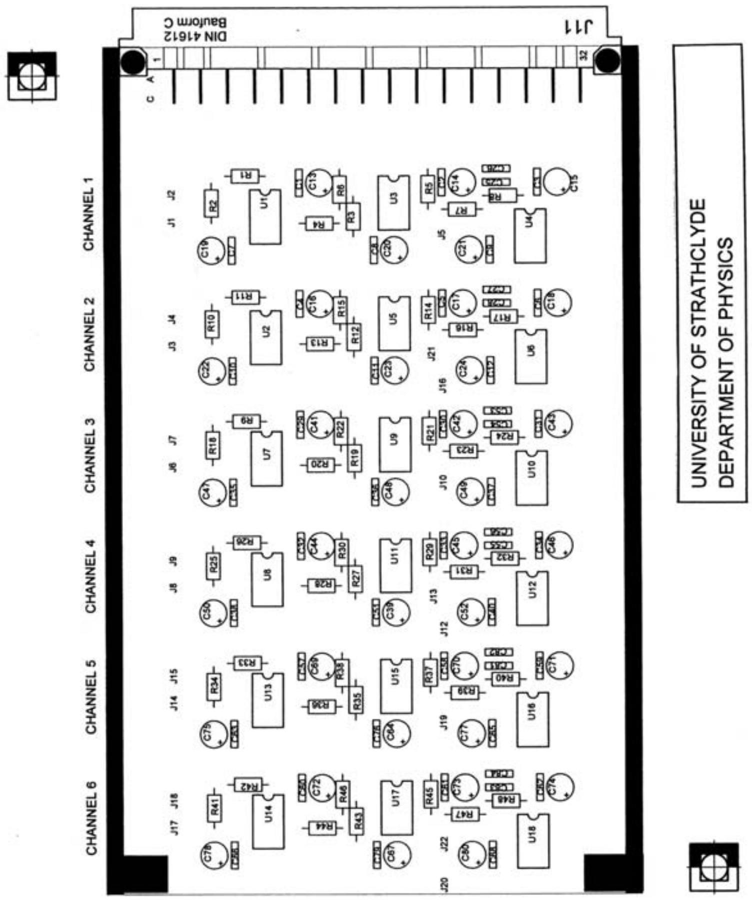
Circuit diagram of Lo preamp, Channels 3 and 4. The capacitors shown dashed could be added for (possible, future) bandwidth limiting.



Circuit diagram of Lo preamp, Channels 5 and 6. The capacitors shown dashed could be added for (possible, future) bandwidth limiting.



Circuit diagram of Lo preamp's capacitive decoupling.



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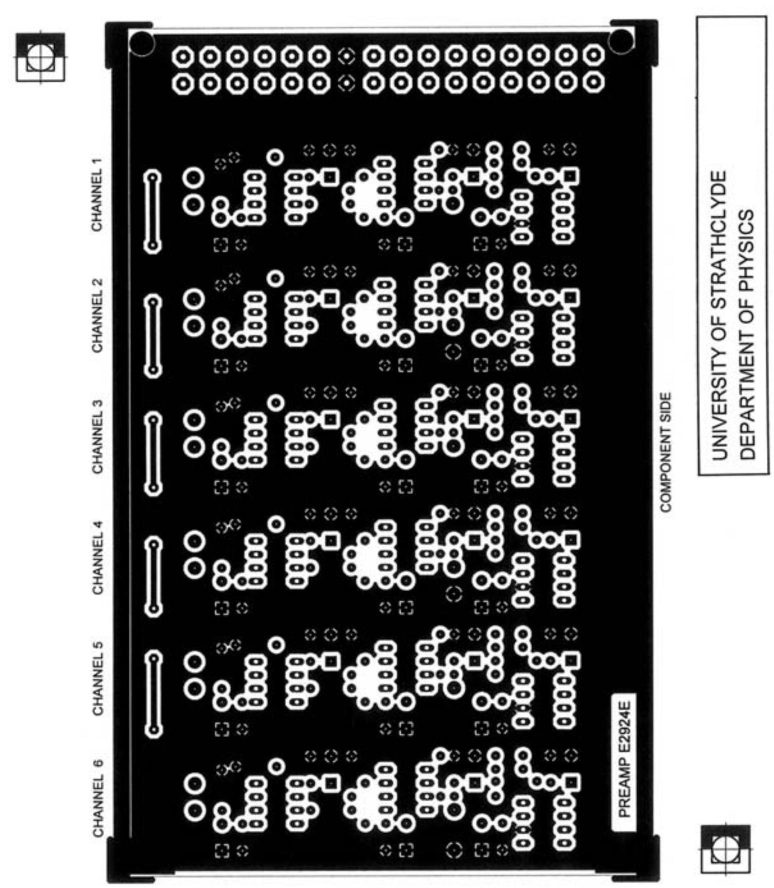
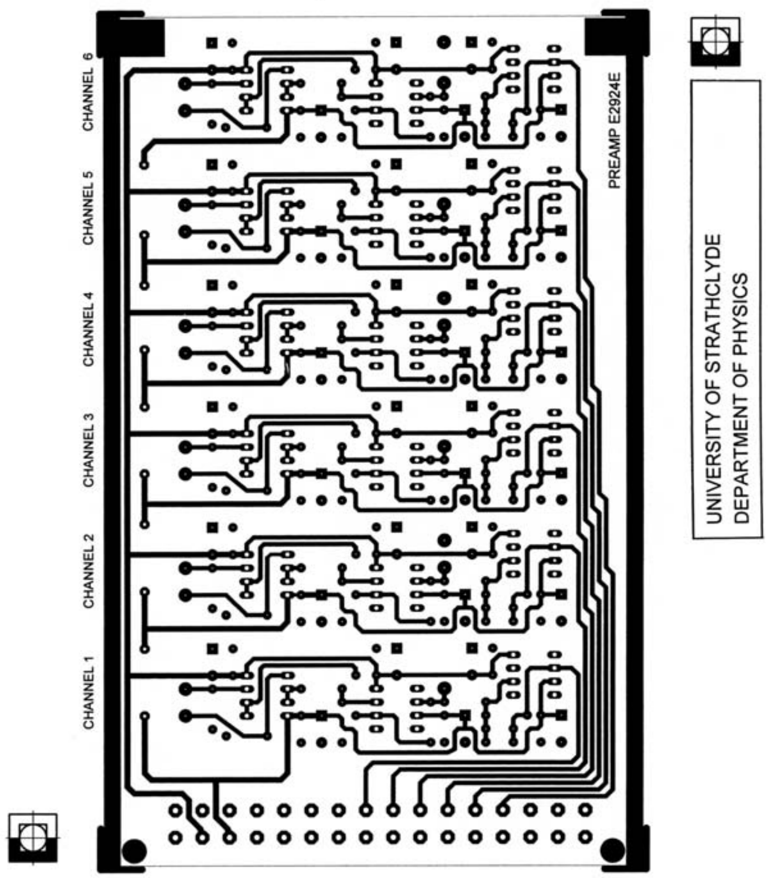
Common circuit component overlay pattern for both Lo and Hi preamps.



Circuit topside (ground-plane) pattern for both Lo and Hi preamp PCBs.



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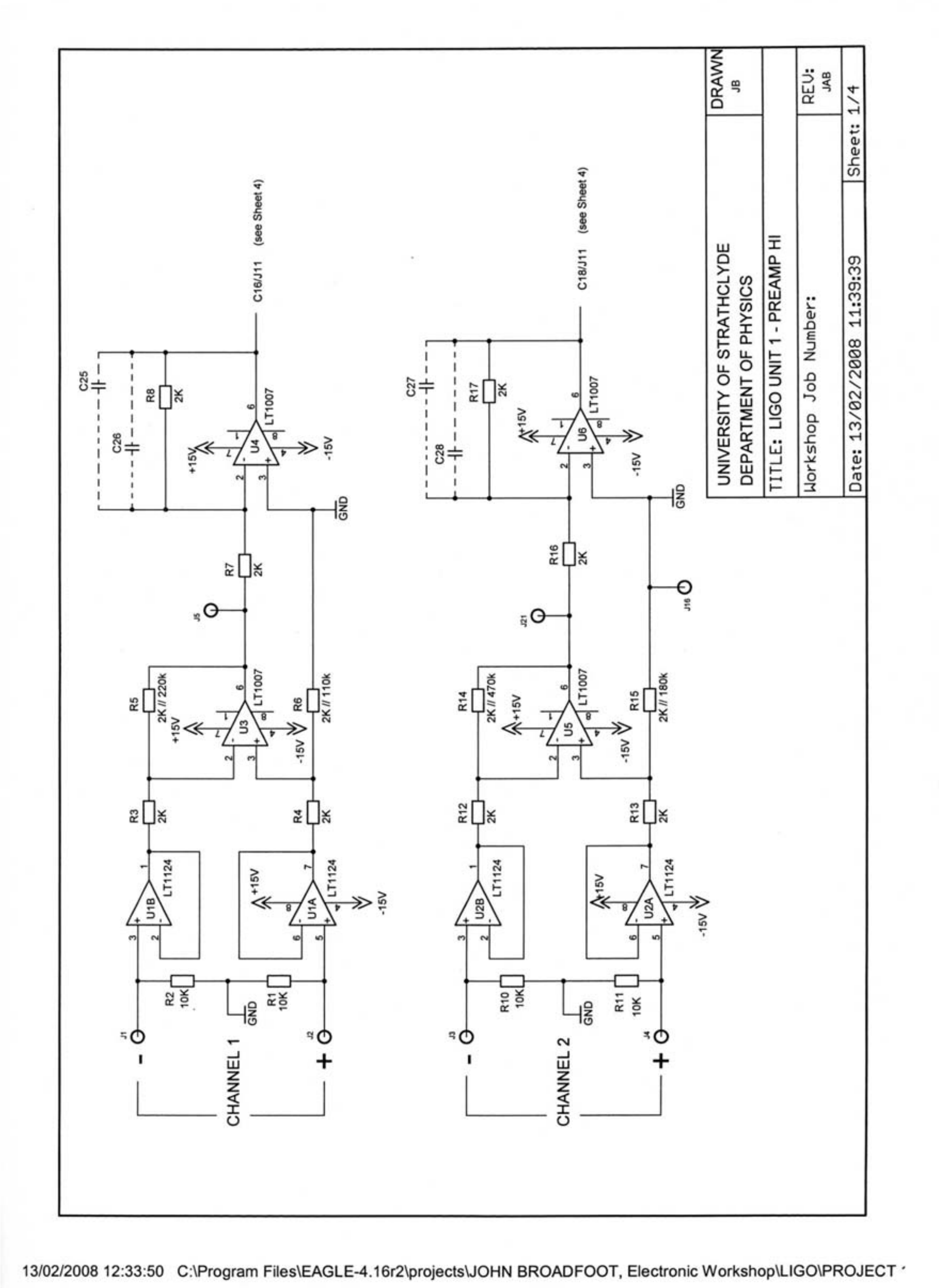
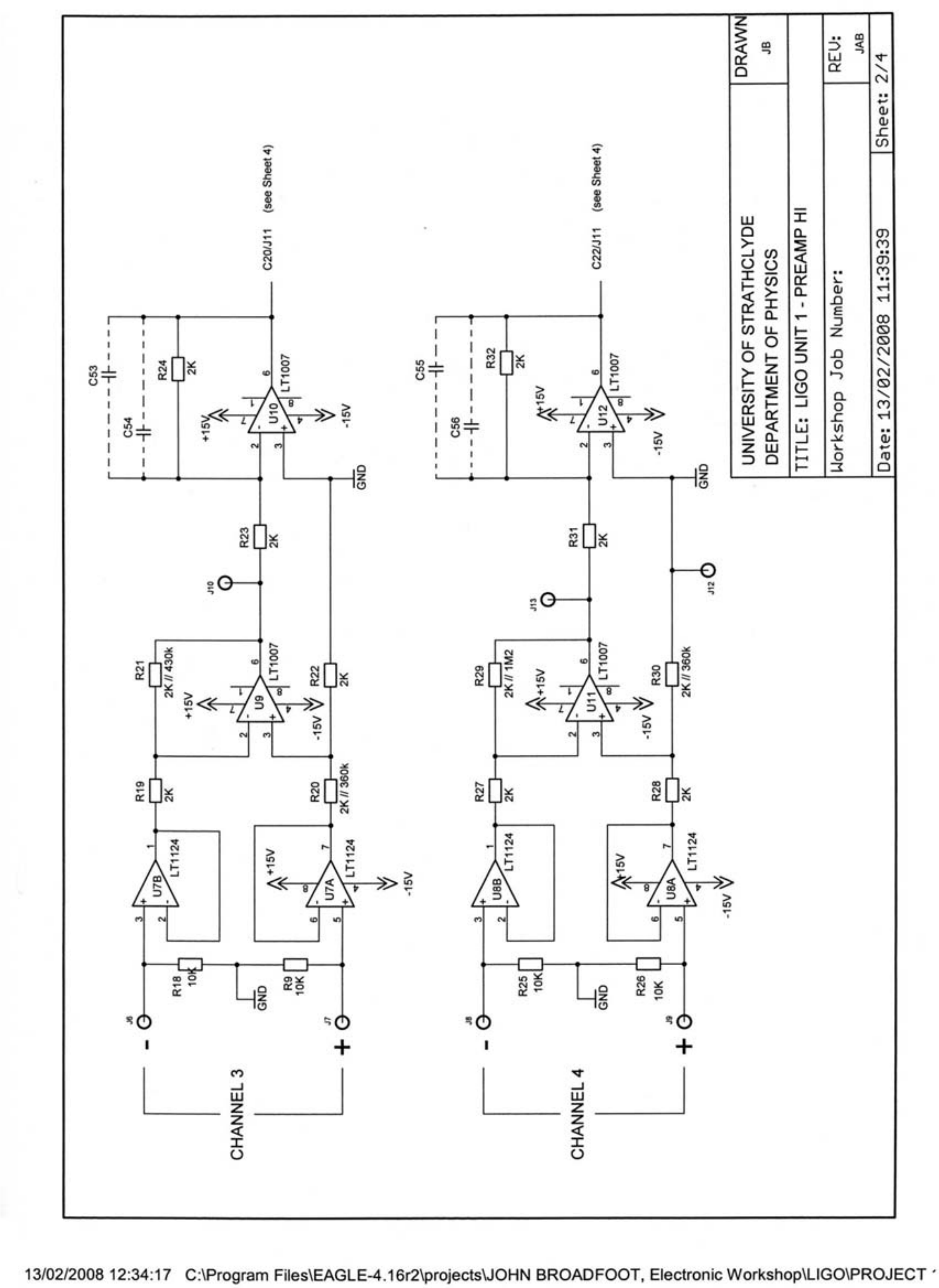
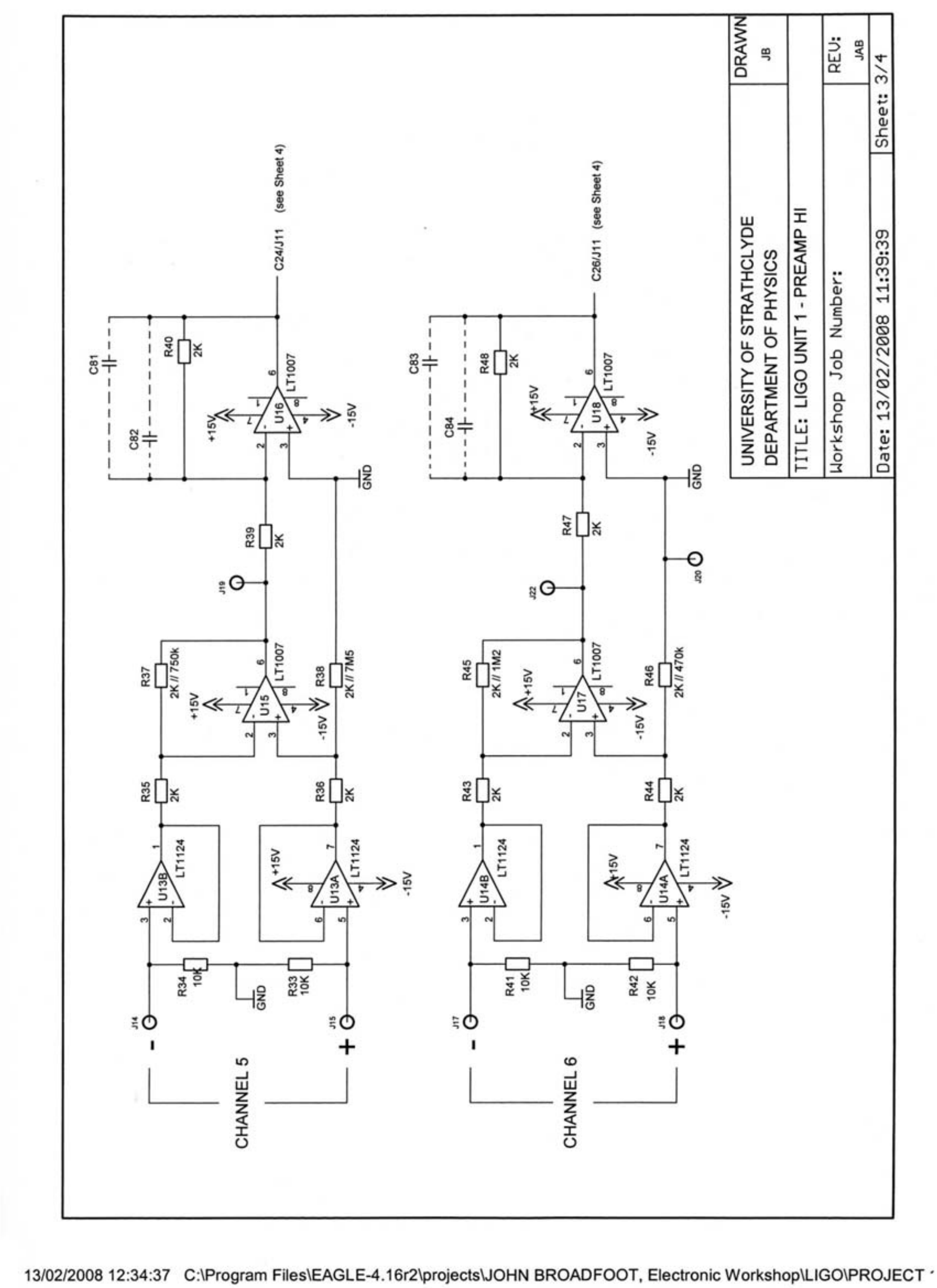
Circuit track (underside) pattern for both Lo and Hi preamp PCBs.



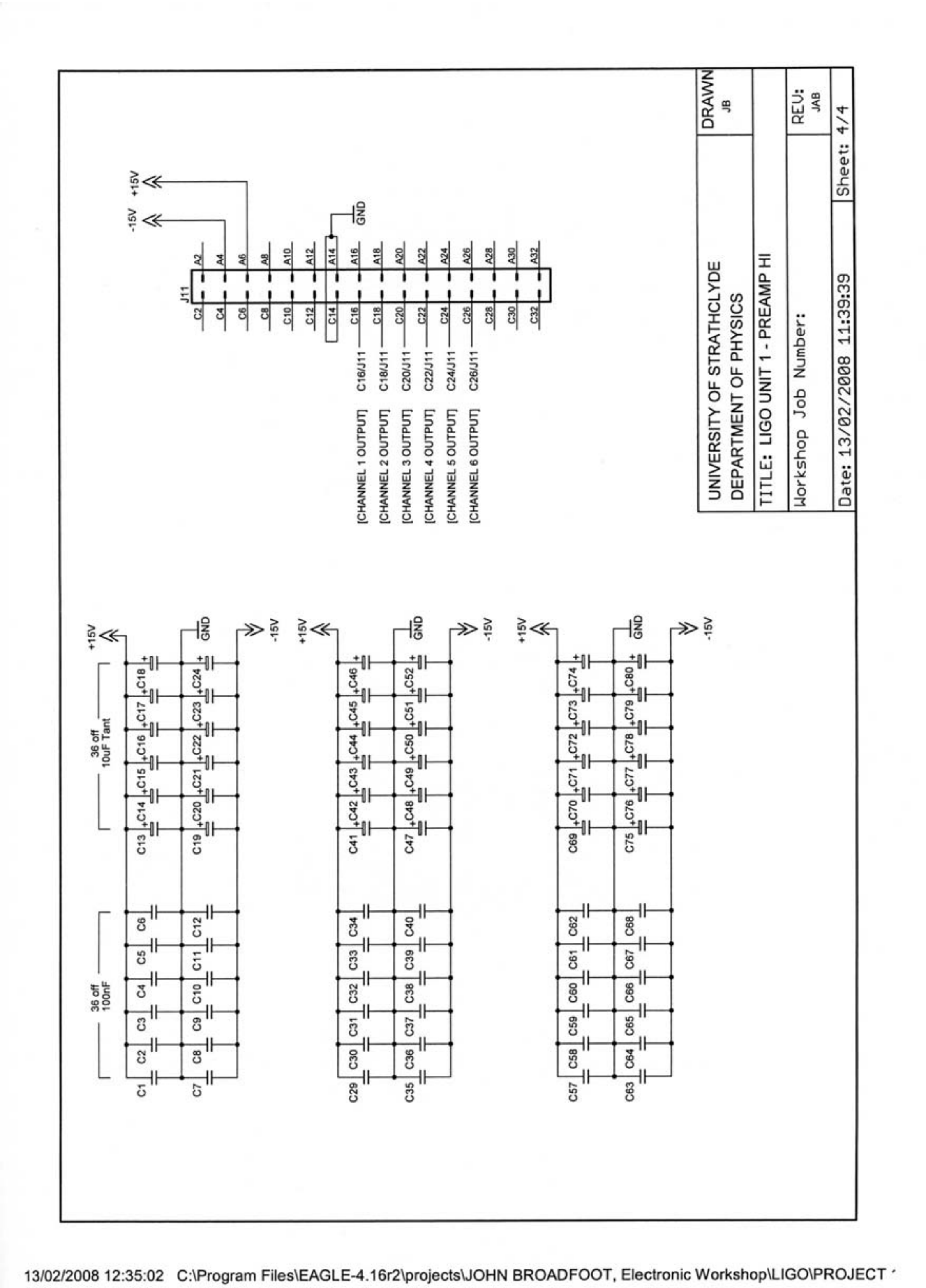
Circuit diagram of Hi preamp, Channels 1 and 2. The capacitors shown dashed could be added for (possible, future) bandwidth limiting.



Circuit diagram of Hi preamp, Channels 3 and 4. The capacitors shown dashed could be added for (possible, future) bandwidth limiting.

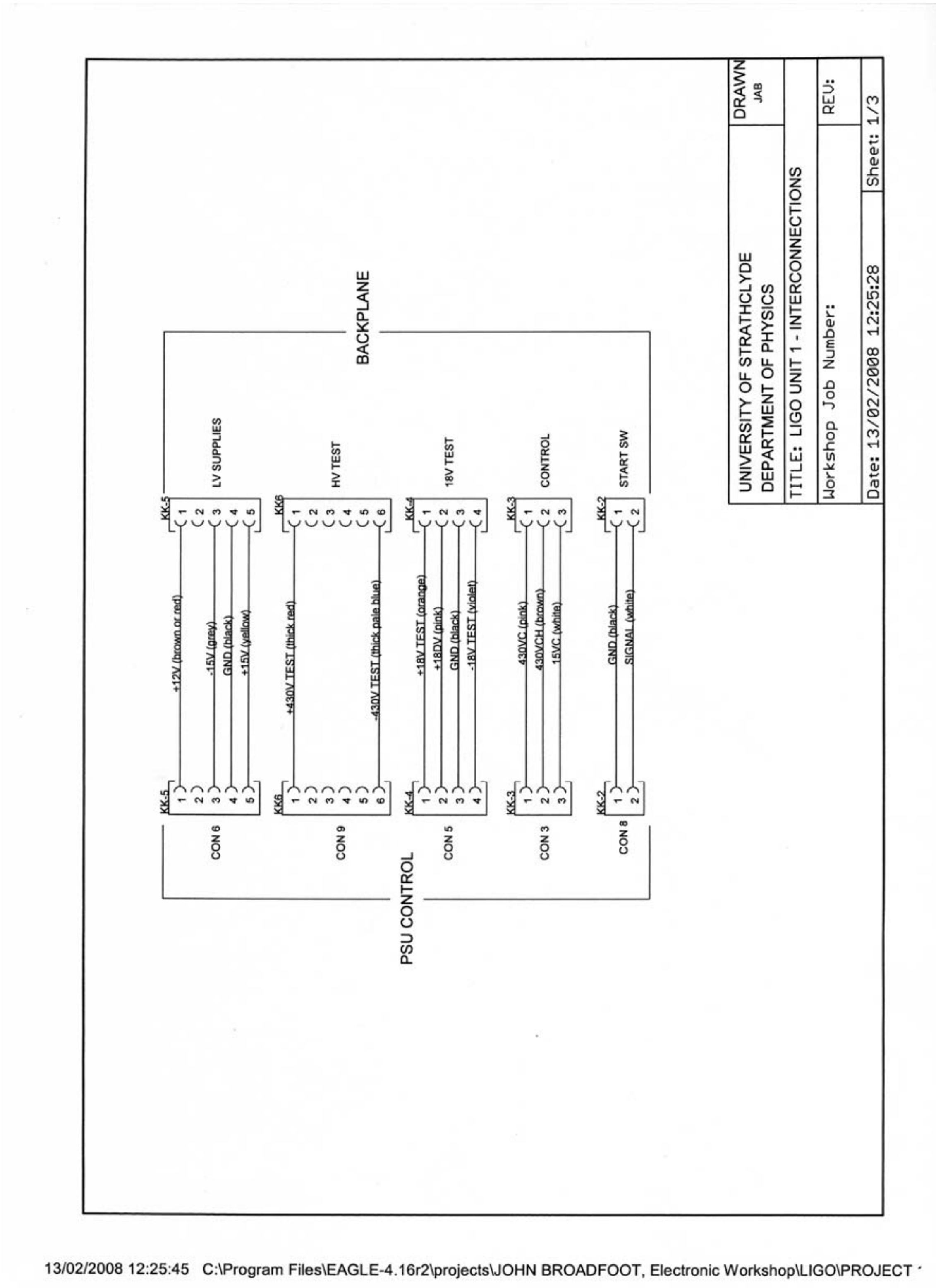


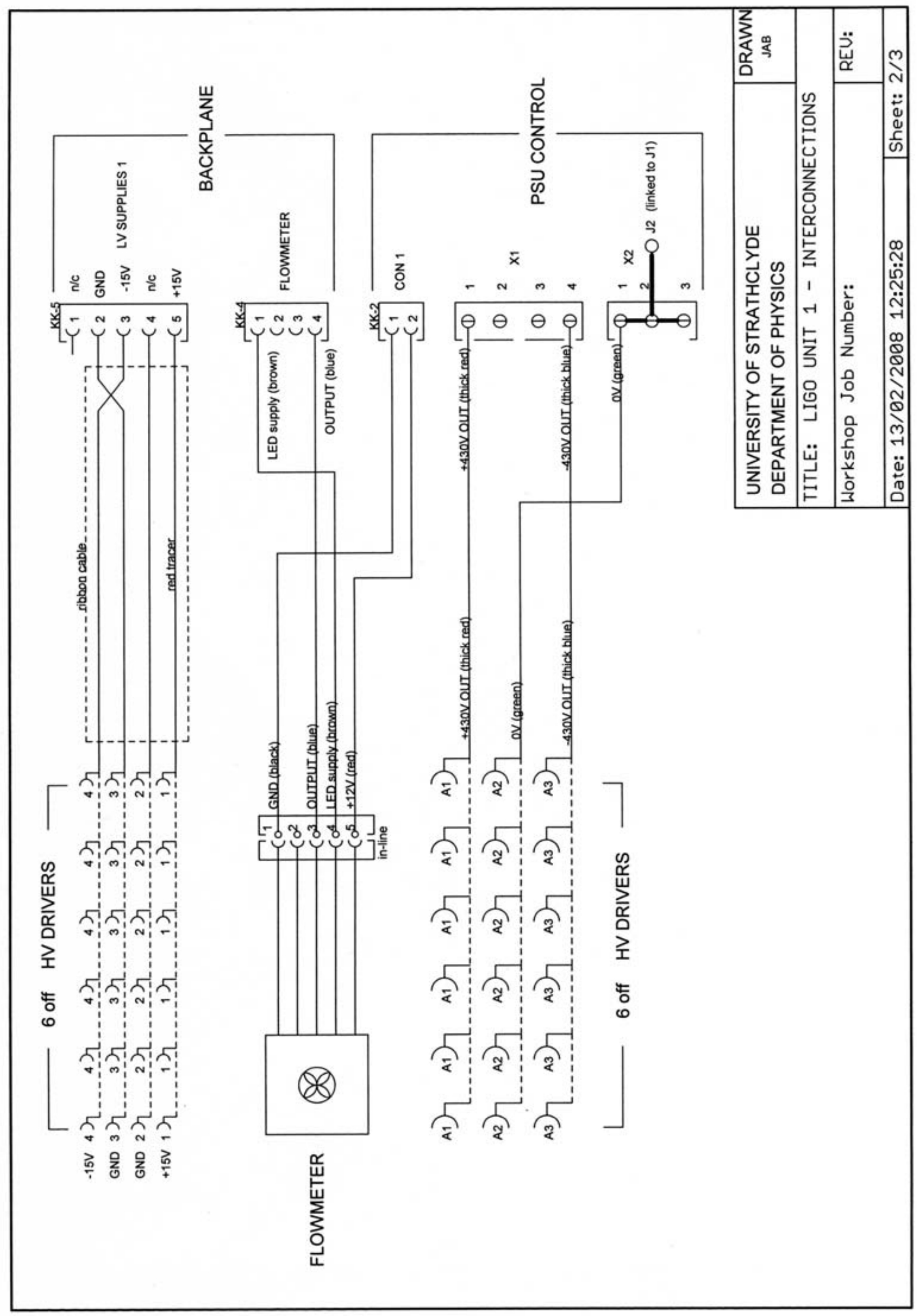
Circuit diagram of Hi preamp, Channels 5 and 6. The capacitors shown dashed could be added for (possible, future) bandwidth limiting.



Circuit diagram of Hi preamp's capacitive decoupling.

Overview of interconnections





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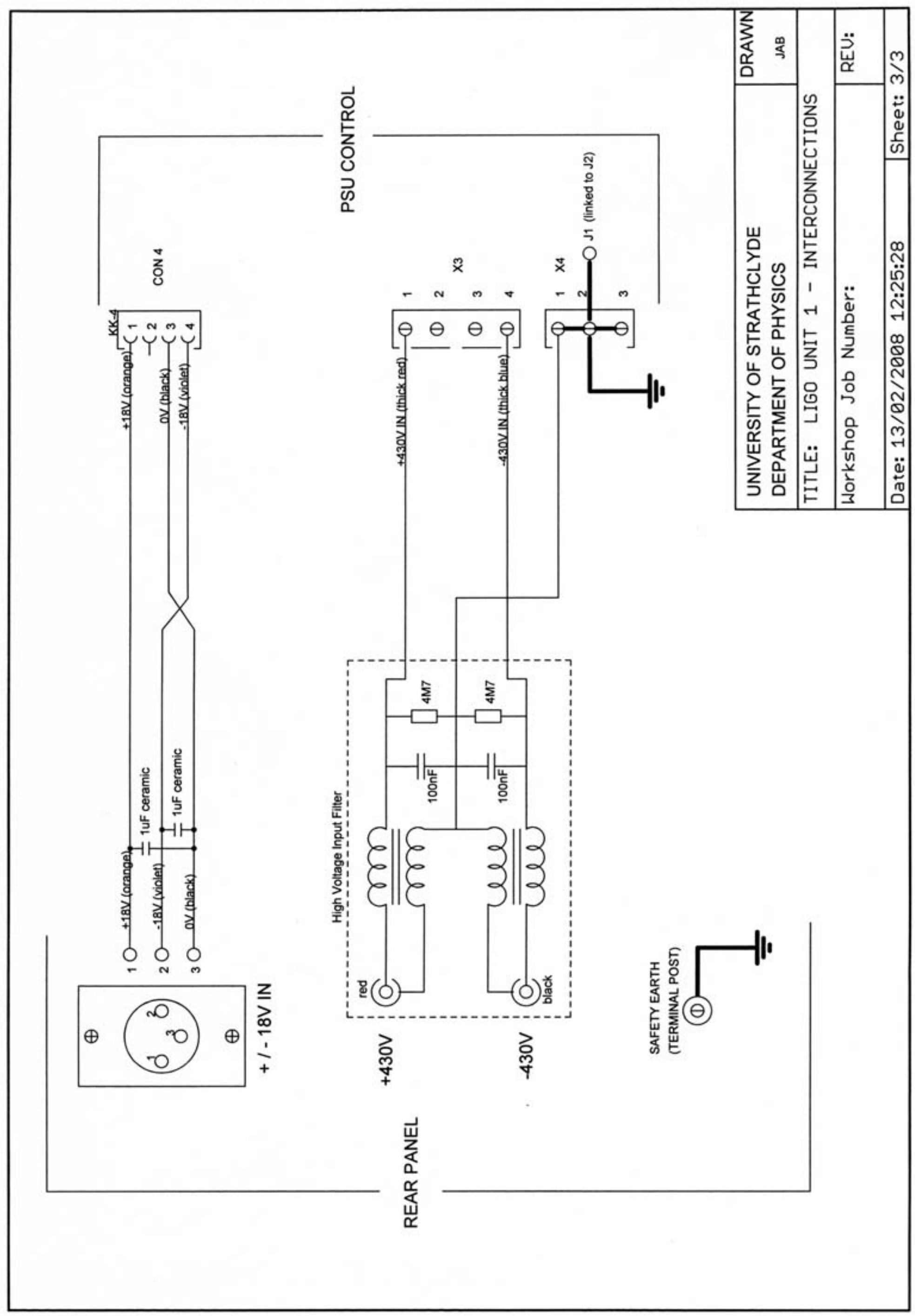

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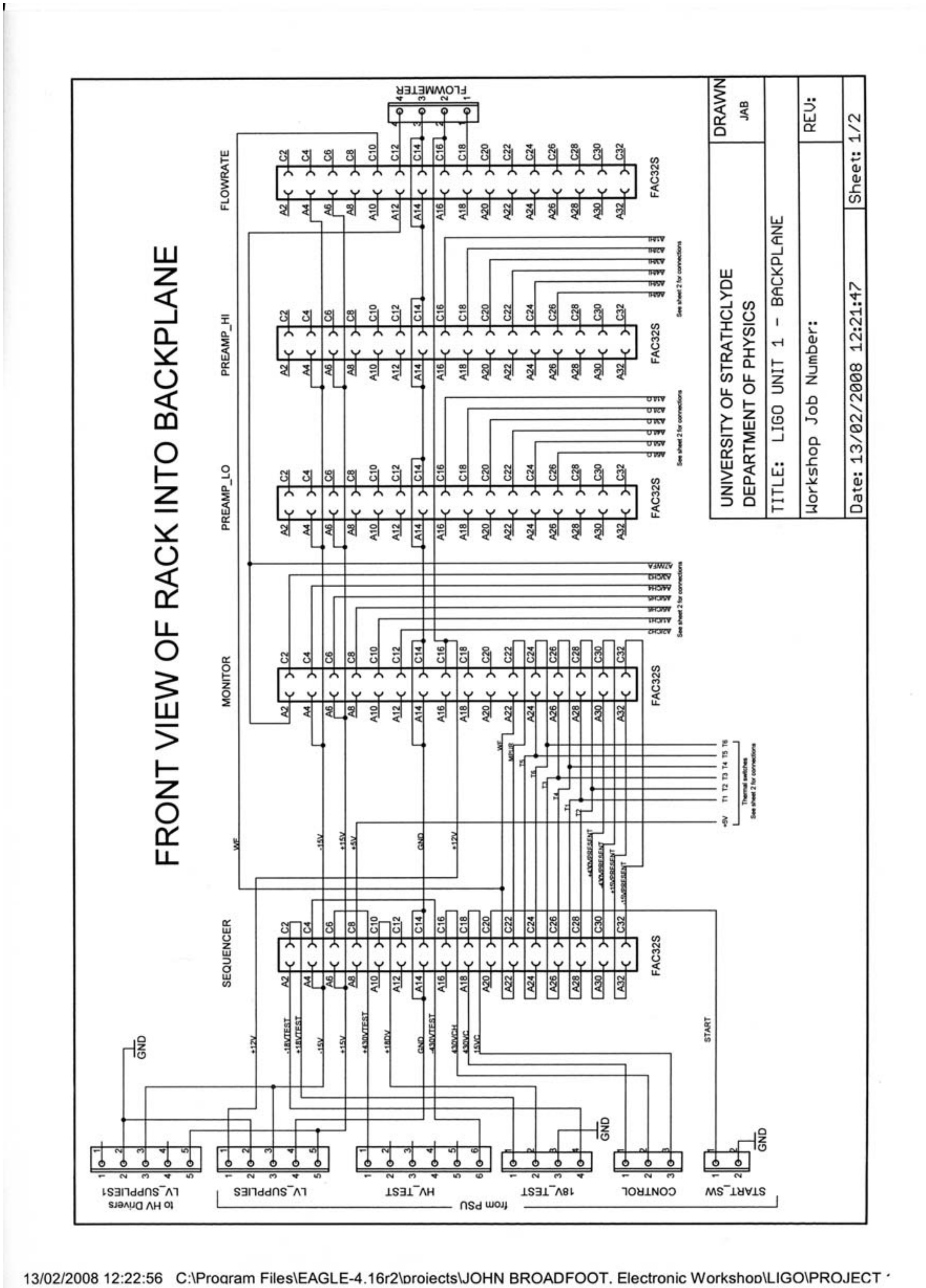
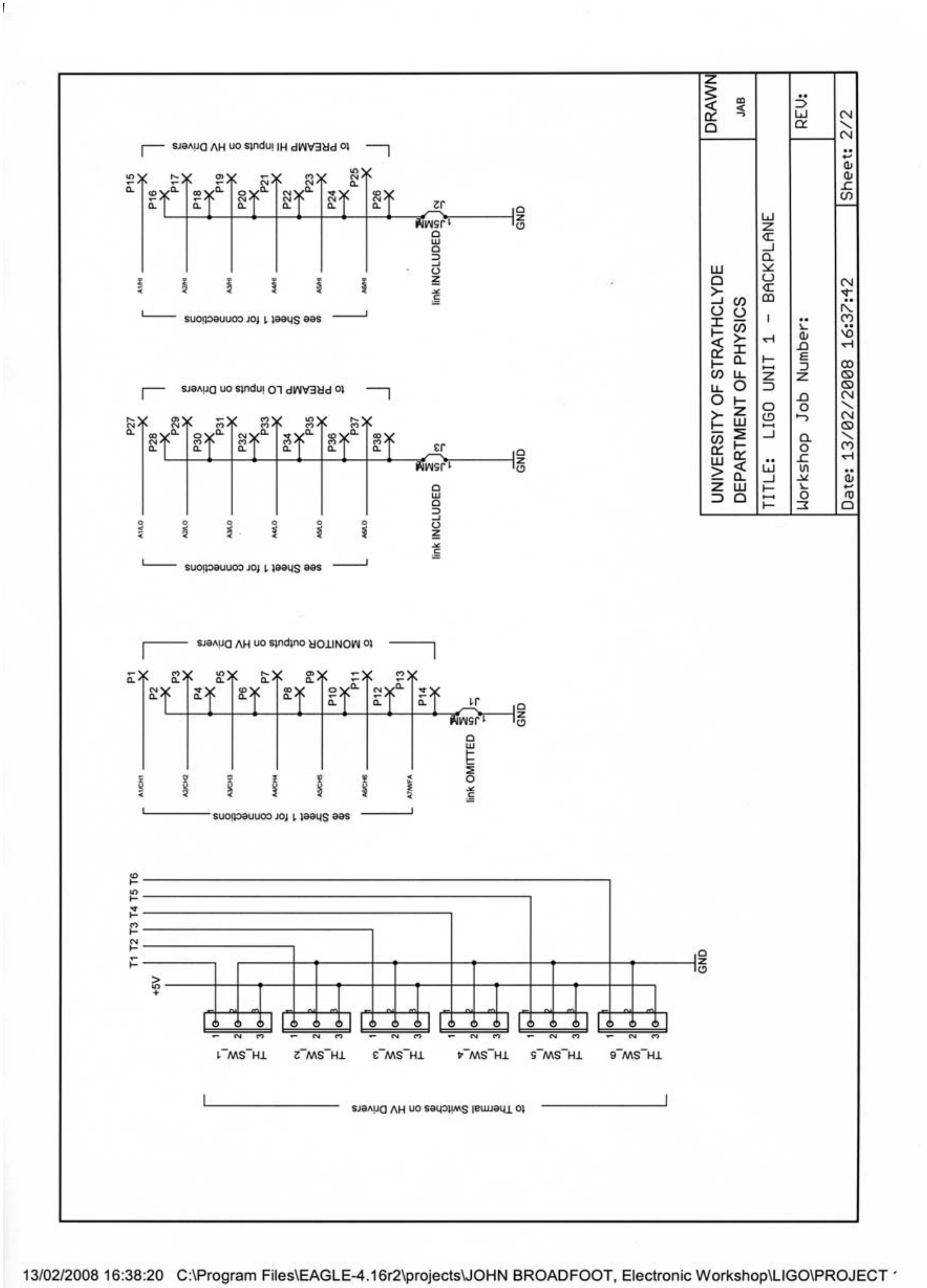
Rear panel power-supply connections.

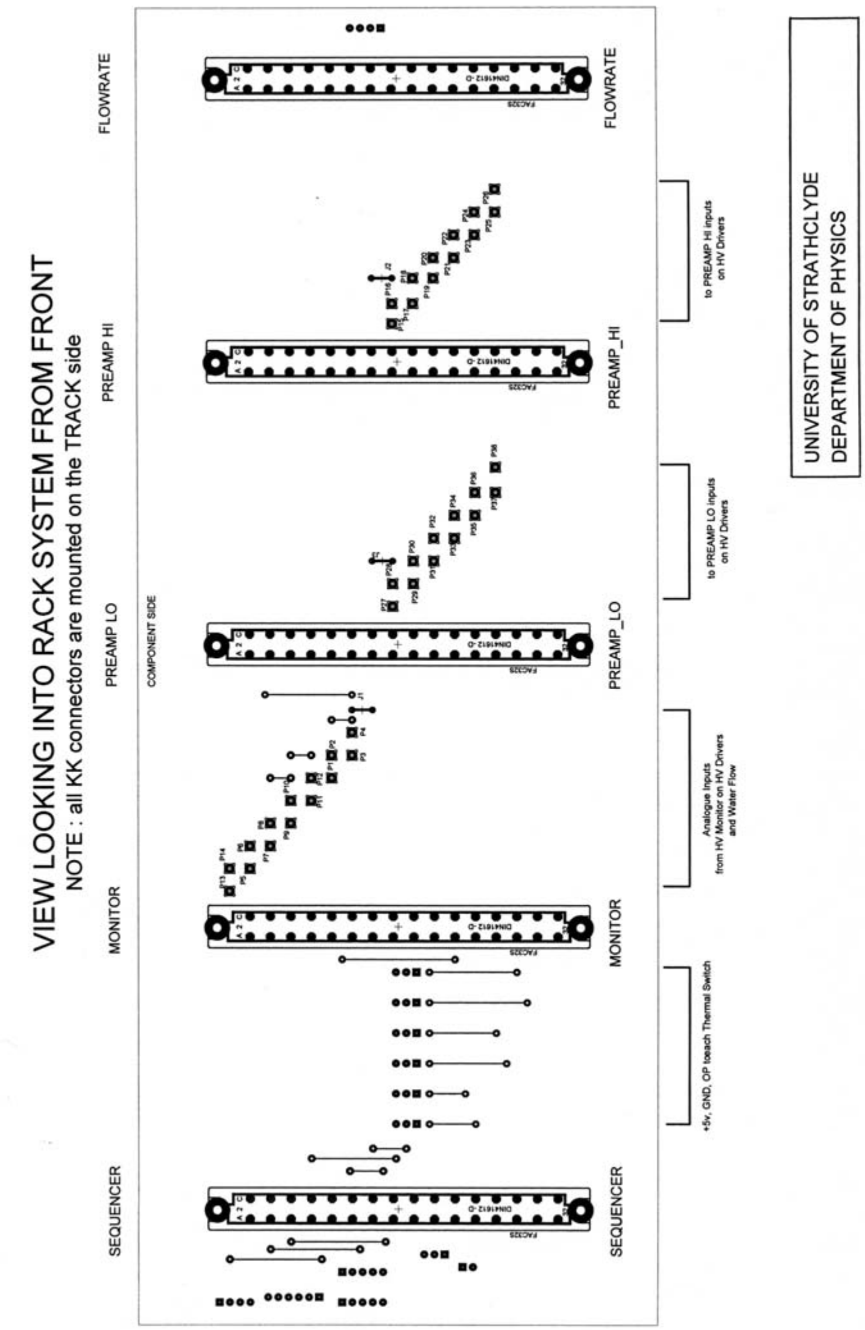
Backplane



Backplane interconnections circuit diagram.



UNIVERSITY OF STRATHCLYDE
DEPARTMENT OF PHYSICS
DRAWN
JAB
TITLE: LIGO UNIT 1 - BACKPLANE
Workshop Job Number:
REV:
Date: 13/02/2008 16:37:42
Sheet: 2/2
to PREAMP HI inputs on HV Drivers
to PREAMP LO inputs on HV Drivers
to MONITOR outputs on HV Drivers
see Sheet 1 for connections
link INCLUDED
link OMITTED
GND
+5V
T1 T2 T3 T4 T5 T6
TH_SW_1
TH_SW_2
TH_SW_3
TH_SW_4
TH_SW_5
TH_SW_6
to Thermal Switches on HV Drivers
13/02/2008 16:38:20 C:\Program Files\EAGLE-4.16r2\projects\JOHN BROADFOOT, Electronic Workshop\LIGO\PROJECT



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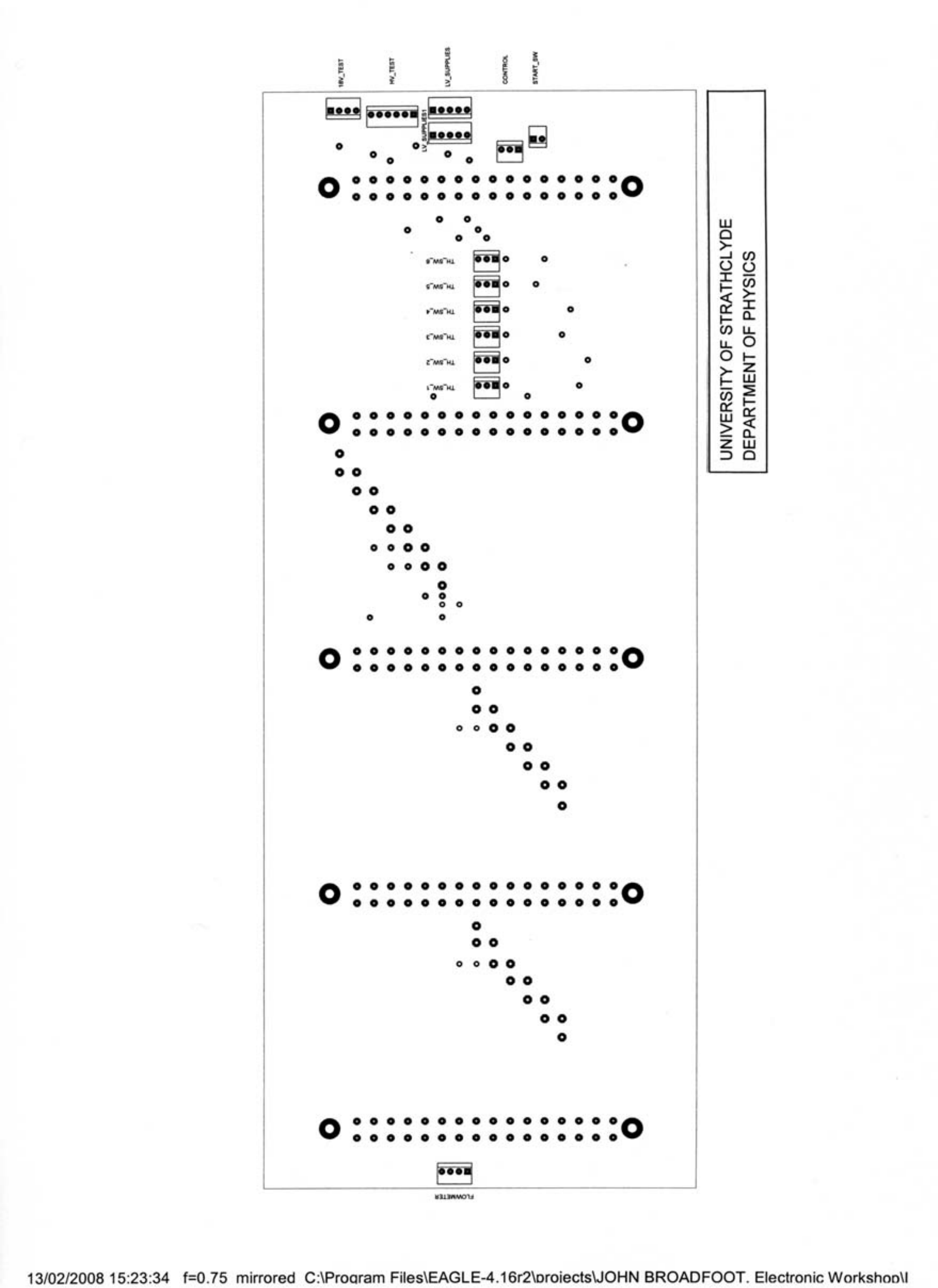
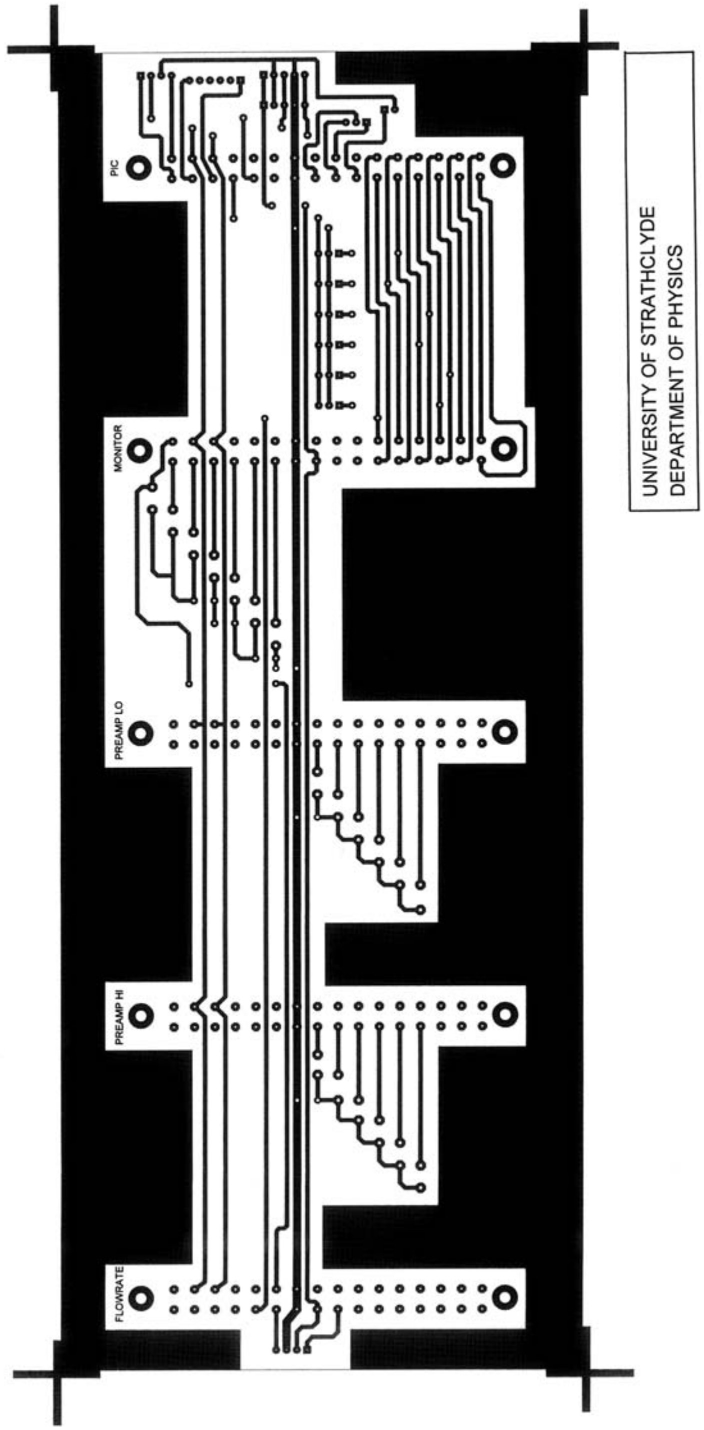


Backplane rear connectors.



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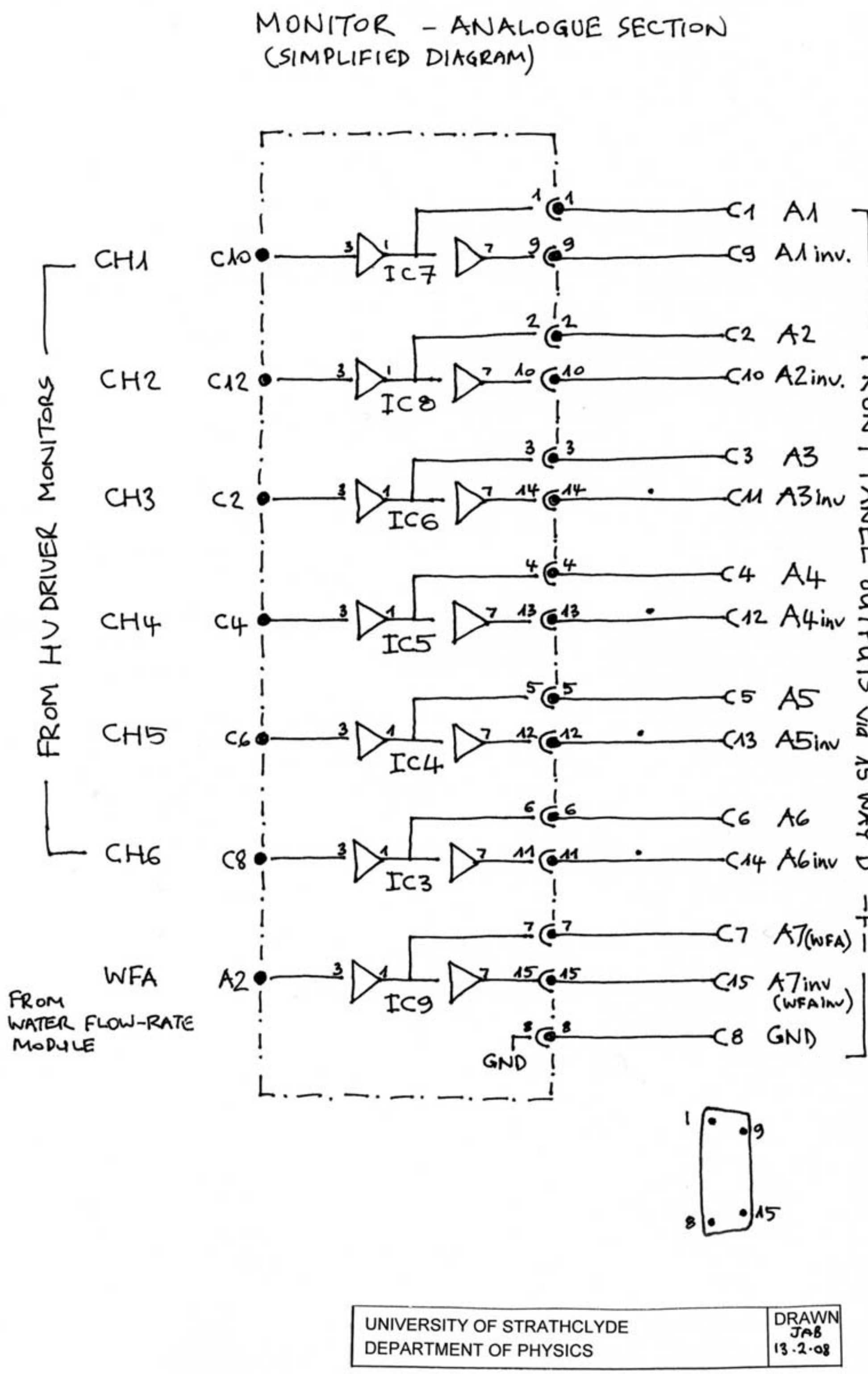
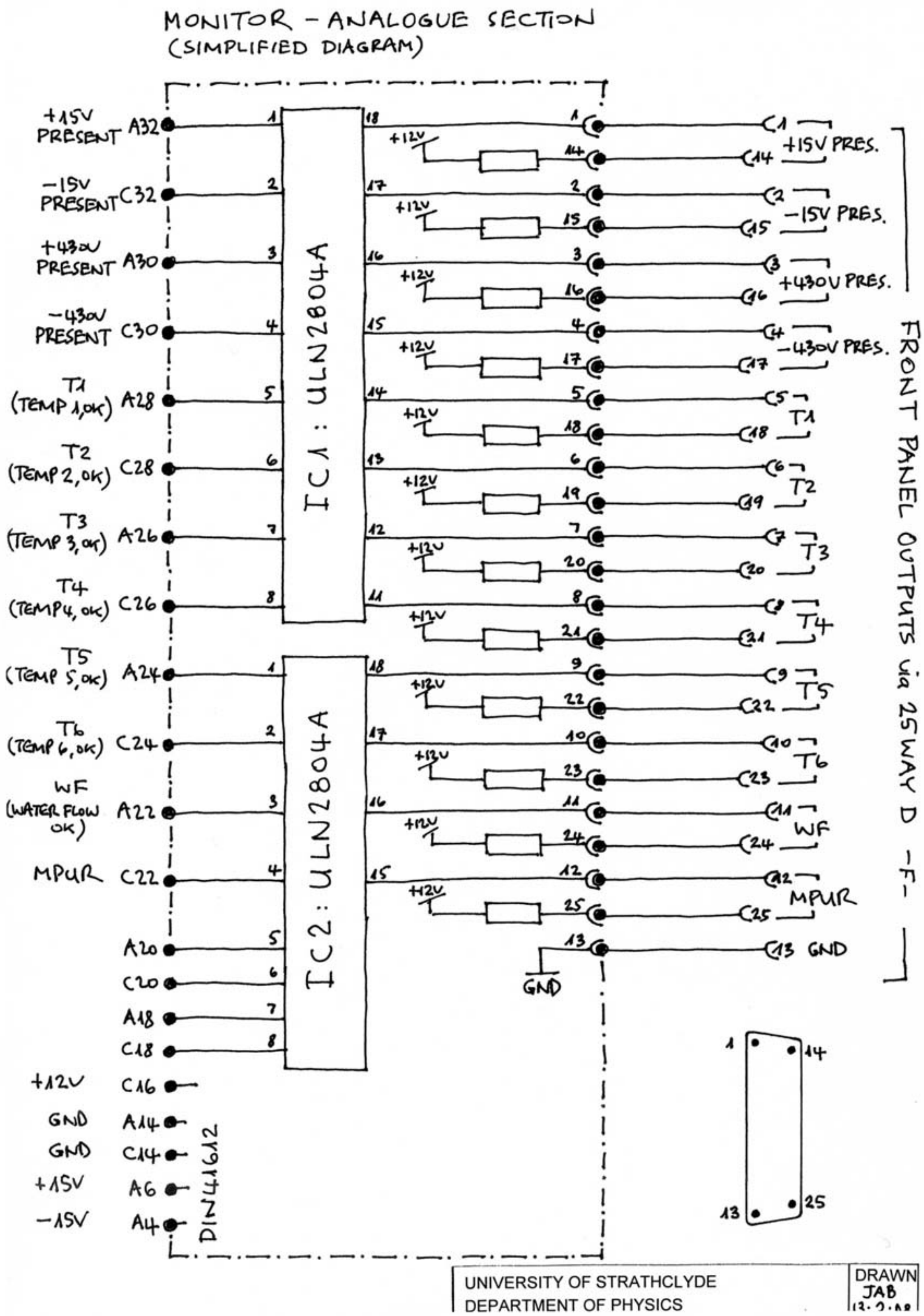
Backplane foil (rear) track layout.

Monitor module




MONITOR - ANALOGUE SECTION
(SIMPLIFIED DIAGRAM)
+15V PRESENT A32
-15V PRESENT C32
+430V PRESENT A30
-430V PRESENT C30
T1 (TEMP 1, OK) A28
T2 (TEMP 2, OK) C28
T3 (TEMP 3, OK) A26
T4 (TEMP 4, OK) C26
T5 (TEMP 5, OK) A24
T6 (TEMP 6, OK) C24
WF (WATER FLOW OK) A22
MPUR C22
A20
C20
A18
C18
+12V C16
GND A14
GND C14
+15V A6
-15V A4
DIN41612
IC1: ULN2804A
IC2: ULN2804A
+12V
GND
+15V PRES.
-15V PRES.
+430V PRES.
-430V PRES.
T1
T2
T3
T4
T5
T6
WF
MPUR
13 GND
FRONT PANEL OUTPUTS via 25 WAY D -F-
UNIVERSITY OF STRATHCLYDE
DEPARTMENT OF PHYSICS
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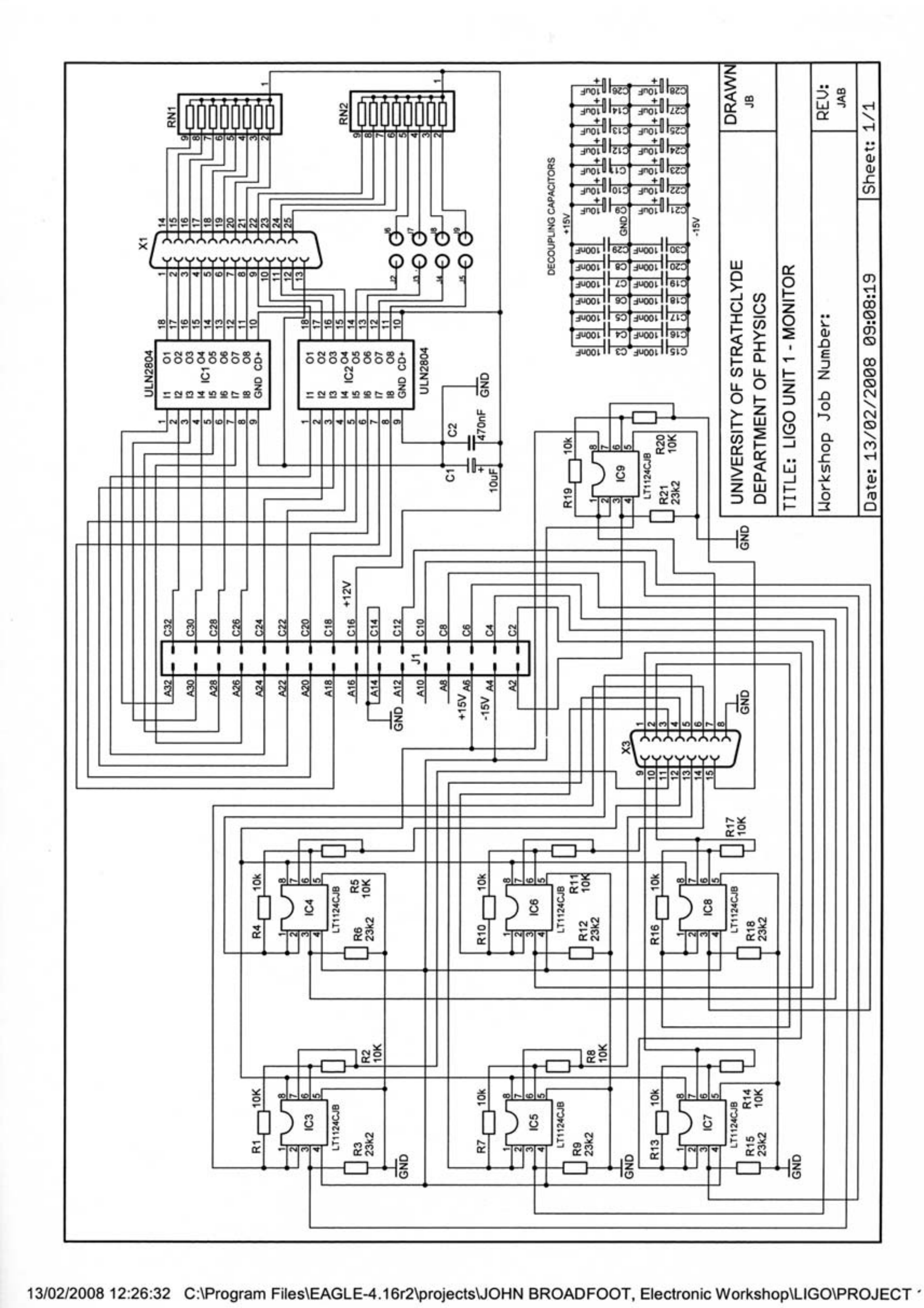
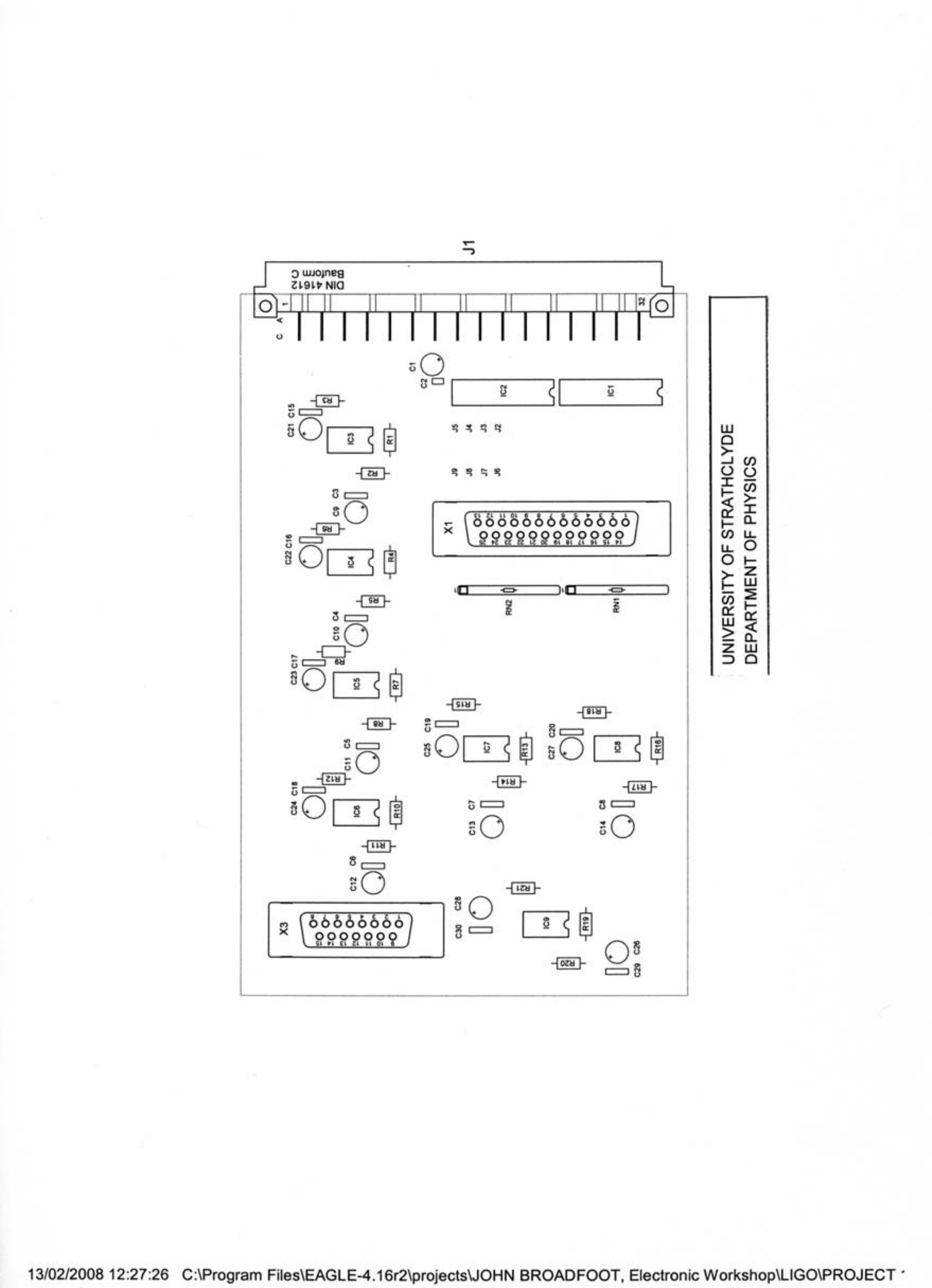
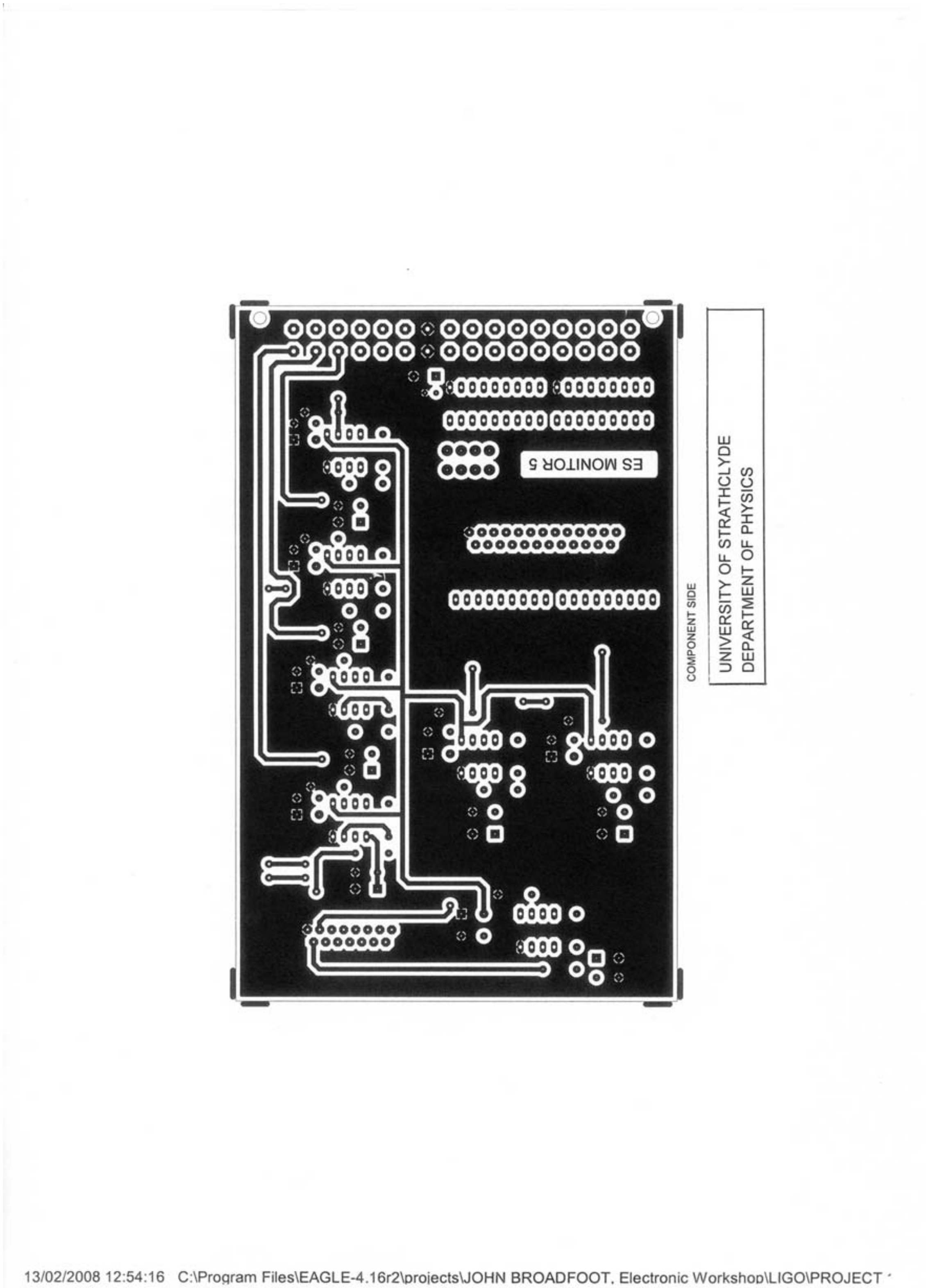


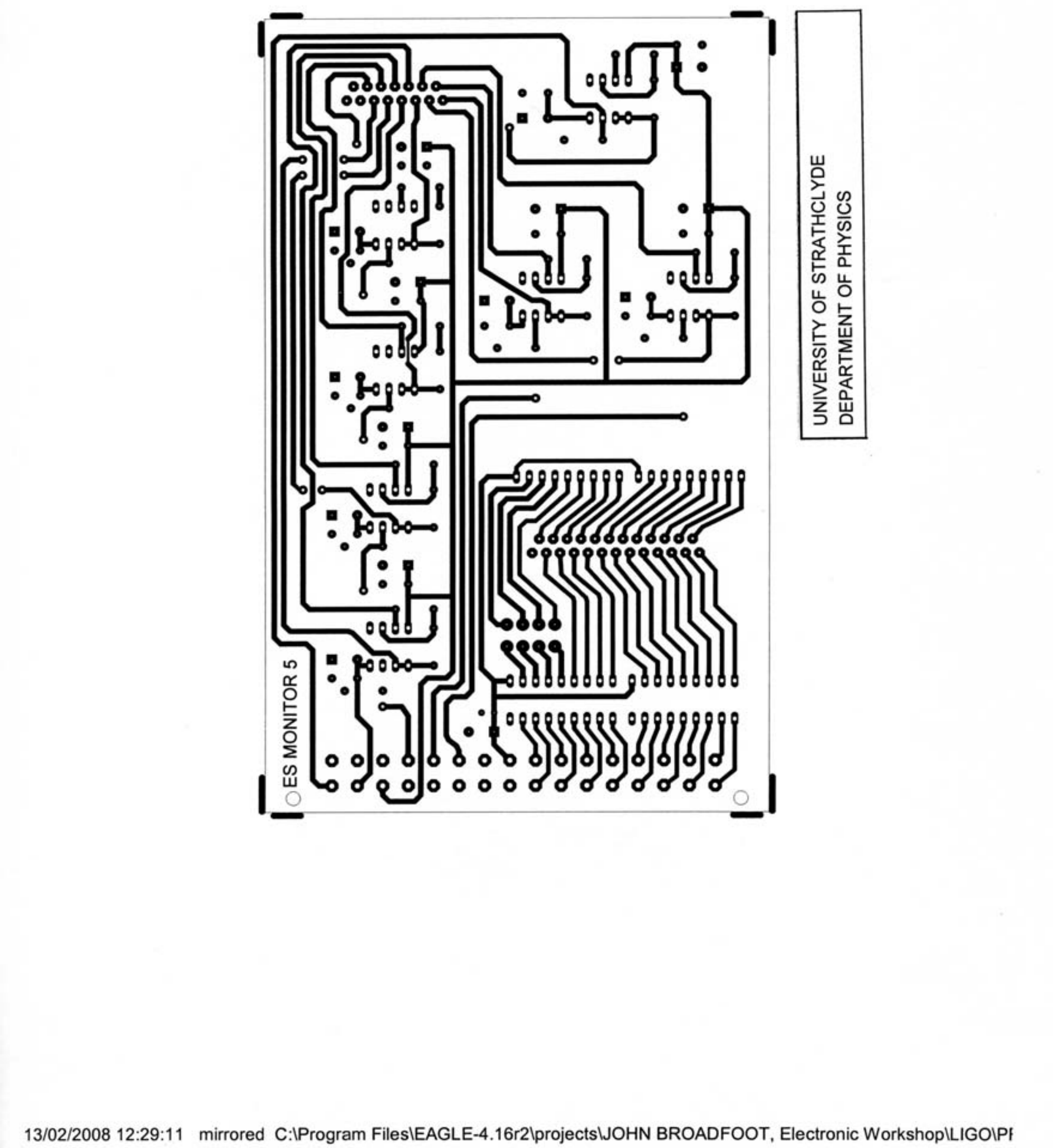
Monitor module circuit diagram—both analog and digital.



Monitor module component overlay.



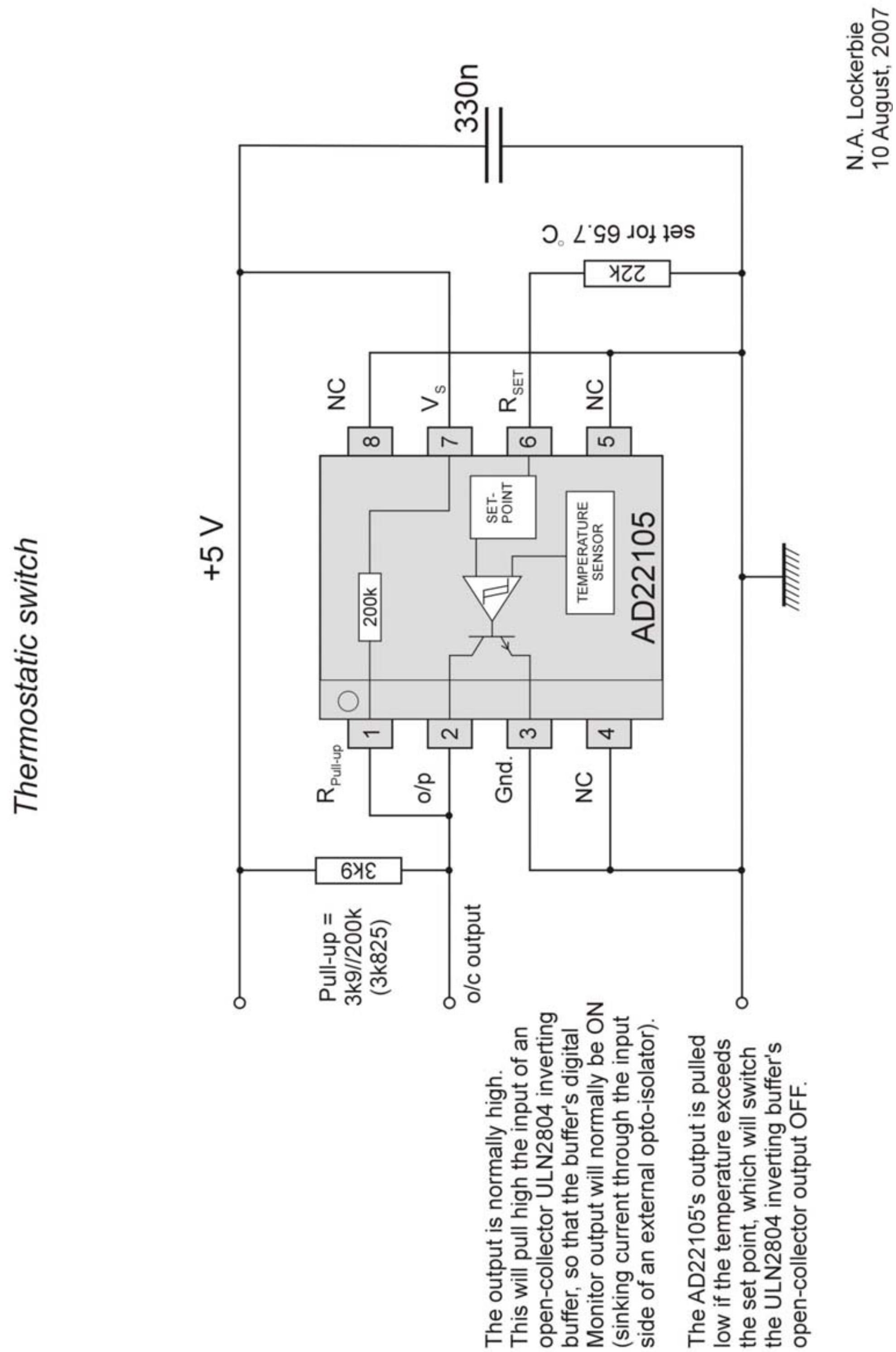
Monitor module component side ground-plane.

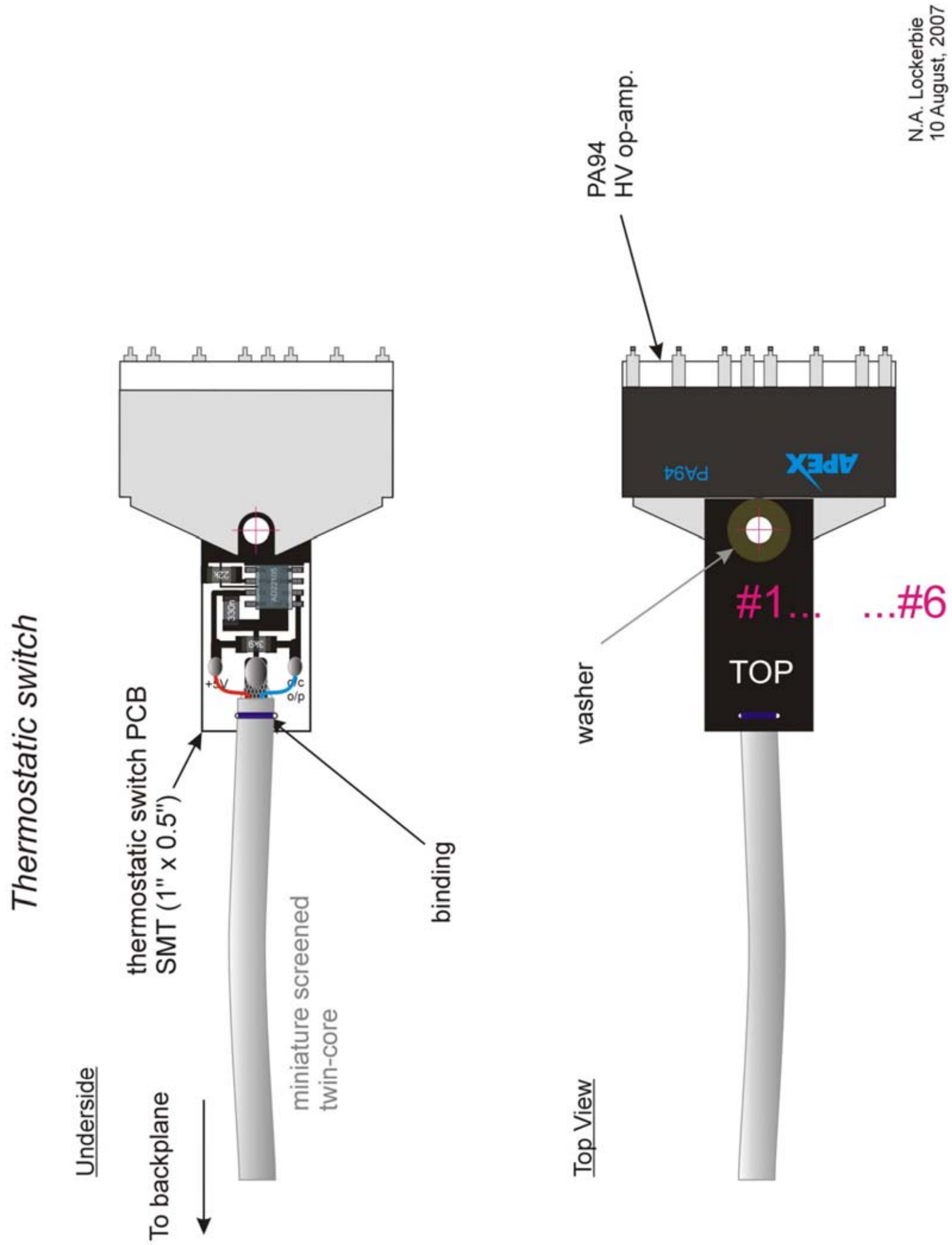


Monitor module track (underside).

Thermostatic switches (one per PA94 HV op-amp.)

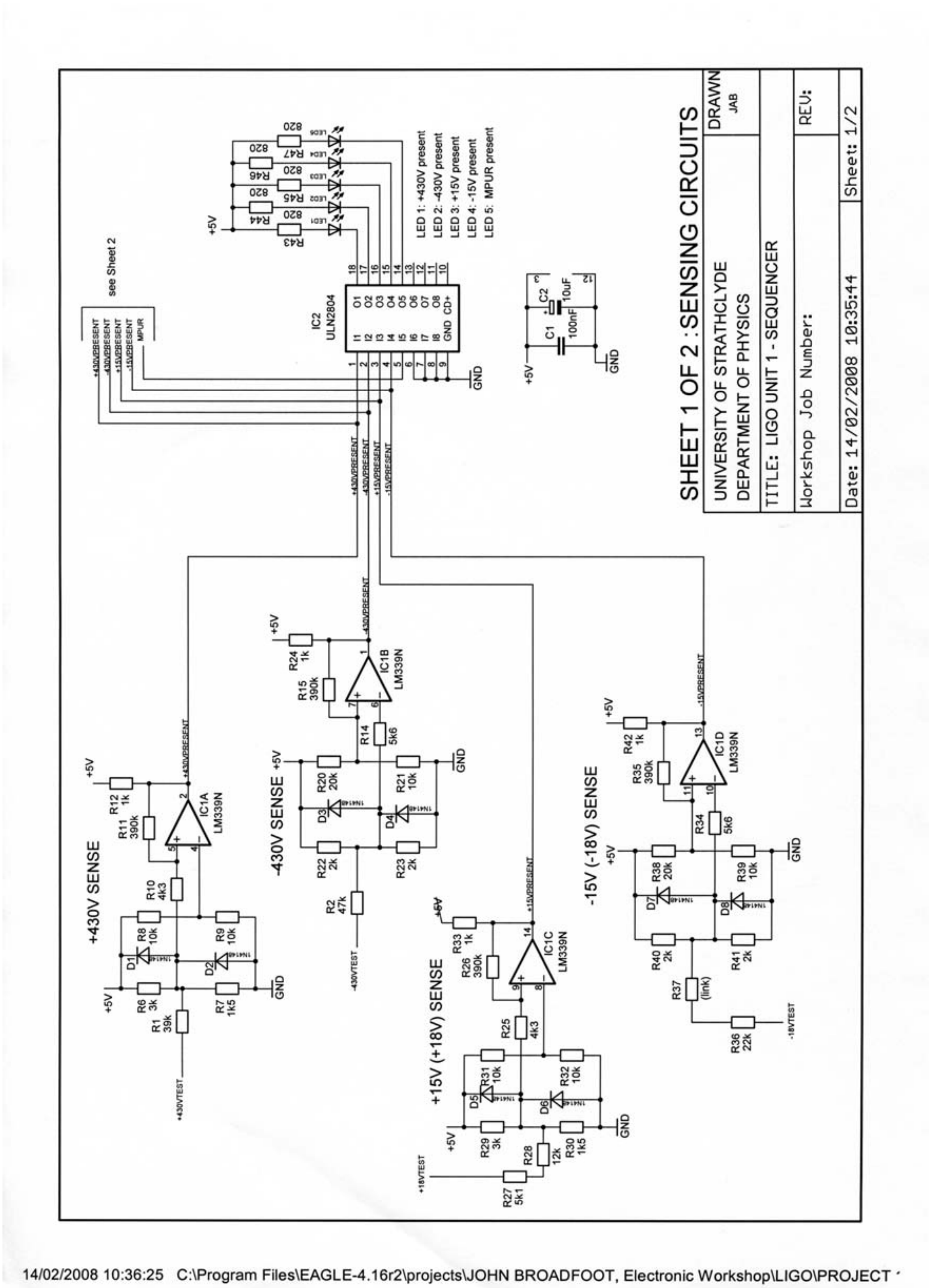
A 0.13 mm thick copper foil was soldered to the broad ground-track on the PCB, and this was lapped-over the AD22105 so as to provide good thermal contact between the top and bottom of the AD22105, and the tab of the PA94 HV op-amp.



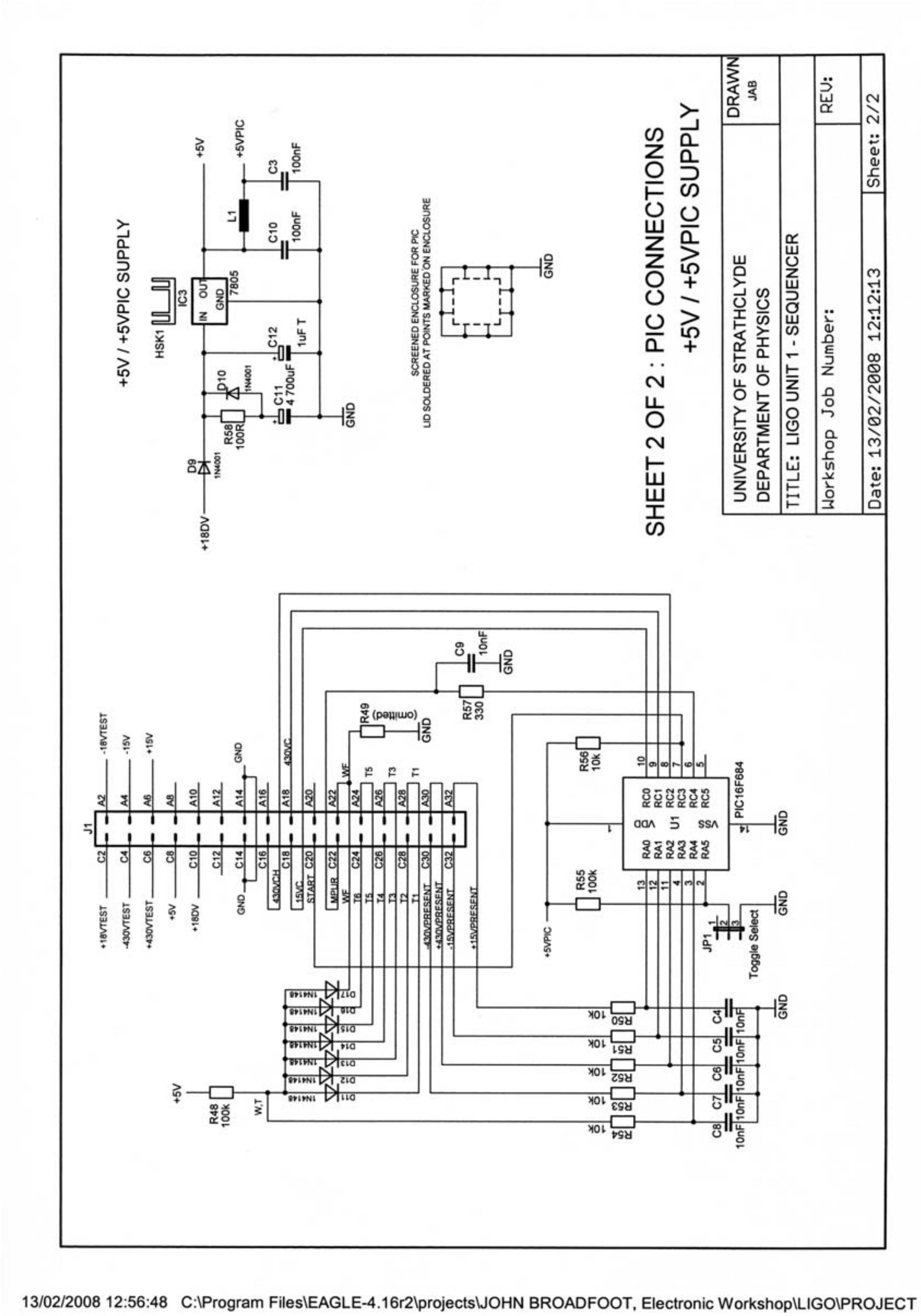


Thermostatic switch component layout, track pattern, and mounting details.

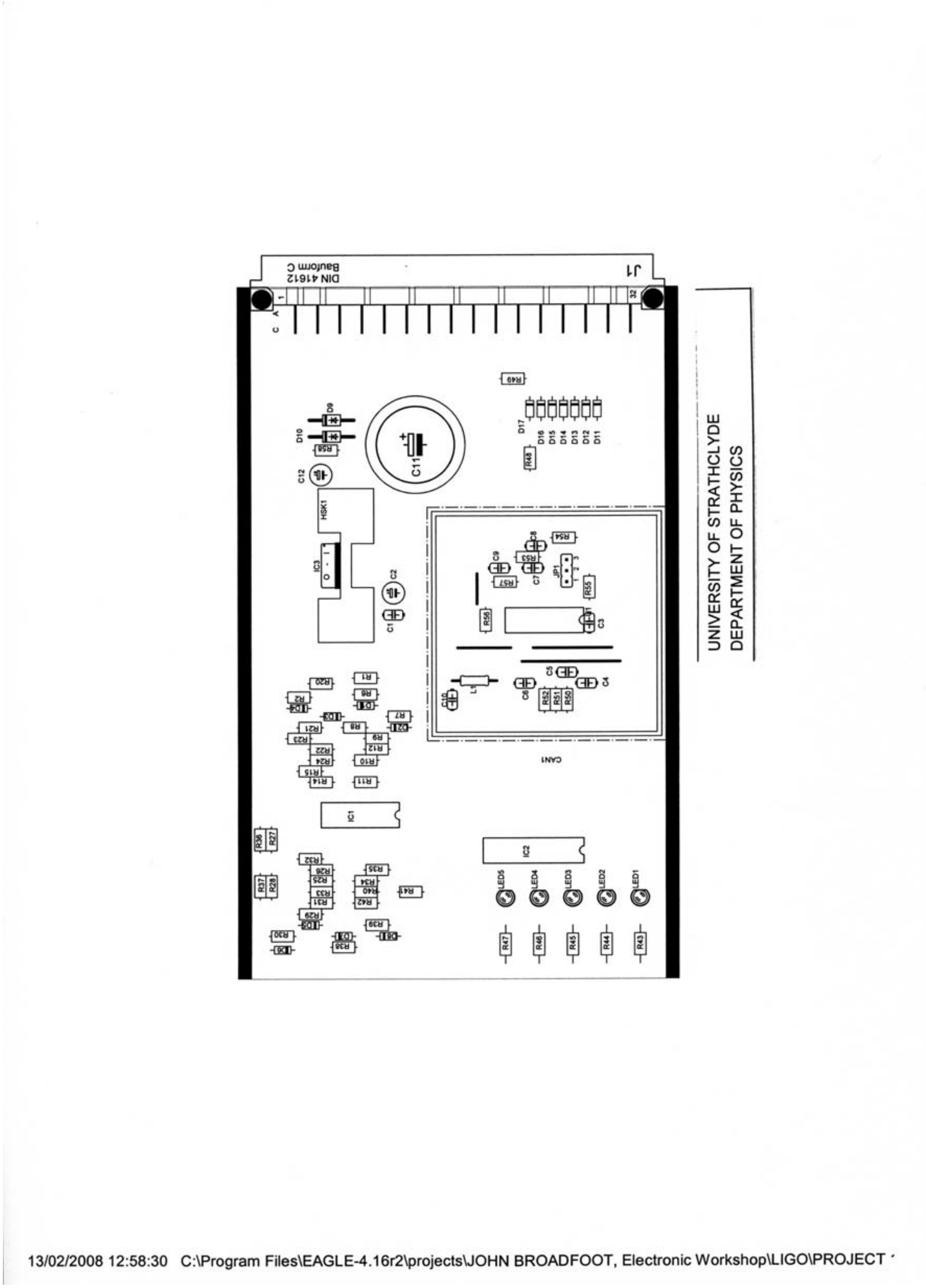
Sequencer module



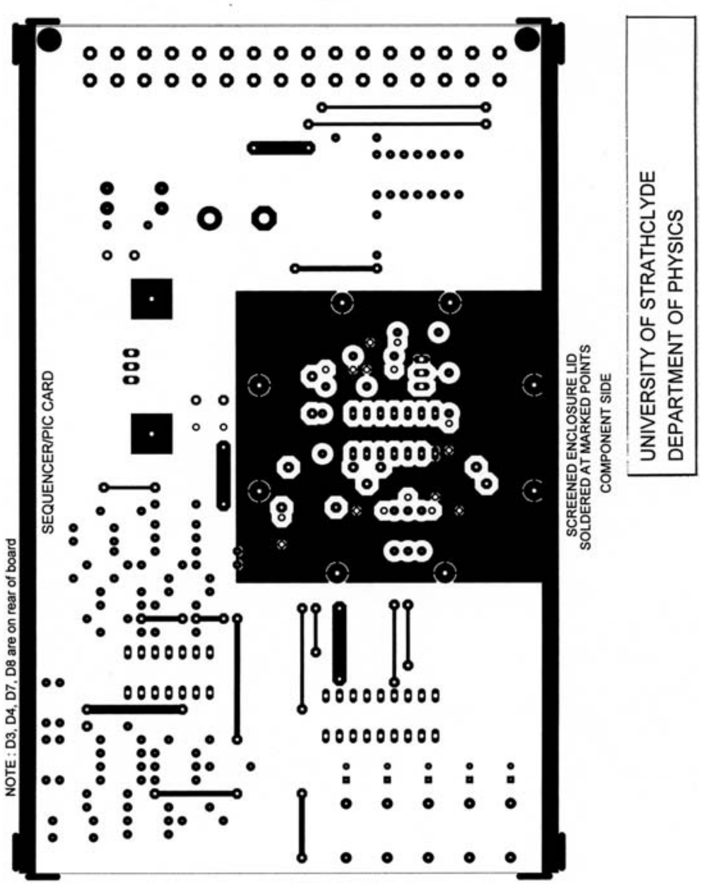
Sequencer module power-rail sensing and front panel LED drivers (Sheet 1 of 2).



Sequencer module power-rail sensing and Microcontroller (MCU) circuit, showing the filtered +5 V supply, '+5VPIC', for the MCU alone (Sheet 2 of 2).



Sequencer module component overlay, showing the PCB-mounted tinned-steel screening can (with lid) containing the PIC16F684 Microcontroller.



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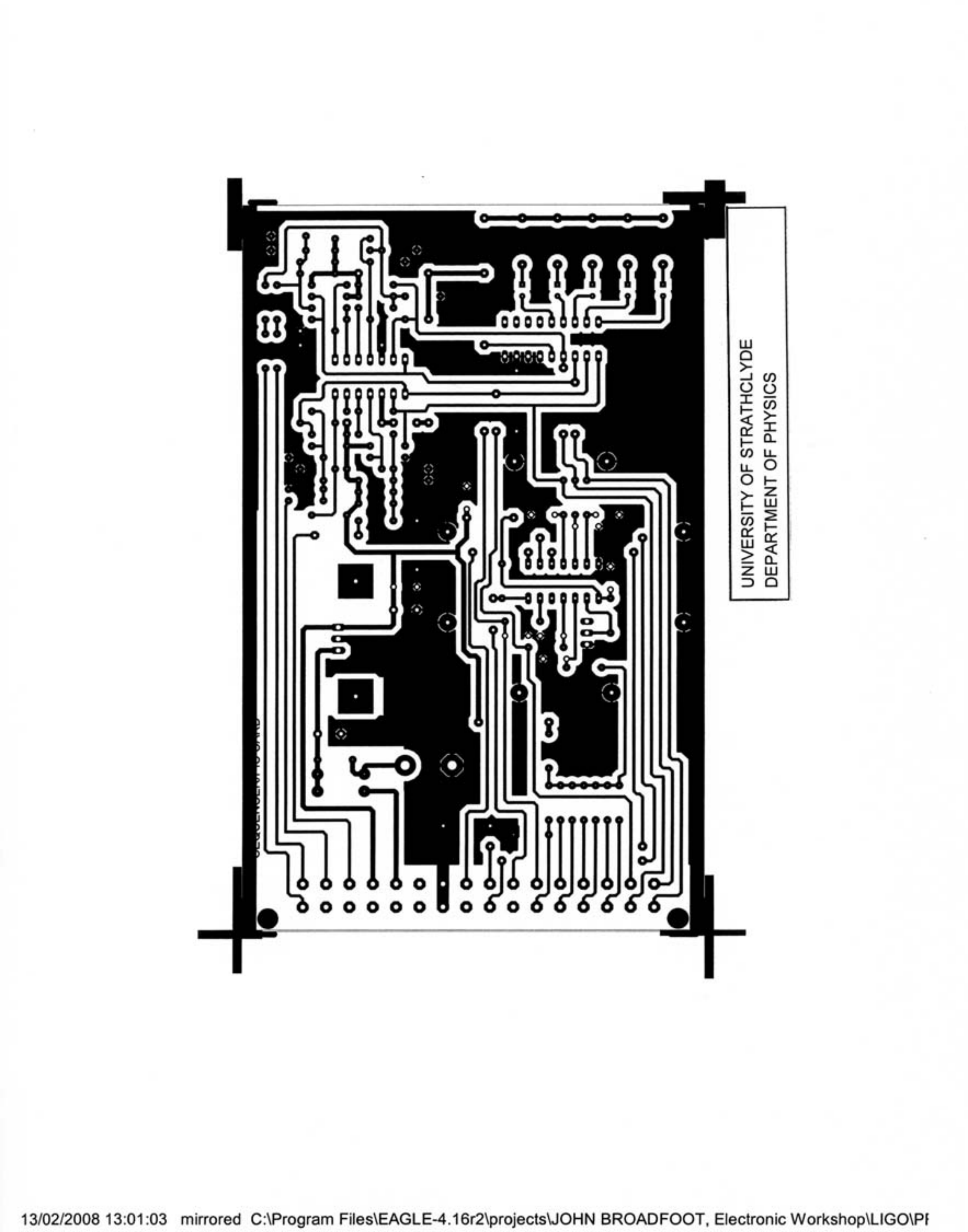
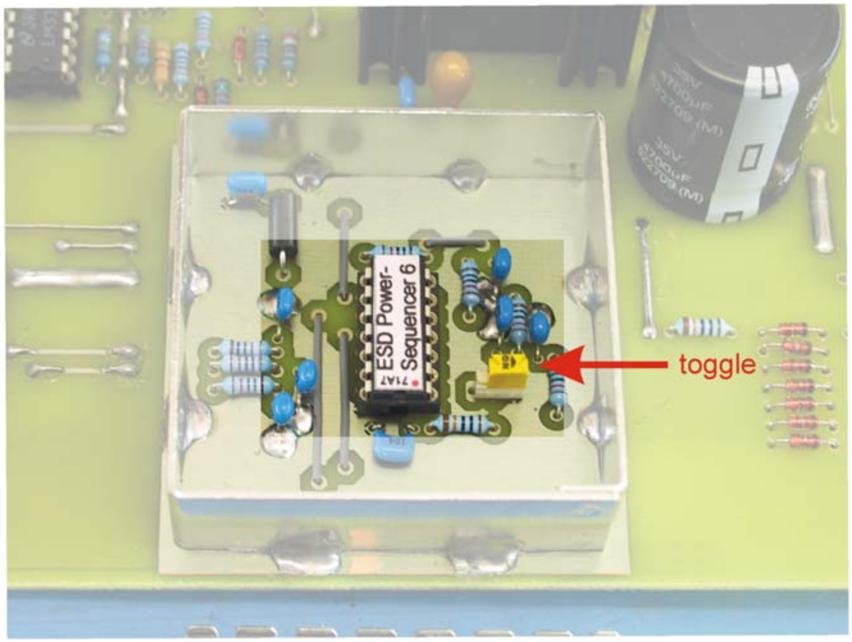
Sequencer module PCB component-side foil pattern.



Sequencer module PCB track (under-) side pattern.

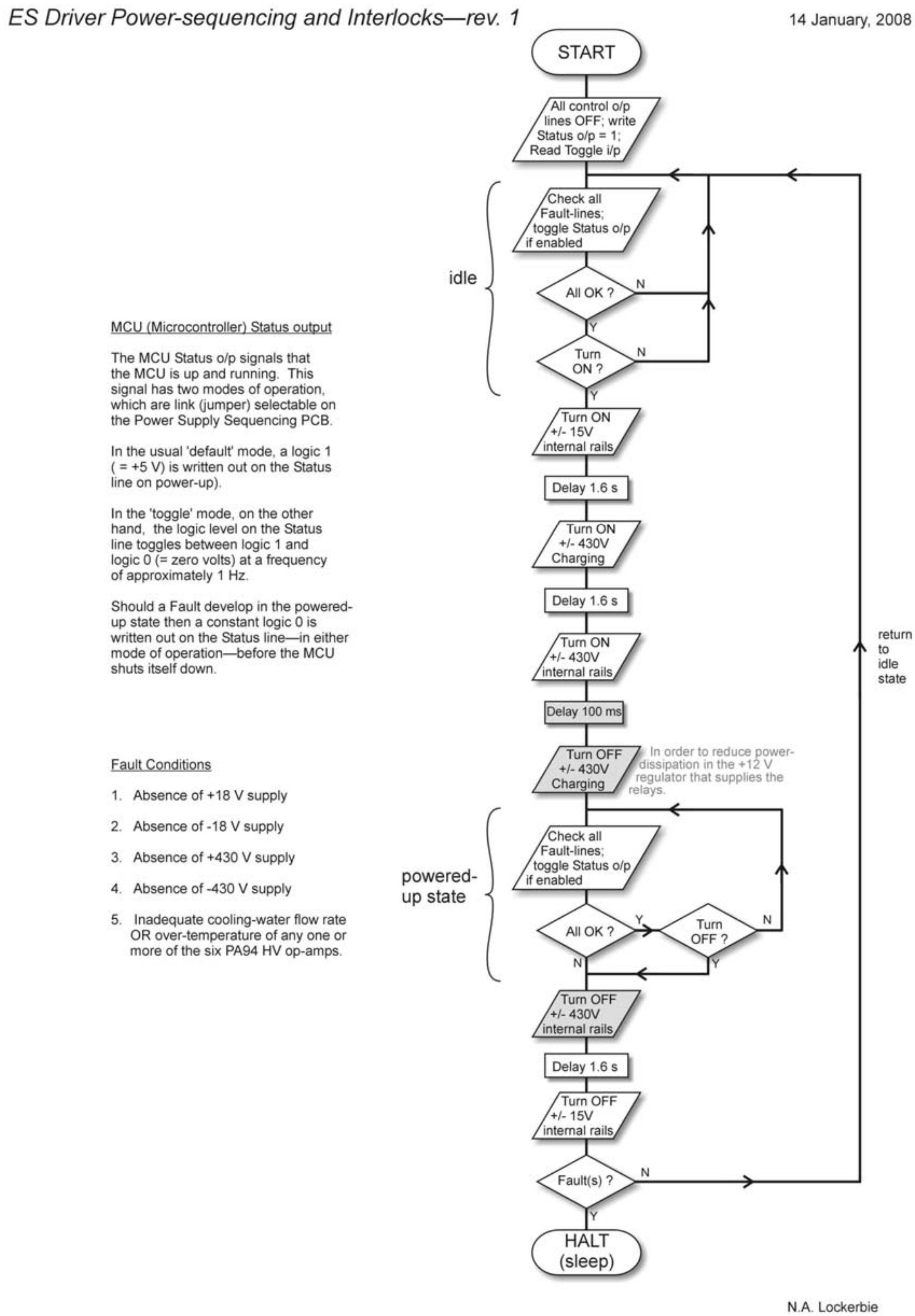
Optional setting of the 'Toggle' mode for the MCU's Status output (and front panel 'MPUR' LED)



By removing just the lid from the microcontroller's (MCU's) screening enclosure, found on the PCB inside the Sequencer module, the yellow jumper switch can be located. If this is switched to the left as shown in the figure above, then the 'toggle' mode for the MCU's Status output is selected, where the MPUR LED, and the open-colllector Status output on the Monitor Outputs module, toggle on-and-off at approximately 1 Hz.

Sequencer Program

Power supply sequencer 'C' Program—flow-chart



Power supply sequencer 'C' Program—description

```
/////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//
// Program: ESD_Power_Sequencer_interlock_6.c          N.A. Lockerbie      Uni. of Strathclyde, Physics       14 January, 2008
//
// The program has been written for a CCS PCWH C-compiler, ver. 3.229.
//
// This program controls the power supply sequencing of the Electroststic Driver.  It runs on a PIC16F684 14-pin microcontroller (MCU).
// Eleven of the MCU's twelve i/o pins are used in this application: -
//
//       PA0       +18V sense i/p (normally high)
//       PA1       -18V sense i/p      "
//       PA2      +430V sense i/p      "
//       PA3      -430V sense i/p      "
//       PA4      HV power-amp temperature and cooling-water flow sense i/p (normally high)
//       PA5      Toggle MCU status line select i/p: 1 = toggle status line at ~ 1 Hz; 0 = output a constant logic 1 on status line.
//
//       PC0      +/-15V control o/p
//       PC1      +/-430V control o/p
//       PC2      +/-430V charging o/p
//       PC3      Start/Reset (active-low) i/p
//       PC4      MCU Status line o/p
//
// The MCU runs using its internal RC oscillator, at a frequency of 31 kHz.
// Brownout recovery (at a supply voltage of < 2V) is enabled, causing an MCU Reset under that condition.
// Operation: -
//
// If the four power rails (+/-18V and +/-430V) are all applied to the ES Driver (ESD) then the ESD enters an 'idle' state.
// If none of the five (fault) 'sense' lines is active (low), then the ESD can be started from the idle state by pressing the front-
// panel Start/Reset PTM switch, causing a momentary logic zero.  The power lines are then sequenced ON in an orderly way: firstly,
// the +/-15V rails are switched ON, followed by a fixed delay of 1.6 seconds, after which the +/-430V rails are charged through
// current-limiting resistors for a period of 1.6 seconds, following which the +/-430V rails are connected directly to the now
// charged decoupling capacitors and HV circuitry of the ESD. After a brief further delay (100 ms) the Charging relay is now switched-
// OFF, in order to reduce power dissipation in the 12 V regulator that supplies the relays.  The ESD is now in its active fully
// powered-up state.
//
// If one or more fault conditions existed during the idle state (such as absence of one or more power rails, and or absence of
// cooling-water), then the ESD cannot be powered-up: the fault condition(s) must first be cleared.
//
// If the ESD has been powered-up, then pressing the Start/Reset PTM switch again will cause the ESD to shut down and re-enter the idle
// state: first the +/-430V 'internal rails' relay is switched OFF, causing the two HV rails to discharge rapidly through
// a pair of dump resistors, and then, after a delay of 1.6 seconds, the +/-15V rails are also switched OFF.  Subsequent pressing of the
// Start/Reset PTM switch will power-up the ESD, as before.
//
// If the ESD is powered-up, and one or more of the five 'fault' conditions should develop, then the ESD will automatically power-down,
// going through the same power-down sequence as if the Start/Reset switch had been pressed in order to initiate a Reset of the ESD; but
// in this case the idle state will not be re-entered, and the MCU will shut itself down as well.  Therefore, subsequent pressing of the
// Start/Reset switch will not cause the ESD topower-up again.  In order for the ESD to be powered up again the cause(s) of the fault
// condition(s) first must be resolved, and the +18V rail (which provides the +5V supply to the MCU) must be removed for several seconds
// and then reconnected---in order to cause a reset of the MCU.
//
// In both the idle and the powered-up states of the ESD a 'Status' output line reflects the status of the MCU's activity.  The operating
// mode of this line is selected by a jumper located on the MCU's PCB.  If the jumper is in the open-circuit position a pull-up resistor
// on pin PA5 of the MCU provides a logic 1 at this input, selecting the 'toggle' mode.  In this mode the status line output toggles
// continuously between logic 1 and 0 at a frequency of approximately 1 Hz. On the other hand, if the jumper is in the grounded position a
// logic 0 is provided at input PA5, selecting the non-toggled mode.  In this mode a constant logic 1 is written out on the Status output
// line, whilst the MCU is active.  If, as a result of a fault, the MCU shuts itself down, it first writes a constant logic 0 out on the
// Status line --- irrespective of whether it was formerly in the toggle or non-toggled Status mode.
//
/////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
```

Power supply sequencer 'C' Program

```
#include "C:\Documents and Settings\Nicholas\My Documents\PICC_files\PIC_power_sequencing\ESD_Power_Sequencer_interlock_6.h"
#use fast_io(C)
#use fast_io(A)
#byte PORTC = 7                                        // Map the created variable in memory onto Port C.
#define SEQNG_DELAY_MS 1600                            // For a 1.6 s delay between activation/deactivation of sequenced power rails.
#define SHORT_DELAY_MS 100                             // Short delay of 100 ms between switching the +/- 430 V 'internal rails' relay ON
                                                       // and switching the +/- 430 V rails Charging relay OFF.
#define TGGLE_DLAY_ITNS 124                            // To toggle MCU_STATUS o/p line at approx. 1 Hz (number was found empirically).
#define ALL_OK 0b00011111                              // For Port A 'Fault' input pins.

void main()
{
intl sw_state, no_faults, flag, op_level = 1, toggle;  // 1-bit variables.
int i = TGGLE_DLAY_ITNS;                               // 8-bit counter variable, loaded initially with 124.

setup_adc_ports(NO_ANALOGS|VSS_VDD);
setup_adc(ADC_OFF);
setup_timer_0(RTCC_INTERNAL|RTCC_DIV_1);
setup_timer_1(T1_DISABLED);
setup_timer_2(T2_DISABLED,0,1);
setup_comparator(NC_NC);                               // Comparators OFF.
setup_vref(FALSE);                                     // vref powered OFF.
setup_oscillator(OSC_31KHZ);                           // Note setup of INTernal RC
                                                       // oscillator frequencey (should radiate less using Internal osc.).
set_tris_a(0xFF);                                      // All inputs.
PORTC = 0;                                             // Deliberately zero all PORTC output pins ahead of configuration.
set_tris_c(0xE8);                                      // 0b11101000 PC4 and PC2,1,0 o/p; PC3 i/p; rest: don't care.

output_bit(MCU_STATUS,op_level);                       // Set MCU_STATUS output Hi initially, then, if selected, toggle output
                                                       // pin to signal correct operation.
toggle = input(TOGGLE_SELECT);                         // Read toggle selector (only at startup).

while(TRUE)                                            // Repeat forever (unless 'sleep()' is encountered)...
   {
                                                       // *** Check Fault lines...

                                                       // Loop here until turn ON comm'd
                                                       // detected AND no Fault
   do
      {                                                // conditions are present.

      sw_state = input(PTM_SW);                        // Normally == 1 (Switch ESD ON == 0).

      no_faults = ((input_a() & ALL_OK) == ALL_OK);    // Test: normally == 1 (if no Faults).
      flag =  no_faults && !sw_state;                  // Normally == 0; but == 1 if a
                                                       // request is made for turn ON, AND
                                                       // there are no Faults.
      i--;                                             // Decrement counter.
      if ((i == 0) && toggle)                          // Only toggle MCU_STATUS pin if toggle is selected.
         {
         op_level = !op_level;                         // Toggle o/p level
         output_bit(MCU_STATUS,op_level);              // Write new level out on MCU_STATUS pin.
         i = TGGLE_DLAY_ITNS;                          // Reset iterations counter for Toggle delay.
         }

      } while (!flag);                                 // So, normally, loop-
                                                       // back.  Also, loop-back if any
                                                       // Fault(s) are detected,
                                                       // irrespective of switch-ON
                                                       // request.

                                                       // Switch ON detected (AND no Faults)...

   output_bit(RAILS_15V_CTRL,ON);                      // Switch ON +/- 15V rails.
   delay_ms(SEQNG_DELAY_MS);                           // 1.6s delay.
   output_bit(RAILS_430V_CHARGE,ON);                   // Charge +/- 430V rails.
   delay_ms(SEQNG_DELAY_MS);                           // 1.6s delay.
   output_bit(RAILS_430V_CTRL,ON);                     // Switch ON +/- 430V rails.
   delay_ms(SHORT_DELAY_MS);                           // 100 ms delay.
   output_bit(RAILS_430V_CHARGE,OFF);                  // +/- 430V Charging relay OFF (to reduce dissipation in the +12 V relay supply).


   do
      {

      sw_state = input(PTM_SW);                        // Read PTM_SW. Normally, will read 1 (OFF == 0, also).

      no_faults = ((input_a() & ALL_OK) == ALL_OK);    // Test: normally == 1; but == 0 if
                                                       // there is a/are Fault condition(s).
                                                       //

      flag =  no_faults && sw_state;                   // Normally == 1, unless PTM switch pressed for OFF, or/
                                                       // and there is a Fault.
      i--;                                             // Decrement counter.
      if ((i == 0) && toggle)                          // Only toggle MCU_STATUS pin if toggle is selected.
         {
         op_level = !op_level;                         // Toggle o/p level
         output_bit(MCU_STATUS,op_level);              // Write new level out on MCU_STATUS pin.
         i = TGGLE_DLAY_ITNS;                          // Reset iterations counter for Toggle delay.
         }

      } while (flag);                                  // Exit do loop if PTM_SW == 0 (switch OFF)
                                                       // OR Fault(s) have occurred.

   output_bit(RAILS_430V_CTRL,OFF);                    // Switch +/- 430V rails OFF.
   delay_ms(SEQNG_DELAY_MS);                           // 1.6s delay.
   output_bit(RAILS_15V_CTRL,OFF);                     // Switch +/- 15V rails OFF.

   if (!no_faults)                                     // There is/are Fault conditon(s), so shut down.
      {                                                // Then, can only be awoken by a complete power-
      output_bit(MCU_STATUS,OFF);                      // down and restart, with Fault(s) fixed.  Ensure
      sleep();                                         // MCU_STATUS pin is low --- to indicate MCU is
      }                                                // switched off.

   }                                                   // ... else loop back to ***, forever.

}                                                      //End of main()... never reached.
```

Header file for power supply sequencer 'C' Program

Header file: ESD_Power_Sequencer_interlock_6.h

```
#include <16F684.h>
#device adc=8

#FUSES NOWDT                 //No Watch Dog Timer
#FUSES INTRC_IO              //Internal RC Osc, no CLKOUT
#FUSES NOPROTECT             //Code not protected from reading
#FUSES BROWNOUT              //Reset when brownout detected
#FUSES NOMCLR                //Master Clear pin used for I/O
#FUSES NOCPD                 //No EE protection
#FUSES PUT                   //Power Up Timer
#FUSES IESO                  //Internal External Switch Over mode enabled
#FUSES FCMEN                 //Fail-safe clock monitor enabled

#use delay(clock=31000)


#define TOGGLE_SELECT       PIN_A5
#define RAILS_15V_CTRL      PIN_C0
#define RAILS_430V_CTRL     PIN_C1
#define RAILS_430V_CHARGE   PIN_C2
#define PTM_SW              PIN_C3
#define MCU_STATUS          PIN_C4

#define ON  1
#define OFF 0
```

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