Operating Manual

Nevzorov hot wire LWC/TWC Probe

(CWCM-B2)

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1. INSTRUMENT DESCRIPTION

1.1 The SkyTech Nevzorov probe (CWCM-1) is an aircraft probe designed for measurements of liquid and total (ice plus liquid) water content (LWC and TWC) of clouds and fogs in the range from 0.003 gm^{-3} to 3 gm^{-3} and air velocities from 10 to 180 ms^{-1}.

1.2 The SkyTech Nevzorov probe belongs to the group of so-called "hot wire constant temperature probes". A sensor unit consists of two sensors: collector sensor and reference sensor. The principle of operation is based on separate measurements of power needed to compensate heat losses caused by evaporation of cloud water and convective losses on the collector sensor and power needed to compensate convective heat losses on a reference sensor.

1.3 The Nevzorov LWC/TWC probe electronics provides analogue output 0 - 10V, which is proportional to the square root of measured water content.

1.4 Liquid and total water content are measured by separate LWC and TWC sensors. Both LWC and TWC sensors are mounted on the same sensor head. The sensor head provides alignment parallel to the airflow in order to compensate changes of the airflow direction during the aircraft pitches.

1.5 Each sensor head is connected to a separate control box. The control boxes are identical and interchangeable.

1.6 The SkyTech Nevzorov probe is designed to operate under all weather conditions. With proper installation and operative de-icing heaters, the system can operate indefinitely under the conditions weather research environment.

2. NEVZOROV PROBE SPECIFICATIONS

Sensitivity	0.003 g/m^3
Range of measured LWC/TWC	0.003 - 3 g/m^3
Accuracy	±10%
Air speed range	10 - 180 ms^{-1}
LWC sensor sample area	0.3 cm^2 (may vary from sensor to sensor)
TWC sensor sample area	0.5 cm^2 (may vary from sensor to sensor)
Time constant of the output filter	0.01 s
Output signal	0 - 10 V
Power requirements	28 ±2 VDC, 1-6 amp (per one control box) depending on LWC/TWC, air speed, air pressure and air temperature
Control Box:	
Weight	4.3 kg
Size	33 cm x 39 cm x 5 cm
Pillar:	
Size	10cm x 9cm x 5cm
Weight	1.2 kg
Deicing pillar	3 x 100 Wt, 120 VAC

2.1 The SkyTech Nevzorov LWC/TWC Probe consists of:

1) Sensor Head
2) Sensor Head Pillar
3) LWC Control Box
4) TWC Control Box
5). Signal Cable
6). Control cable
7). Power Cable

2.2 Each control box provides the operation of one sensor, either LWC or TWC. The control boxes are interchangeable and have the same electronics.

2.3 Both LWC and TWC sensors consist of two sensors (Fig. 1):

(i) the leading sensor, or collector (CS) has the sampling surface exposed to the airflow and cloud particles,

(ii) the reference sensor (RS) is aerodynamically protected from collision with cloud particles, and it remains dry in clouds.

The reference sensor is intended to compensate dry air heat losses. Both collector and reference are ventilated by the same air flow. Both the LWC and TWC sensors are mounted on the same vane (Fig. 2a) that provides sensors alignment parallel to the airflow (Fig 2b). This increases the stability and accuracy of measurements of cloud water content.

3. INSTALLATION

3.1 The power required for the SkyTech Nevzorov LWC/TWC probe is 28 ± 2 VDC, 1 to 6 Amp capability for each of the control boxes. The current consumption depends on liquid or total water content, air speed, air temperature, and air pressure. Normally, in cloud free sky at 100 ms^{-1} and temperature $0^{o}C$ to $-30^{o}C$ each control box consumes form 1 to 1.5 Amp.

3.2 The control boxes (Fig. 3) should be installed inside fuselage.

3.3 The pillar with the sensor head should be mounted on the aircraft horizontally in order to allow the vane to remain parallel to the airflow during aircraft pitch changes. Vertical mounting of the pillar may cause the probe disbalancing during aircraft maneuvers and reduce the accuracy of measurements.

3.4 The connection between the control boxes and the sensor head is provided by a signal cable, which should not exceed 30 meters. Each wire must have a resistance of no more than 0.5 Ohm. If the cable length exceeds 5 meters, the wires should be shielded to avoid noise induction. The wires of the cable must not be twisted.

3.5 One end of the cable with 26 pin connector is connected to the pylon with the sensor head. The other end of the cable terminates into two connectors. Each connectors (10 pin) is marked “LWC” or “TWC”. The “LWC” cable must be connected to the LWC control box and the “TWC” cable must be connected to TWC control box.

4. THEORY OF OPERATION

4.1 The general circuit schematic of Nevzorov probe is shown on Fig 4.

4.2 The operation of the probe is based on measurements of heat needed for evaporation of dispersed cloud water impacted with hot collector sensor. The power heat losses on the collector sensor consist of two parts: (i) convective (or dry) heat losses, and (ii) heat losses due to cloud water evaporated from the sensor surface. The dry heat losses are automatically deduced from total heat losses measured by the collector sensor based on measurements of convective heat losses by reference sensor, which is protected from impact with cloud particles. The temperatures of both collector (CS) and reference (RS) sensors (Fig. 1) are maintained automatically to be the same and constant. The automatic control of the temperature is provided by alternating current in the feedback loops of the bridges of CS and RS.

4.3 The temperature of the sensors must be preset to provide total evaporation of water collected by the sensor. In this case, the power consumed by CS P_{CS} can be written as

$$P_{CS} = P_{conv\,CS} + P_{w\,CS} \tag{1}$$

here $P_{conv\,CS}$ is the convective heat losses, $P_{w\,CS}$ is wet heat losses of CS. Since, the RS is protected from collision with cloud particles, the power consumed by this sensor is

$$P_{RS} = P_{conv\,RS} \tag{2}$$

The electronics of the probe provides the equality

$$P_{conv\,RS} = P_{conv\,CS}/k \tag{3}$$

here k is coefficient. Thus the power consumed by CS is

$$P_{CS} = kP_{conv\,RS} + P_{w\,CS} \tag{4}$$

The circuit shown on Fig. 4 provides the continuous direct measurement of $P_{w\ CS}$ through the compensating of CS convective heat losses by subtracting $kP_{conv\ RS}$ from P_{CS}. The idea of direct measurements $P_{w\ CS}$ is based on the principle of additivity of noncoherent currents that flow through the same load.

4.4 Both CS and RS have high coefficient of dependence of its resistance on temperature. CS and RS are the arms of two different bridges.

4.5 The electric circuit consists of three loops (Fig. 4)

a) the RS loop (Module A1)

b) the middle loop (Module A2, A4)

c) the CS loop (Module A6)

All three loops are controlled by alternating current

4.6 Module A1 provides balancing of RS loop (equal input voltages +V1, -V1) by means of the negative feedback loop and maintains the constant temperature of RS. The precision potentiometer KNB1, located on the front panel of the control box (Fig. 3), presets RS temperature.

4.7 Module A2 provides balancing of CS loop (equal input voltages +V2, -V2) by means of the negative feedback loop and maintains the constant temperature of RS. The precision potentiometer KNB2 , located on the front panel of the control box (Fig. 3), presets CS temperature. The middle loop provides the equality of RS and CS temperatures in dry air, if current in CS bridge was adjusted to zero.

4.8 Module A6 detects the difference between +V6 and –V6 in the CS loop. The output signal from the A6 (Error Signal) is equal to 0V while +V6 is equal to -V6. The 1.5 kHz clock generator synchronously controls switches SW1, SW2, SW3. The temperature of the sensors is assumed do not change within 0.3ms. It allows extracting the A6 output signal, which is responsible for wet heat losses. While SW2 connects B terminal to the bridge, the collector's dissipated power is $W = (-V2)^2/R$, here R is the resistance of CS. The average dissipated power $W_{aver} = (V_{out})^2/R_{collect.} = W/2$, provided the clock generator has a 50% duty cycle. Therefore $V_{out} = (-V2) / \sqrt{2}$, here V_{out} is the output voltage on CS.

4.9 The term “balancing” hereinafter implies the zeroing of DC current in CS loop. The balancing of the probe must be fulfilled in clear (dry) air. During the balancing the alternating current in the CS bridge is adjusted roughly by the potentiometer “ADJ” on the front panel. The increase of AC in CS loop leads to heating of collector sensor and increase of its resistance. The increase of CS resistance causes the reduction on DC in CS loop.

4.10 When droplets impact with the CS a disbalancing of CS bridge occurs. It gives rise to current in CS feedback loop A6.

4.11 The current in the CS feedback loop must compensate the heat losses needed for cloud particles evaporation. Thus, the equality of DC power consumed by collector sensor and power needed for evaporation of cloud water yields

$$WSUL^{*}=\frac{V^{2}}{R} \qquad (6)$$

here W is water content,
S is the sample area of CS,
U is the air speed,
V is the output voltage on CS,
R is the resistance of CS at temperature T,
L^{*} is expended latent heat of evaporation

From Eq. 6 the measured water content is expressed as

$$W=\frac{V^{2}}{RSUL^{*}} \qquad (7)$$

The direct current component of CS output signal is displayed on the meter "OUTPUT" on the front panel and goes to the output connector of the control box.

5. ELECTRONICS OPERATION

The wiring is assembled at separate modules with the following functions:

5.1 Module A1 (Fig. 5) provides the constant-temperature mode of RS. Module A1 input stage incorporates precision instrumentation amplifier INA128 . Main features of INA128 are low temperature drift (0.5 μ V/^{0}C), high common-mode rejection (120dB) and internal input protection up to +/- 40V without damage. Second stage utilizes the LF398 sample-and-hold circuit to achieve high stability of the feedback loop. Third stage based on high-current (up to 10A) power amplifier OPA549. The stage provides thermal shutdown along with current-limit protection.

Besides the above, Module A1 provides bias DC voltage, that stabilizes the RS bridge balancing and improves the accuracy of measurements. The bias voltage can be adjusted of potentiometer under the transparent cover at the front panel (Fig. 3).

5.2 The A2 Module (Fig. 6) provides the balancing of CS bridge made from CONST, REF resistors (Fig. 5.1, Module A1) and CONST, COLLECT resistors (Fig. 6, Module A2). This module is similar to A1.

5.3 Module A3 (Fig. 7) converts +28V into +5V, +24V, -12V by means of 3-terminal positive/negative voltage regulators. These regulators are self-protected due to internal current limiting and thermal shutdown. Module A3 is intended for protection of the electronics from the current overload.

5.4 Module A4 (Figure 8) is an automatic controller for changing of the transmission factor in the middle loop (Module A2) on the basis of the error signal in the CS loop. It incorporates two digital potentiometers to adjust roughly and fine the error signal (marked as "Balance") to 0V. The digital potentiometer sets the "wiper" position to midscale at power-up.

While pressing the "AUTO" button on the front panel, the rough balancing begins. It brings (approximately in 5 seconds) the arrow of the front panel meter close to 0, slightly right-side position. Releasing the button starts the fine balancing (the meter's arrow goes from right to left and stops at 0).

5.5 Module A5 (Figure 9) protects the output stages.

5.6 Module A6 (Figure 10) is to power up and monitor the sensor's heater.

5.7 Module A7 (Figure 11) shows the connection between two devices and the output signals' diagram.

All modules are assembled as a single printed circuit board (Fig. 12).

It is recommended to place a simple low pass RC filter directly between the external controlling device (ADC, voltmeter, etc.) and the probe's output cable. Note, that the input impedance of the controlling device forms an additional RC filter, limiting the probe's signal bandwidth.

The control boxes of both LWC and TWC probes have the same electronics and can work independently. However, to eliminate parasitic interference between the boxes, the Master/Slave mode is arranged. In this mode only one generator (master) is used for both boxes. Another generator (slave) is automatically disconnected. To provide the Master/Slave architecture it is necessary to connect the control cable (Figure 11) to both DB-9 connectors on the rear panels of LWC and TWC control boxes. In a single control box operation mode the control cable must be disconnected.

The electronic circuit is subjected to insignificant changes without notifications.

6. SENSORS

6.1 Both collector and reference sensors have high coefficient resistance with temperature.

6.2 The LWC and TWC sensors consist of close single-layer windings of 0.15 mm enamel-covered nickel wire. For the TWC probe, the collector winding is cemented to the hollow cone at the end of a textolite cylinder, and the reference sensor is wound within a shallow ring groove around the same cylinder (Fig.1a). Both collector and reference sensors for the LWC probe are wound on solid cooper rods and cemented to the opposite edges of a flat textolite plate (Fig 1b).

6.3 The diameter of the sampling area of the TWC collector is 8 mm, cone angle being 120°. The dimensions of the cylindrical LWC collector are 1.8 mm diameter by 16 mm length. The resistance of all sensor wires at 90°C is typically from 2 to 3.5 Ohm.

6.4 Each sensor head includes also four cylindrical manganin wire windings, combining two different functions. First, each is connected in series with a sensor (RS or CS) to form the power thermostable arm of the sensor bridge, because the temperature dependence of manganin resistivity is four orders less than that of nickel and so may be neglected. This allows to separate cable connection pairs, one only for power feeding of the half-bridge and the other for bridge completing with the rest high-resistance arms, to ensure precise remote adjusting and control of the sensor temperature. Second, they serve as anti-icing heaters on the leading edge of the vane plate.

6.5 The phase discriminating capability of the LWC and TWC collectors results from the difference in behavior of liquid and solid particles impacting with their surfaces. Small liquid droplets, after collision with the LWC or TWC collector sensors are flattened into a thin surface film and completely evaporate. At the same time, ice particles will remain inside the conical hollow of the TWC collector until melting and evaporation is complete. In contrast to that, ice particles instantly break away from the convex surface of the LWC collector, with negligible heat expended, relative to that for complete ice evaporation.

6.6 The LWC and TWC sensors are mounted at the same vane plate. It remains parallel to the airstream during airplane pitch changes (Fig. 2b). This stabilizes the thermodynamics of the sensors and protects the reference sensors from particle impacts.

6.7 The deicing side heaters on the vane protects the sensor head from ice build up in supercooled clouds. The heaters provides 28Watts at 28 VDC.

7. OPERATION

7.1 Preset the temperature of CS and RS

(i) Remove the transparent plastic cover on a right side of the front panel.

(ii) Choose the operating temperature of the sensor (70°C or 90°C). From the calibrating tables (Appendix D) find the values $\mathbf{N}_{ref}$ and $\mathbf{N}_{oper}$, respectively.

(iii) Set these values on the resistance boxes "reference" and "collector" (the fourth sign should be rounded). In absence of airflow it is recommended to install the temperature 70° C. Low temperatures 50°C to 70°C are recommended for more accurate measurements of low LWC/TWC (<0.02 gm^{-1}). The decrease of the sensor temperature will result in a decrease of the maximum measured (saturation) water content. The values $\mathbf{N}_{ref}$ and $\mathbf{N}_{oper}$ can be calculated for any other operative temperature (see Appendix B).

***CAUTION*:**
Do not to set sensor temperature higher 140°C.

7.2 Before connecting the control box to the external 28VDC power source ensure that:

- the switch "Power" on the front panel is in position OFF;
- the switch "Heater" on the front panel is in position OFF;
- the sensor head is connected to the pylon
- the signal cable connects the pylon to the control box.
- the control cable connects two output "DB-9" connectors on the rear panels of the LWC and TWC control boxes. For a single control box operation mode the control cable should be disconnected from the second control box.
- the label "LWC" or "TWC" on the signal cable must correspond to LWC or TWC control box, respectively.

7.3 Connect the control box to the external 28V DC power source following polarity.

7.4 Turn on the power switch on one of the control boxes. The power indicator and the "ALARM" should light on. Turn on the power on the second control box. The "ALARM" on the first control box should go out after the second control box is powered up. If the 'ALARM' still lights on, the probe electronics is malfunctioning.

7.5 Adjust the “BALANCE” meter on “0” using the potentiometer “MANUAL” on the front panel. At the same time the needle of the "OUTPUT" meter must go to "0".

7.6 The probe can be balanced by pressing the button "AUTO". Wait until the needle of the "BALANCE" meter stops on "0". At the same time the needle of the "OUTPUT" meter must go to "0". This procedure takes 4-6 seconds. If this procedure is failed, repeat 7.5.

***CAUTION*:**

The balancing of the probe (steps 7.5 and 7.6) must be fulfilled in dry air. Otherwise the measurements of water content will be biased. The balancing in the cloud with high water content (>1gm^{-3}) may lead to overheating the sensors after exit the cloud.

7.7 The probe balancing can be fulfilled, if the logic "0" is sent on the pin 7 of the output connector “DB-9” on the rear panel. The process of balancing is completed when the signal on pin 7 is logic "1". The duration of logic “0” for proper balancing should be 4 to 6 seconds.

7.8 For the quick check the probe operation the following simple test may be fulfilled. Cool the collector sensor and leave the reference sensor without changes. In this case the needle of the ‘OUTPUT’ meter will go right, while the ‘BALANCE’ meter will go left (“cold” direction). Then, cool the reference sensor and leave the collector sensor without changes. In this case the needle of the ‘BALANCE’ meter will go right (towards ‘hot’, see Fig. 3). The ‘OUTPUT’ signal slowly will go towards zero. The cooling of the sensors can be done by spraying or by gentle touching of the sensor surface by a finger, watered Q-tip, etc.

7.9 For proper installation of the bias voltage in the RS loop:
(i) remove transparent cover on the front panel
(ii) turn on the probe
(iii) press the “REG” button
(iv) keeping the “REG” button pressed set zero on the “BALANCE” meter with the help of the “REG” potentiometer (above the button).

This procedure should be done once after installation the probe on an airplane for typical flight conditions.

7.10 To activate the vane de-icing heaters turn on the “HEATER” switch on the right side of the front panel on both control boxes. If the “HEATER” switch is ‘on’ on one of the control boxes and ‘off’ on the other one, the vane de-icing heaters will not be activated. For a single control box operation mode the vane heaters can be activated, if the control cable on the rear panel is disconnected from the second control box.

7.11 Output connector (RS232)

pin 1	output LWC/TWC signal 0-10V
pin 6	output balance signal 0-10V
pin 7	auto balancing
pin 9	ground

***WARNING*:**

Hailstones in clouds or melting ice in wind tunnels may cause damages of the TWC sensor.

APPENDIX A

CALCULATION OF WATER CONTENT

Liquid clouds

In liquid clouds liquid water content W_w can be calculated from measurements of LWC or TWC sensors as

$$W_w = \frac{P_L}{\varepsilon_{Lw} U S_L L_w^*} \quad (8)$$

$$W_w = \frac{P_T}{\varepsilon_{Tw} U S_T L_w^*}, \quad (9)$$

respectively. Here U is true air speed in the vicinity of the sensor head; S_T and S_L are the sample areas of the LWC and TWC collector sensors, respectively; ε_{Lw}, ε_{Tw} are the integral liquid droplets collection efficiencies for LWC and TWC sensors, respectively;

$$L_w^* = (T_e - T_a)C_l + L_w(T_e), \quad (10)$$

are expanded heat for water; C_w is the specific heat of liquid water; L_w is the latent heat of evaporation at temperature T_e; T_a is air temperature; T_e is the temperature of evaporation. The temperature T_e can be assumed to be equal to sensor temperature to a good accuracy. For practical purposes it is convenient to use value L_w^* =2589 J/g, which adds ±5% error to the LWC in the temperature interval from -40°C to +20°C; P_L and P_T are heat losses on LWC and TWC collectors, respectively, associated with evaporation of cloud particles:

$$P_L = \frac{V_{L\,col}^2}{R_{L\,col}}, \quad (11)$$

$$P_T = \frac{V_{T\,col}^2}{R_{T\,col}} \quad (12)$$

$V_{L\,col}$, $V_{L\,ref}$, $V_{T\,col}$, $V_{T\,ref}$ are the signal output voltages from LWC and TWC collector sensors, respectively; $R_{L\,col}$, $R_{T\,col}$, are resistances of LWC and TWC collector sensors, respectively, for a chosen temperature. The coefficients k_L and k_T are calculated for the cloud free air using Eq.8.

For droplets with d >5μm the collection efficiency of LWC sensor can be assumed $\varepsilon_{Lw} \approx 1$ with accuracy no worse than 10%.

Ice clouds

In ice clouds ice water content W_i should be calculated from measurements of theTWC sensor as

$$W_i = \frac{P_T}{\varepsilon_{Ti} U S_T L_i^*}, \tag{13}$$

respectively. Here ε_{Ti} is ice particle collection efficiency for the TWC sensor;

$$L_w^* = (T_0 - T_a)C_i + (T_e - T_0)C_w + L_i, \tag{14}$$

is the expanded heat for ice; C_i is the specific heat of ice, L_i is the latent heat of ice melting; T_0 =0°C. For characteristic sizes of ice particles typical for ice clouds (d>25μm) it can be assumed to a good accuracy $\varepsilon_{Ti} \approx 1$.

Mixed phase clouds

In mixed phase clouds the heat losses on LWC and TWC collectors associated with evaporation of cloud particles can be written as

$$P_L = \beta W_i L_i^* S_L U + \varepsilon_{Lw} W_w L_w^* S_L U \tag{15}$$

$$P_T = \varepsilon_{Ti} W_i L_i^* S_T U + \varepsilon_{Tw} W_w L_w^* S_T U \tag{16}$$

Combining Eqs. 16 and 17 yields

$$W_w = \frac{P_L - P_T \dfrac{\beta S_L}{\varepsilon_{Ti} S_T}}{L_w^* S_L U \left(\varepsilon_{Lw} - \dfrac{\beta \varepsilon_{Tw}}{\varepsilon_{Ti}} \right)} \tag{17}$$

$$W_i = \frac{P_T - P_L \dfrac{\varepsilon_{Tw} S_T}{\varepsilon_{Lw} S_L}}{L_i^* S_T U \left(\varepsilon_{Ti} - \dfrac{\beta \varepsilon_{Tw}}{\varepsilon_{Lw}} \right)} \tag{18}$$

Here β is the residual effect of ice (or collection efficiency of ice particles) for the LWC collector. The coefficient β is a function of ice particle shape, size, and air speed. In average at 100m/s for typical ice particles in tropospheric ice and mixed clouds $\beta \approx 0.11$.

The value $S_L R_{L\ col}$, $S_T R_{T\ col}$ for T=70°C and T=90°C are given in calibration tables (Appendix D). For other T the resistances may be calculated based on Appendix B.

APPENDIX B

CALCULATION OF N_{oper} AND N_{ref} FOR DIFFERENT TEMPERATURES

The resistance of the sensor R_T at temperature T may be calculated from equation

$$R_T = R_0 \frac{1+K_{20}(T-20)}{1+K_{20}(T_0-20)}$$

Here R_0 is the measured resistance of the sensor at temperature T_0 (°C); K_{20} is the coefficient the dependence of the resistance on temperature at T=20°C. For nickel K_{20}=0.0062 $^{\circ}C^{-1}$.

The resistance R_0 has to be measured in laboratory conditions. Since the sensor's resistance (1-4 Ohm) may be comparable with the resistance of contacts, it should be measured using 4-wire line. The sensor during measurements has to be placed in a thermo stable environment with a circulating air (or liquid) in order to prevent a cushion of warm air (liquid) around the sensor. The fluctuations of temperature during measurements and the accuracy of temperature measurements should be no worse than 0.3°C.

The values N_{oper} and N_{ref} are derived from the equations

$$N_{oper} = \frac{R_{oper}}{R_{const\ oper}}$$

$$N_{ref} = \frac{R_{ref}}{R_{const\ ref}}$$

The resistance $R_{const\ oper}$ and $R_{const\ ref}$ are parts of the bridge and are mounted on the sensor head. The schematic of connections of the resistance R_{oper} , R_{ref}, $R_{const\ oper}$ and $R_{const\ ref}$ is shown in the wiring diagram.

APPENDIX C

REPLACEMENT OF A SENSOR HEAD

To replace the sensor head remove two screws from the sensor holder mounted on the top of the pillar. The sensor holder consists of two parts. To split it, remove two screws on cylindrical side of the sensor holder. Put the sensor head between two pieces of the sensor holder and tight the screws. Mount the sensor head on the top of the pillar and fix the sensor holder by two screws.

***WARNING*:**

Change $\mathbf{N}_{ref}$ and $\mathbf{N}_{oper}$ in the front panels of both LWC and TWC control boxes after each replacement of a sensor head.

APPENDIX D

CALIBRATION TABLES OF SENSORS

IVO SENSOR HEAD # 167

	R1	*R2 (coll.)*	*R3 (ref.)*	*R4*	at *T* (°C)
LWC	1.535	2.369	2.016	1.51	21.1
TWC	1.526	2.24	2.287	1.525	21.3

	d (mm)	*l* (mm)	*S* (cm^2)
LWC	1.85	16.3	0.302
TWC	8		0.503

Sensor temperature			0°C	70°C	90°C	
LWC sensor	R_{ref}		1.773	2.580	2.810	
	R_{col}		2.081	3.028	3.298	
	N_{ref}		1.174	**1.708**	**1.861**	
	N_{col}		1.356	**1.972**	**2.149**	
	RS		0.627	**0.913**	**0.995**	

TWC sensor	R_{ref}		1.992	2.961	3.238	
	R_{col}		1.951	2.900	3.172	
	N_{ref}		1.306	**1.942**	**2.123**	
	N_{col}		1.279	**1.901**	**2.078**	
	RS		0.981	**1.458**	**1.594**	

FIGURES AND DIAGRAMS

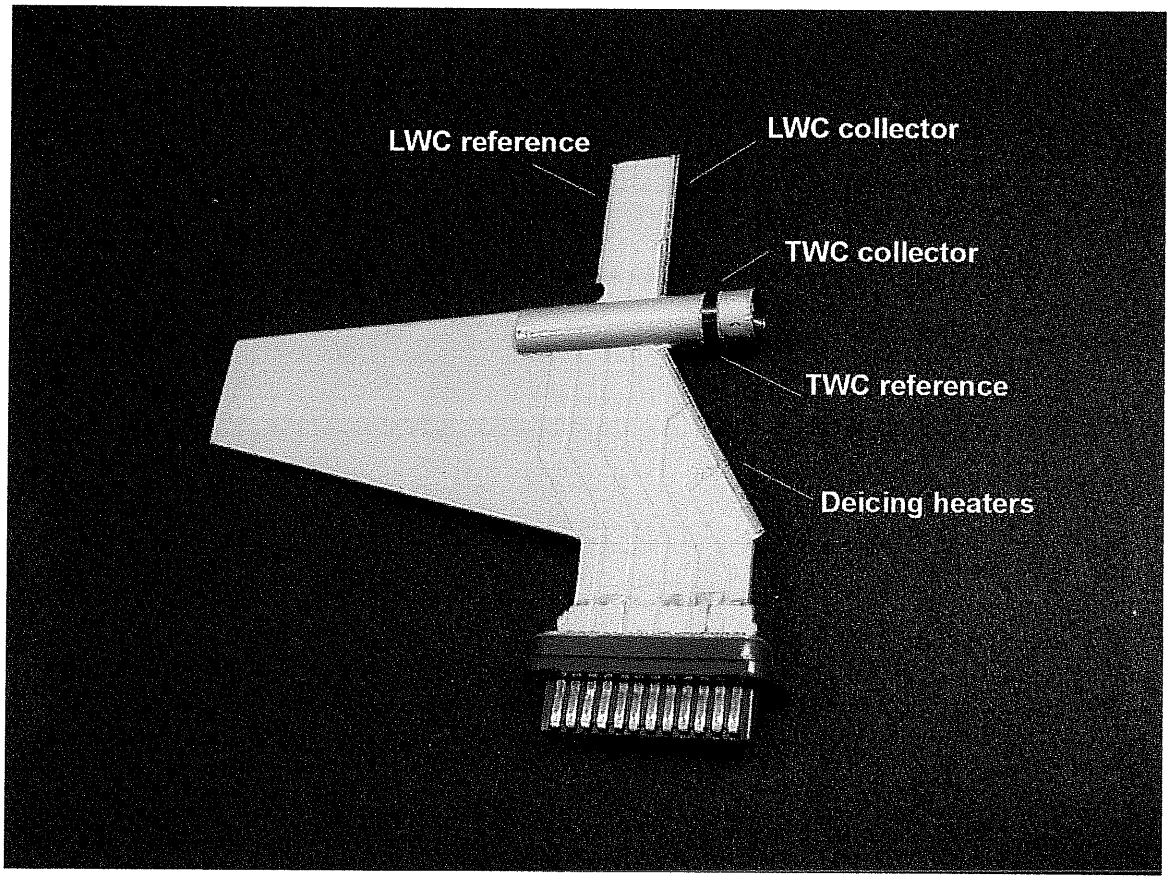

LWC reference
LWC collector
TWC collector
TWC reference
Deicing heaters

Figure 1

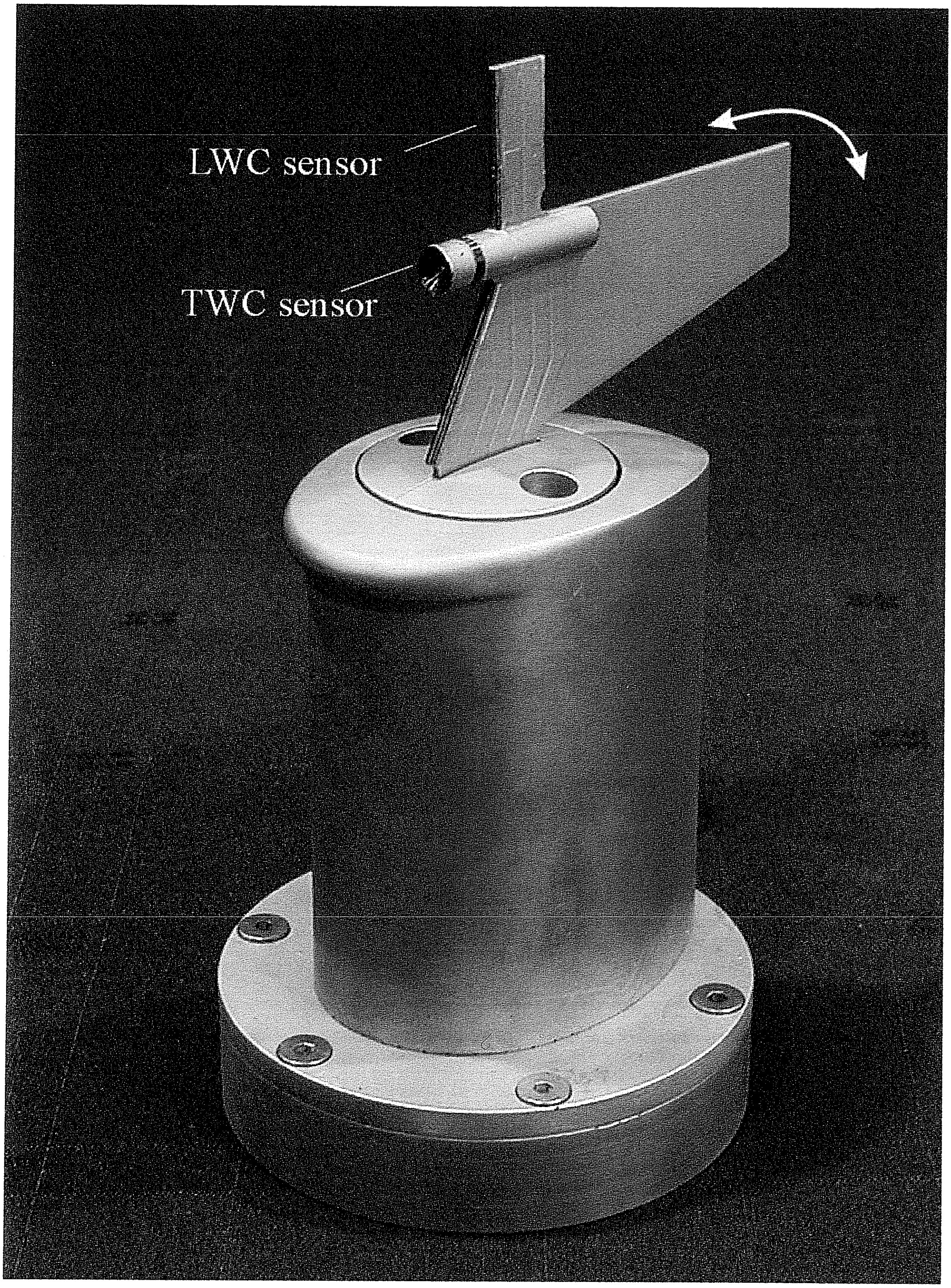


Figure 2


CWCM
ST
Sky Tech Research
POWER
ON
OFF
OUTPUT
BALANCE
COLD - - HOT
MANUAL
AUTO
REG
REFERENCE
COLLECTOR
1 5 0
1 5 0
1 8 1
2 1 9
ALARM
ON
OFF
HEATER

Figure 3

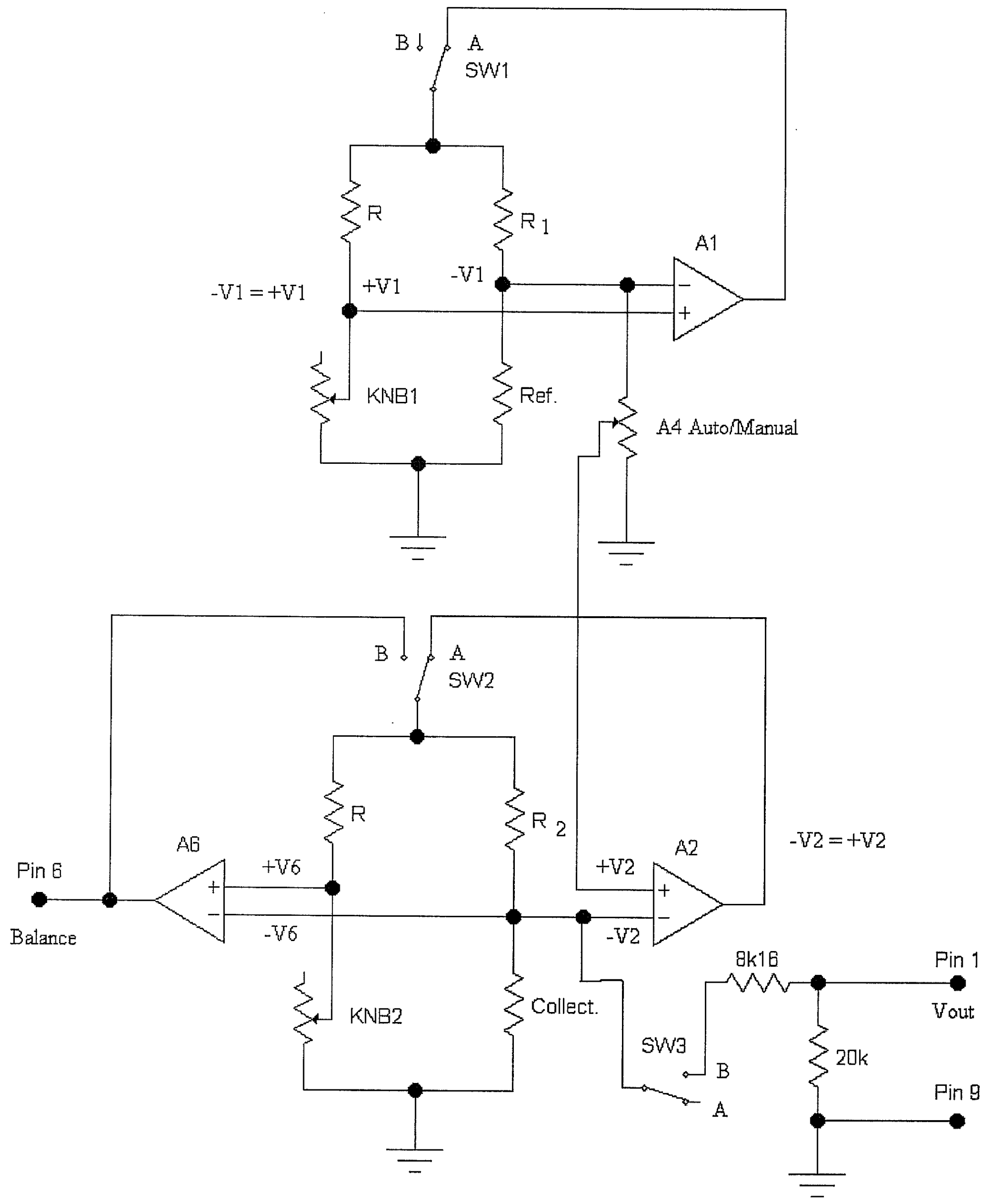

B
A
SW1
R
R 1
A1
-V1 = +V1
+V1
-V1
KNB1
Ref.
A4 Auto/Manual
B
A
SW2
R
R 2
A6
A2
-V2 = +V2
Pin 6
+V6
+V2
Balance
-V6
-V2
8k16
Pin 1
KNB2
Collect.
Vout
SW3
B
20k
A
Pin 9

Figure 4

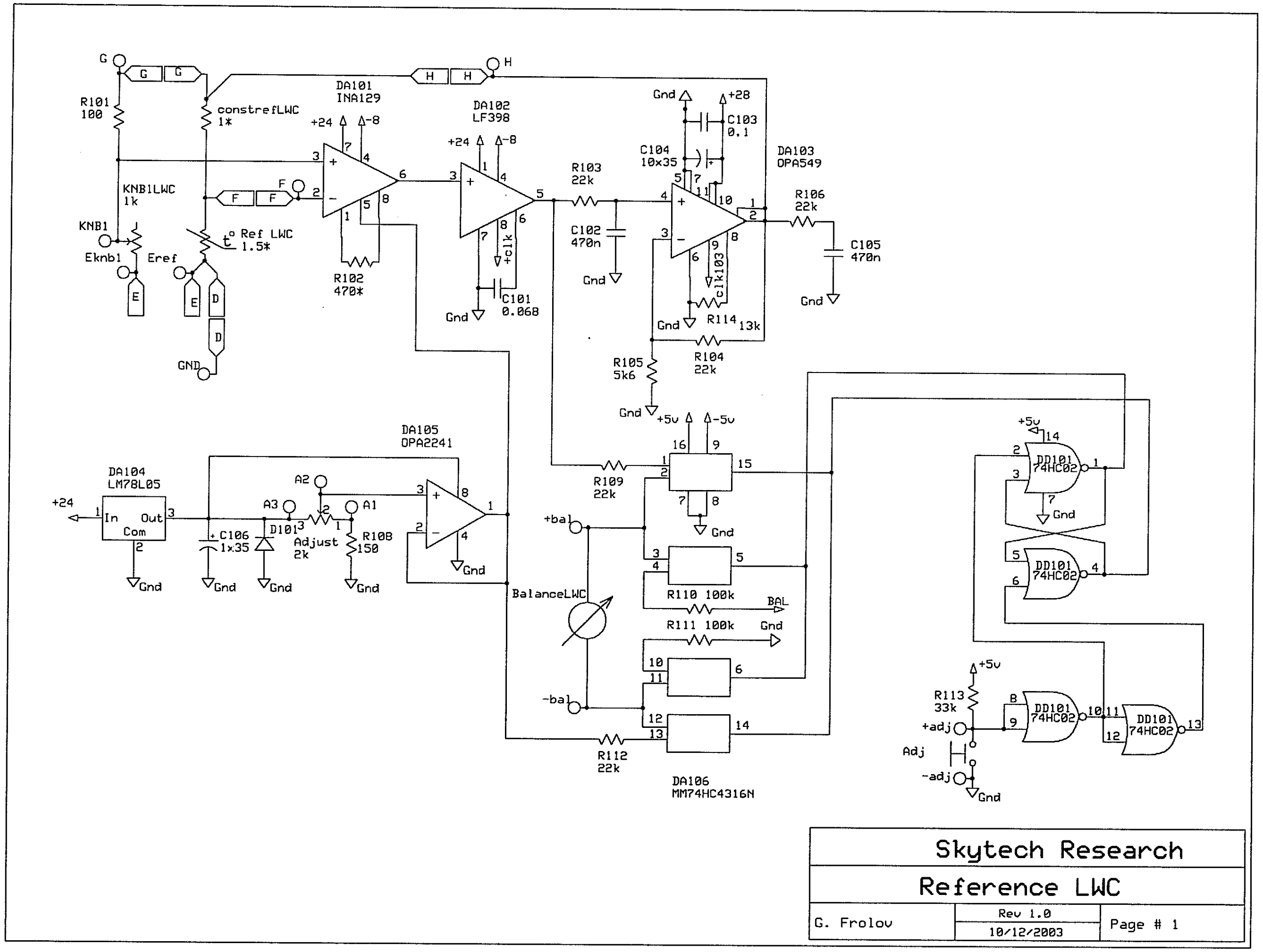


Figure 5.. Module A1, LWC (or TWC).

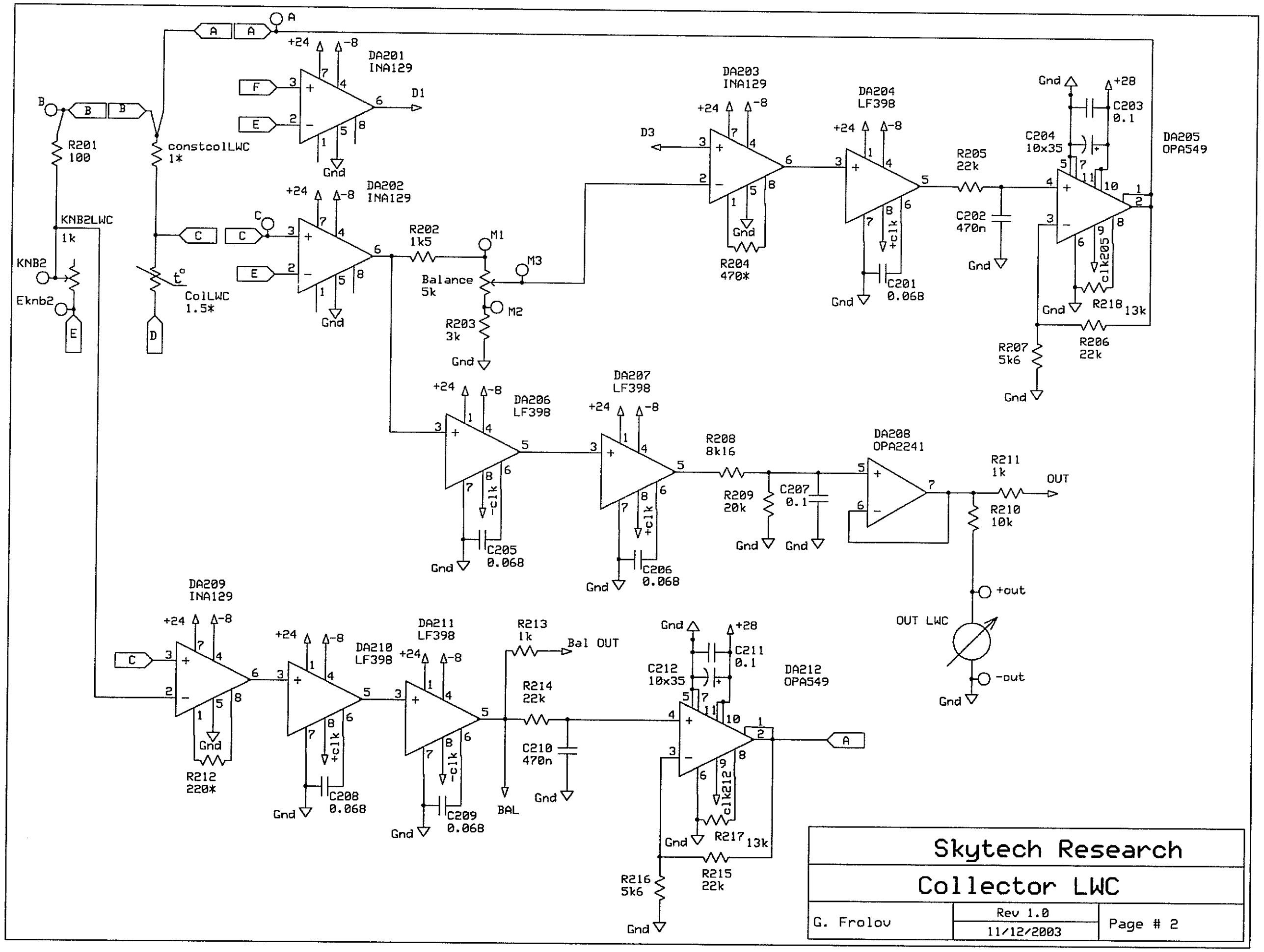


Figure 6. Module A2, LWC (or TWC).

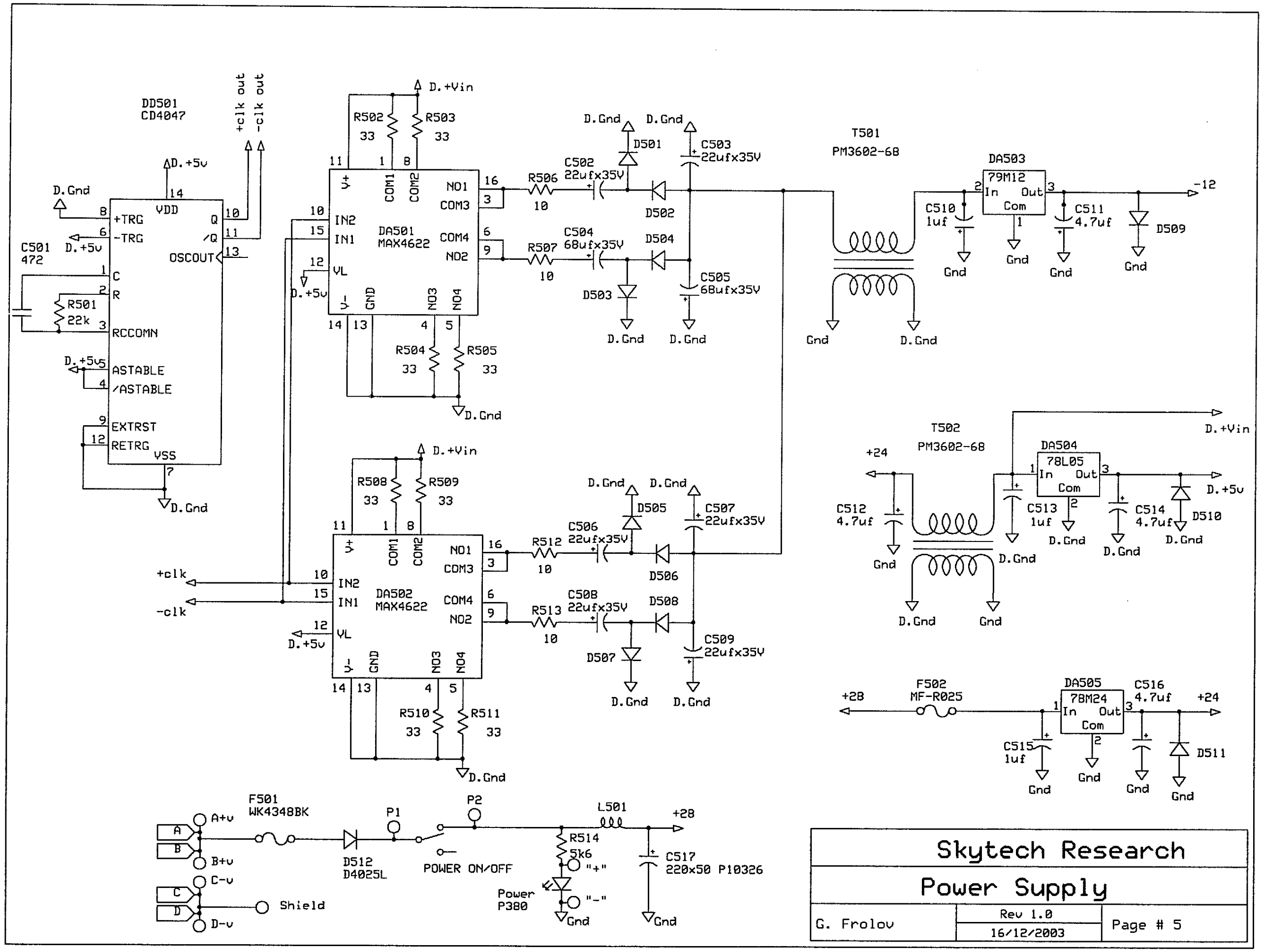


Figure 7. Module A3.

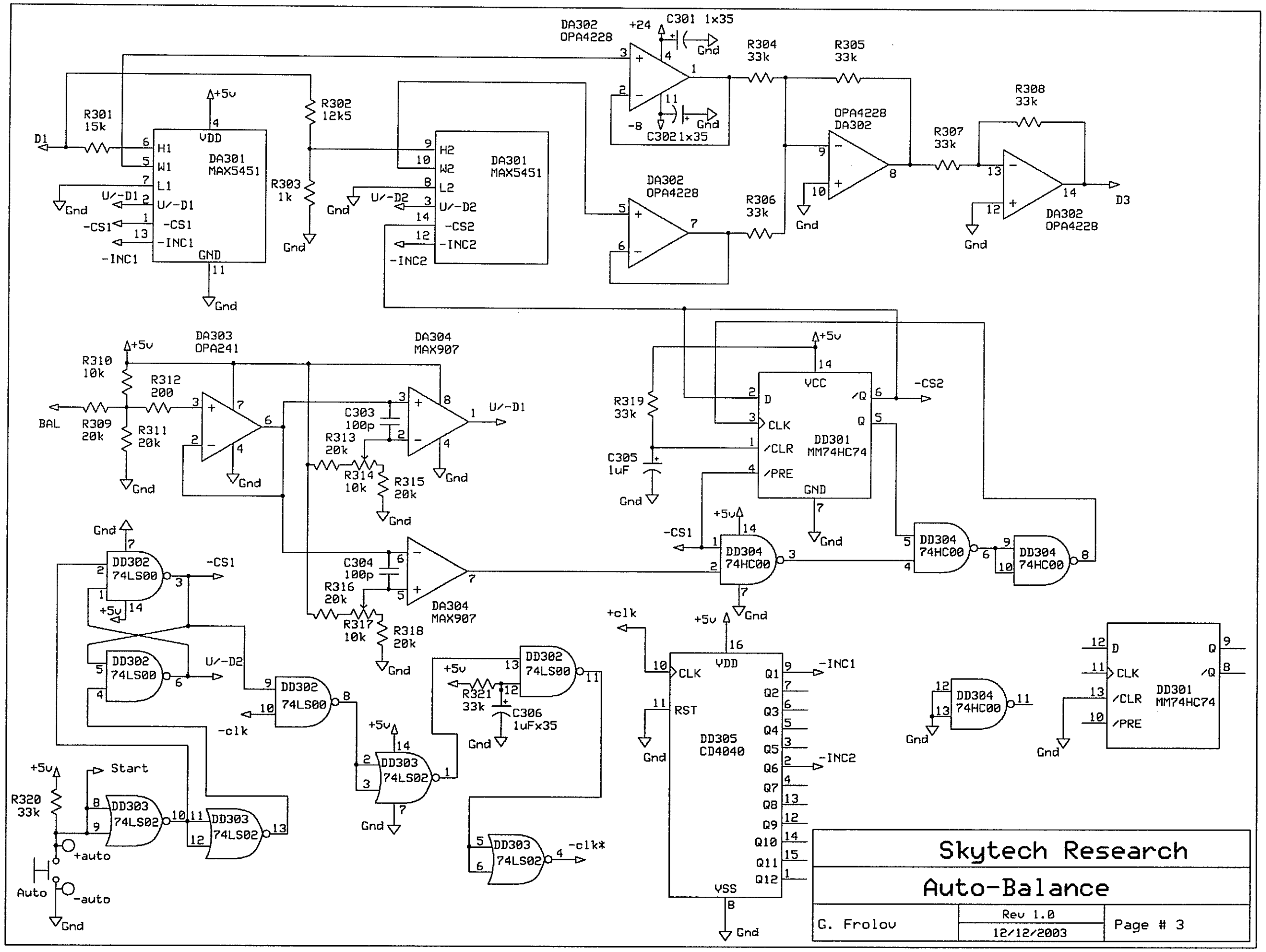


Figure 8. Module 4.

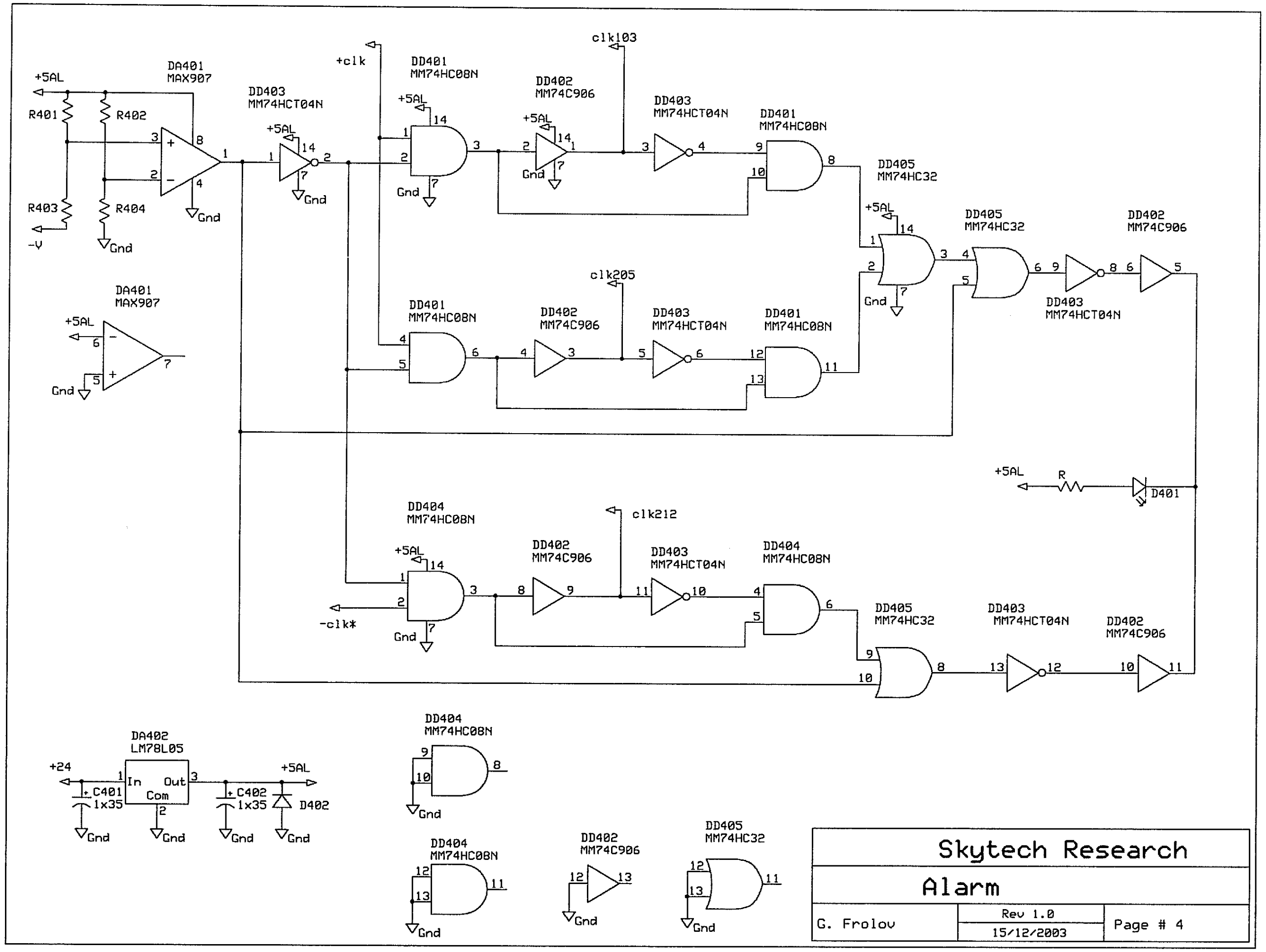


Figure 9. Module A5.

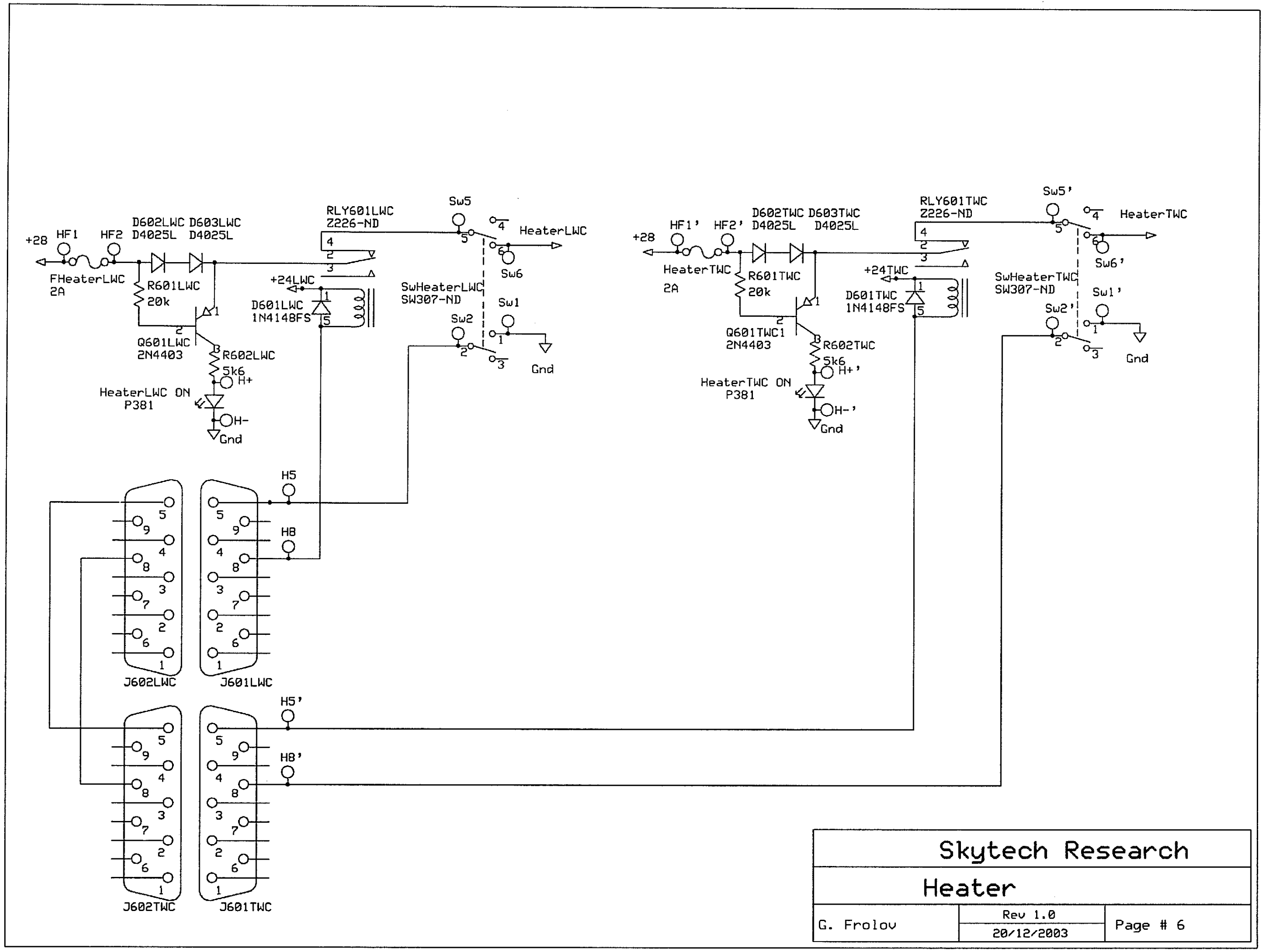


Figure 10. Module A6.

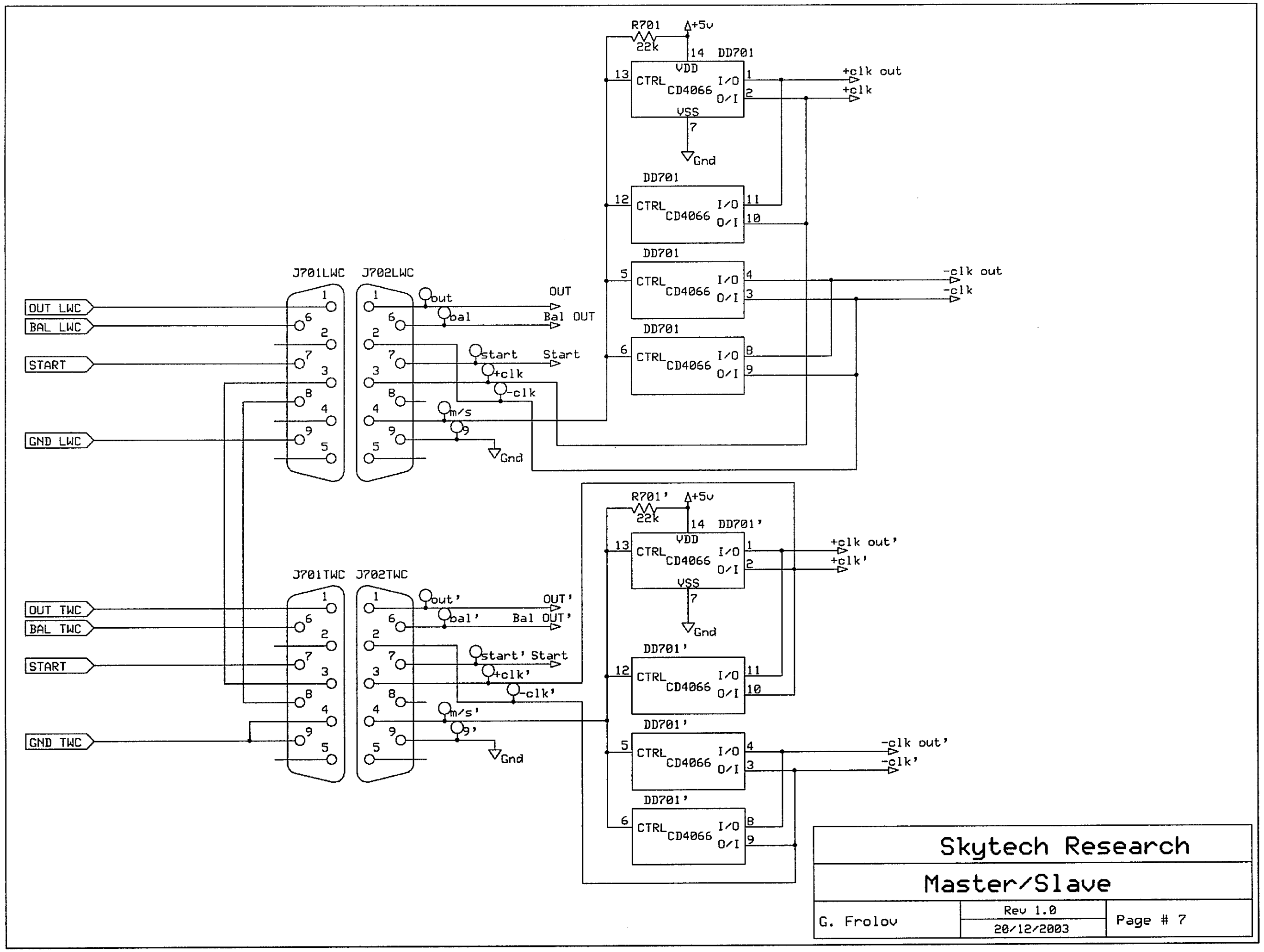


Figure 11. Module A7.

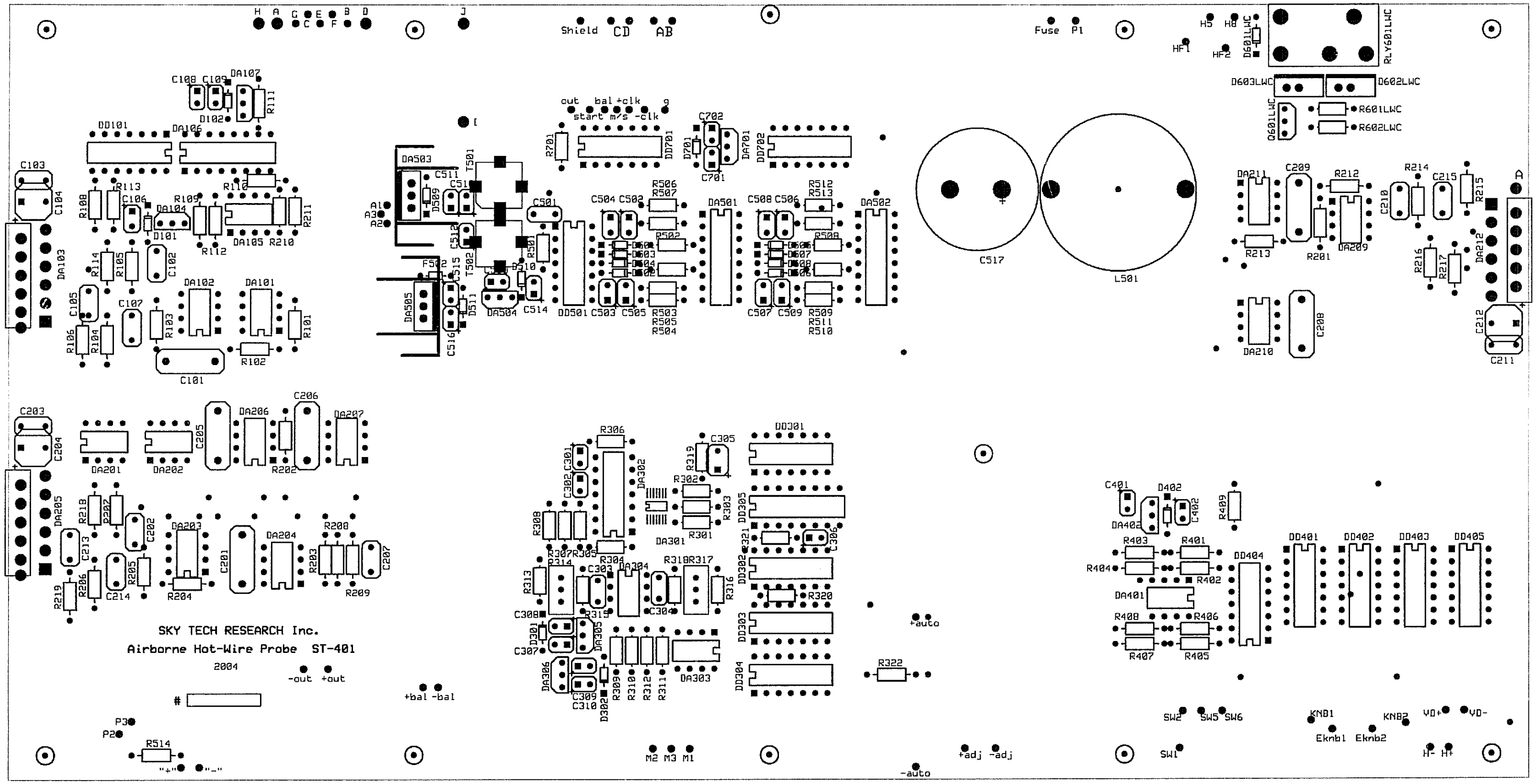
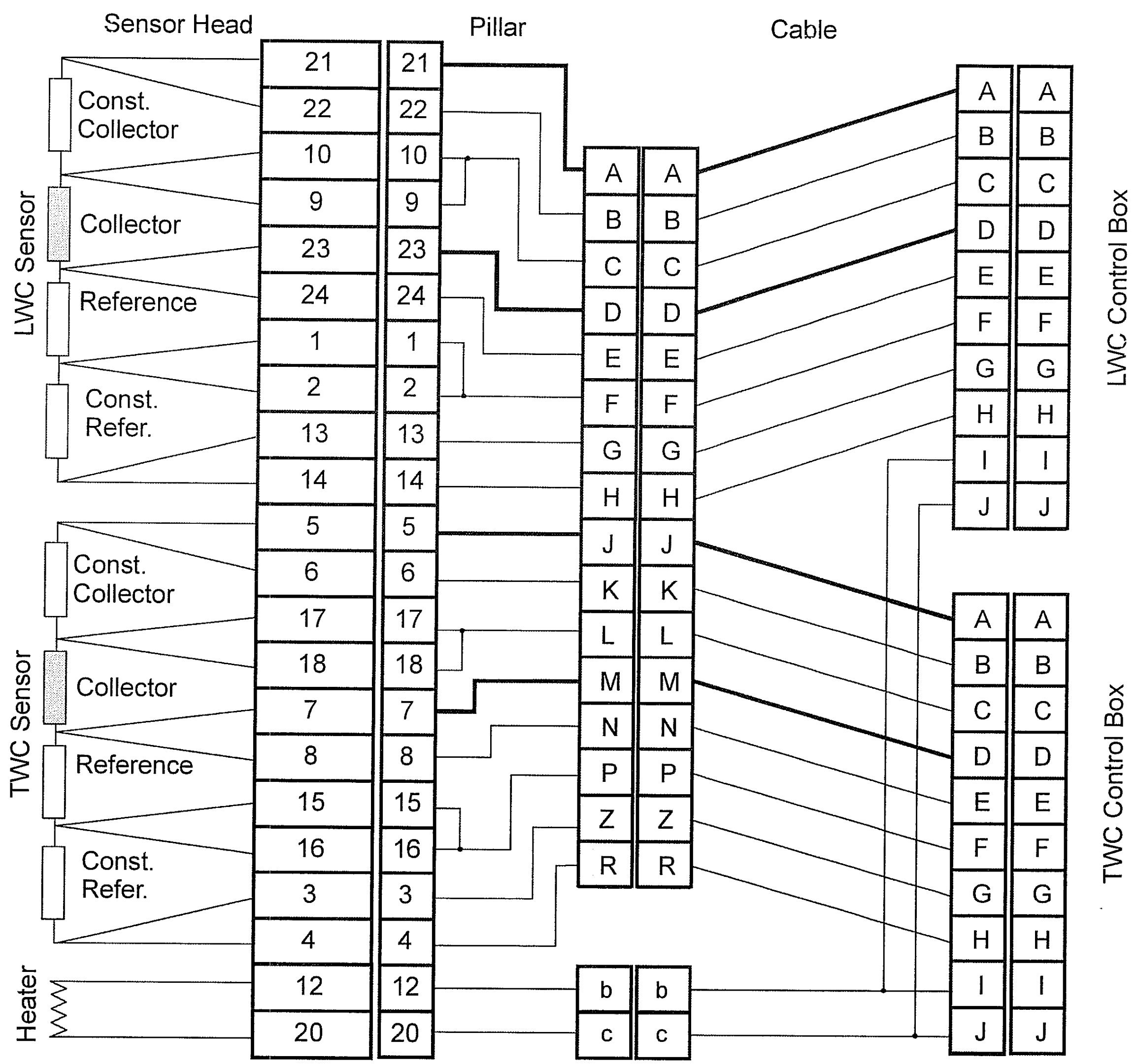
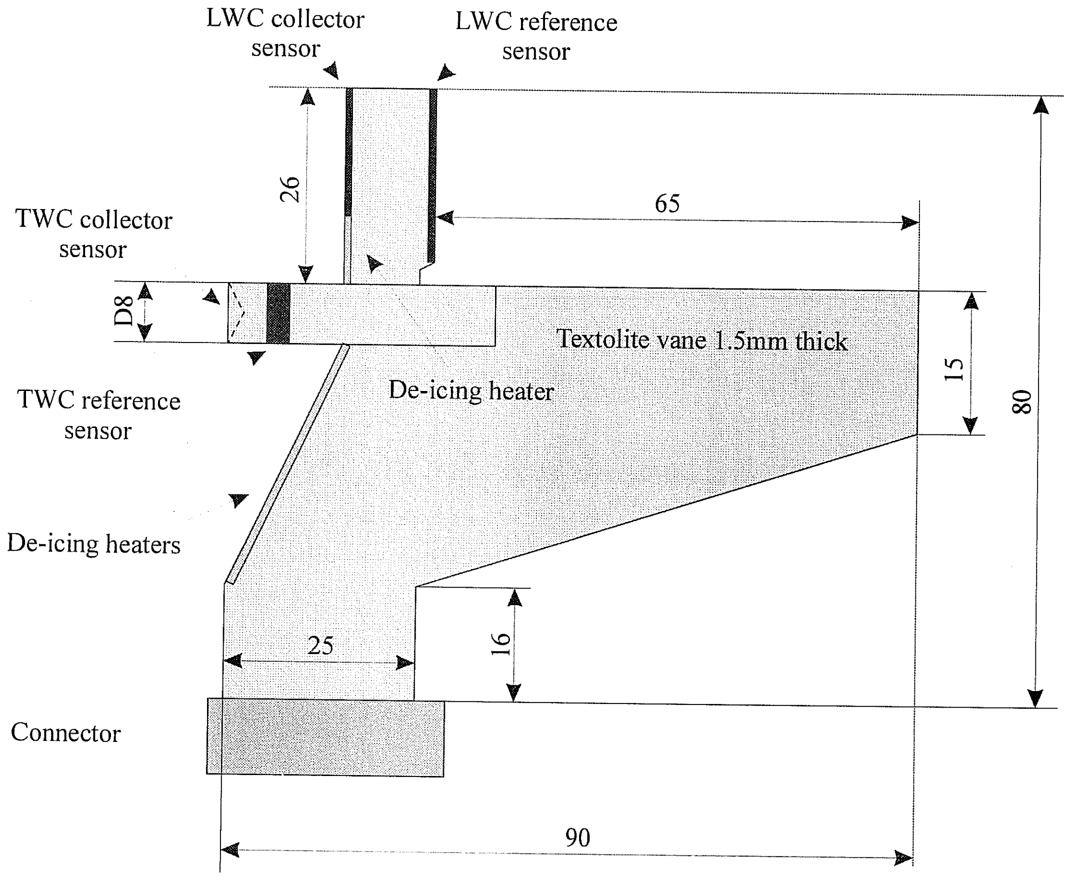


Figure 12. PCB board and component outlines.

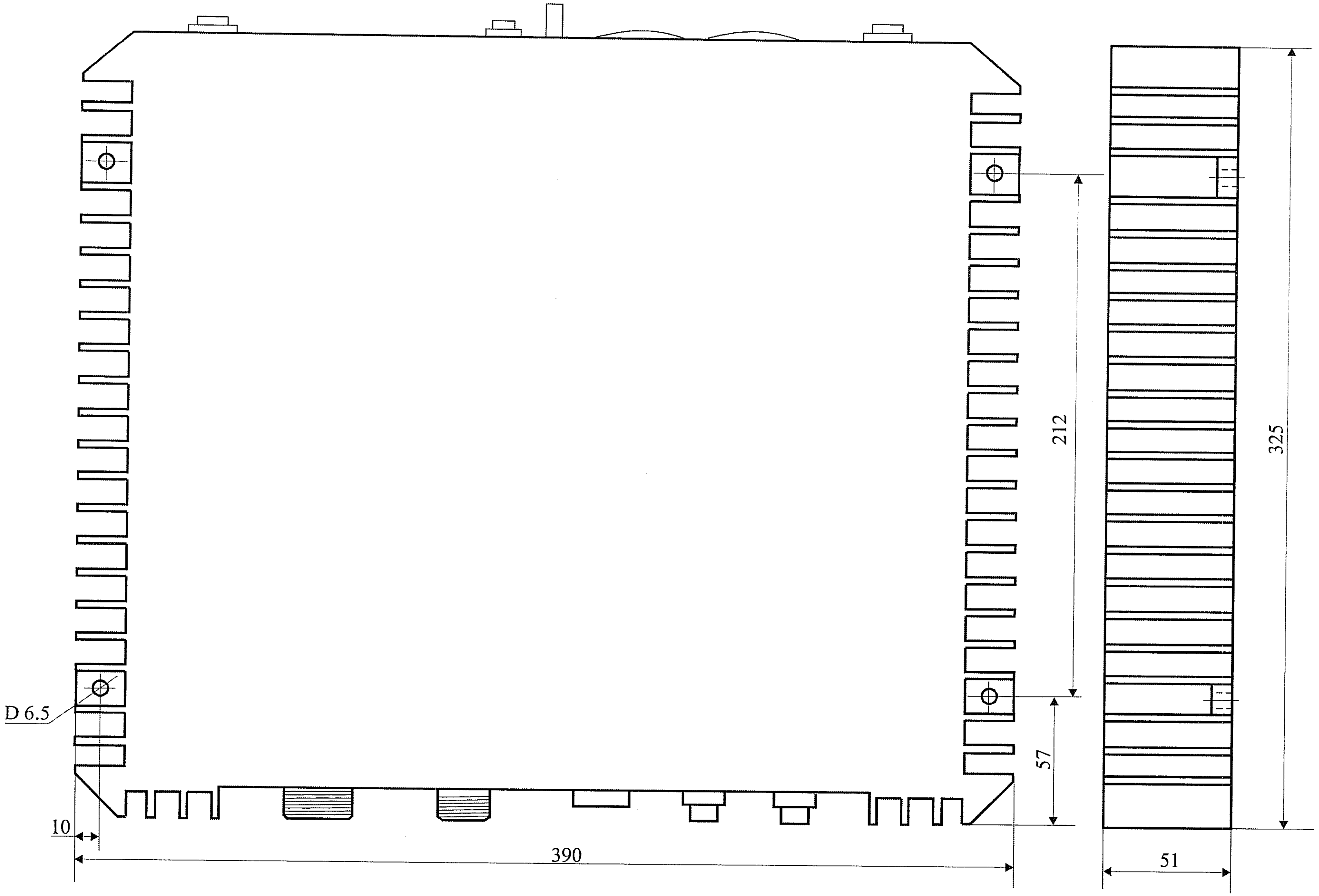


Nevzorov Probe Wiring Diagram

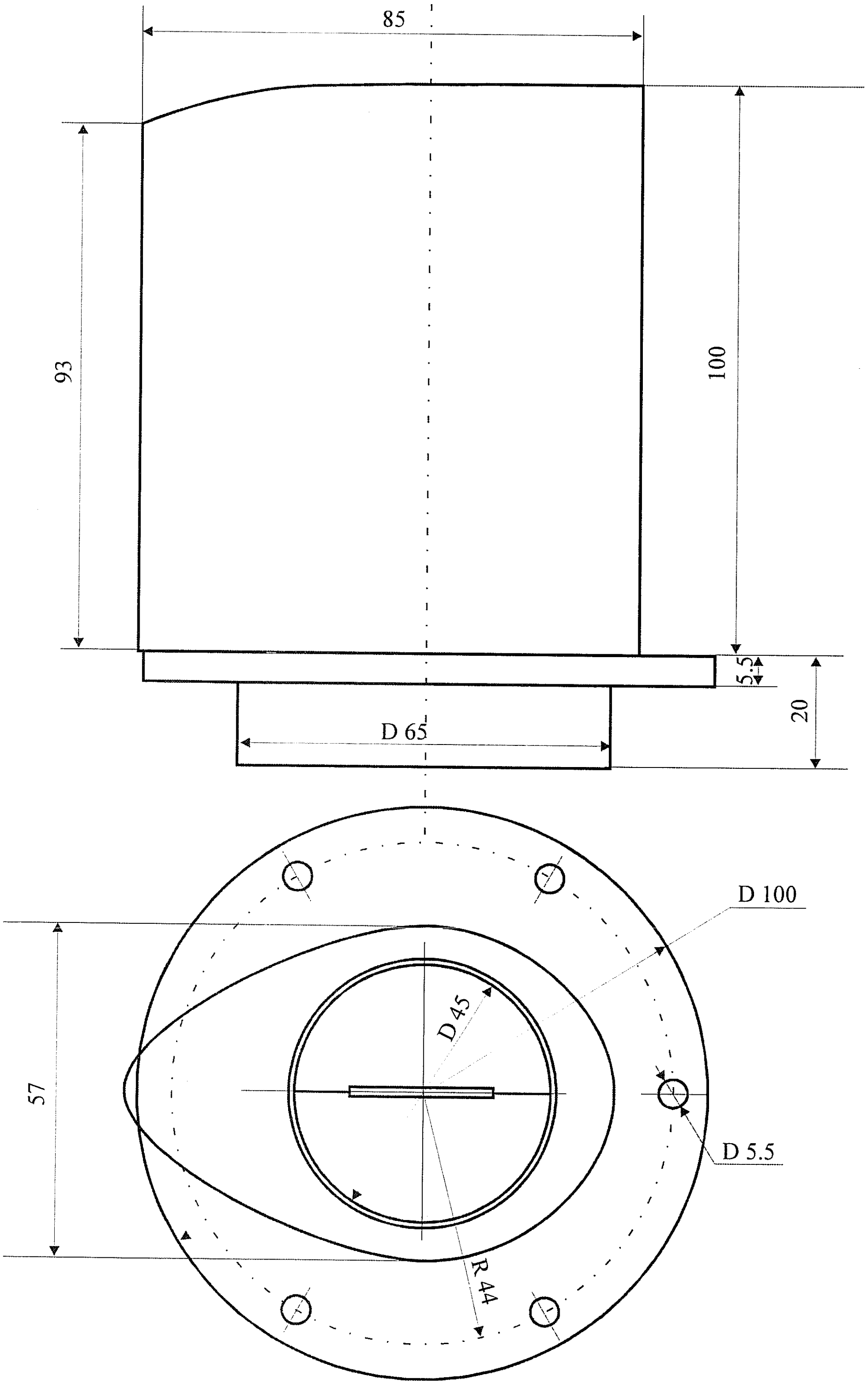
Nevzorov Sensor Vane



Nevzorov Contol Box



Nevzorov Probe Pillar



Footprint for Nevzorov Probe Pillar

A-A