Hydraulics Research
Wallingford

FIELD MEASUREMENT OF THERMAL PLUMES

C B WATERS

Report No. SR 20
March 1985

This report describes work funded by the Department of the Environment under Reserach Contract PECD 7/7/050. It was supervised by Mr C B Waters in the Services Department of Hydraulics Research, Wallingford, under the management of Mr M F C Thorn.

ABSTRACT

This report describes the development of instrumentation for field measurement of the thermal effluent from power station outfalls. The equipment consists of an array of five short time-constant thermistor probes and a pressure sensing depth meter which are towed from a survey vessel. An inboard microprocessor-based instrument displays simultaneously the five temperature readings and the depth measurement on liquid crystal displays. The sensor interrogation rate is adjustable from 1 second upwards. Recording of the sensor outputs together with real time is made on a dot-matrix printer. A simultaneous fix mark enables a correlation to be made between the sensor readings and the vessel's position.

The results of field measurements of the thermal outfall plume from Fawley Power Station are presented.

A preliminary evaluation of the "Stewkie" kite-mounted aerial photography system for photographing thermal plumes is also reported on.

CONTENTS

1 INTRODUCTION

For many years Hydraulics Research (HR) has been involved in studies aimed at predicting the behaviour of thermal plumes emanating from the offshore discharge of cooling water from coastal power stations. In many cases, studies have been carried out prior to power station construction in order to optimise the siting of the outfall and intake structures. Clearly any recirculation of the heated water would result in a reduction in power station efficiency.

Mathematical and physical models have been developed to assist in the predictive process. Proving data for these models are obtained from extensive field measurements of the flow patterns, salinity structure etc at the particular site. Subsequent post-construction field measurements of the thermal plume are carried out in order to confirm the prediction and/or to provide further data for refining future models.

In the development of many existing power station sites expansion of the generating capacity will result in a proportional increase in the discharge of heated water to the sea, either through the existing outfall or through additional outfalls. The complex nature of the thermal interchange poses further problems for the modeller and necessitates a greater understanding of the processes involved.

In order to improve our capabilities in the field measurement of the temperature distributions within a thermal plume a new instrument system has been developed.

A technical specification was prepared at HR and, after a competitive tendering exercise, the contract for the detailed design and manufacture of the equipment was let to Cirtronic Instruments Ltd, Reading.

Sensors

The underwater sensor array consists of five thermistor temperature probes and a single pressure-sensing depth meter.

The construction of one of the thermistor units is shown in Fig 1 and consists of a Fenwall GB34 MM132 thermistor moulded, using epoxy resin, to an individual electro-mechanical cable. A circular cage around the thermistor provides good mechanical protection without adversely affecting the flow around the thermistor or the measurement time constant. The thermistors used are glass encapsulated and are designed for oceanographic use. The resistance-temperature (R-T) characteristics are matched to a standard R-T curve to give an interchangeability to within ±0.1°C over the temperature range 0 - 30°C. This sensor interchangeability simplifies the electronic circuitry and eliminates the need for individual circuit adjustment.

By having the sensors on individual cables it is easy to make up the measurement array to suit the site requirements and also allows rapid sensor exchange or level adjustment in the field.

Normally the sensors are strapped at the required measurements levels either to a rigid streamlined mast attached to the side of the tracking vessel or to a common towing line with a heavy streamlined weight or a cable depressor at its lower end. The total depth of the array is measured using a Druck PDCR 10 strain-gauge pressure transducer attached at the lower end of the array. The depth of each temperature sensor is then determined by interpolation.

The characteristics of the sensors, including the R-T thermistor values, are given in the following table:

TABLE 1 SENSOR CHARACTERISTICS

(a) R-T characteristics of Fenwall GB 34 MM 132 thermistors

Temp (°C)	R (Ω)	Temp (°C)	R (Ω)	Temp (°C)	R (Ω)	Temp (°C)	R (Ω)
0.0	11,400	5.1	9,089.6	10.2	7,298.0	15.3	5,898.2
0.1	11,349	5.2	9,050.0	10.3	7,267.1	15.4	5,874.0
0.2	11,298	5.3	9,010.6	10.4	7,236.4	15.5	5,849.9
0.3	11,247	5.4	8,971.3	10.5	7,205.8	15.6	5,826.0
0.4	11,196	5.5	8,932.3	10.6	7,175.4	15.7	5,802.1
0.5	11,146	5.6	8,893.4	10.7	7,145.1	15.8	5,778.4
0.6	11,096	5.7	8,854.7	10.8	7,115.0	15.9	5,754.7
0.7	11,046	5.8	8,816.3	10.9	7,085.0	16.0	5,731.2
0.8	10,997	5.9	8,778.0	11.0	7,055.2	16.1	5,707.8
0.9	10,948	6.0	8,739.9	11.1	7,025.5	16.2	5,684.5
1.0	10,899	6.1	8,702.0	11.2	6,996.0	16.3	5,661.3
1.1	10,850	6.2	8.664.3	11.3	6,966.6	16.4	5,638.2
1.2	10,801	6.3	8,626.8	11.4	6,937.3	16.5	5,615.2
1.3	10,753	6.4	8,589.4	11.5	6,908.2	16.6	5,592.3
1.4	10.705	6.5	8,552.2	11.6	6,879.2	16.7	5,569.5
1.5	10,658	6.6	8,515.3	11.7	6,850.3	16.8	5,546.9
1.6	10,610	6.7	8,478.5	11.8	6,821.6	16.9	5,524.3
1.7	10,563	6.8	8,441.9	11.9	6,793.0	17.0	5,501.8
1.8	10,516	6.9	8,405.4	12.0	6,764.6	17.1	5,479.5
1.9	10,469	7.0	8,369.2	12.1	6,736.3	17.2	5,457.2
2.0	10,422	7.1	8,333.1	12.2	6,708.1	17.3	5,435.1
2.1	10,376	7.2	8,297.2	12.3	6,680.1	17.4	5,413.1
2.2	10,330	7.3	8,261.5	12.4	6,652.2	17.5	5,391.1
2.3	10,284	7.4	8,225.9	12.5	6,624.4	17.6	5,369.3
2.4	10,238	7.5	8,190.5	12.6	6.596.8	17.7	5,347.5
2.5	10,193	7.6	8,155.3	12.7	6,569.3	17.8	5,325.9
2.6	10,148	7.7	8,120.3	12.8	6.541.9	17.9	5,304.4
2.7	10,103	7.8	8,085.5	12.9	6,514.7	18.0	5,282.9
2.8	10,058	7.9	8,050.8	13.0	6,487.6	18.1	5,261.6
2.9	10,014	8.0	8,016.3	13.1	6,460.6	18.2	5,240.4
3.0	9,969.5	8.1	7,981.9	13.2	6,433.7	18.3	5,219.2
3.1	9,925.5	8.2	7,947.7	13.3	6,407.0	18.4	5,198.2
3.2	9,881.6	8.3	7,913.7	13.4	6,380.4	18.5	5,177.2
3.3	9,838.1	8.4	7,879.9	13.5	6,353.9	18.6	5,156.4
3.4	9,794.7	8.5	7,846.2	13.6	6,327.6	18.7	5,135.6
3.5	9,751.5	8.6	7,812.7	13.7	6,301.4	18.8	5,115.0
3.6	9,708.6	8.7	7,779.3	13.8	6,275.3	18.9	5,094.4
3.7	9,665.9	8.8	7,746.1	13.9	6,249.3	19.0	5,073.9
3.8	9,623.3	8.9	7,713.1	14.0	6,223.4	19.1	5,053.6
3.9	9,581.0	9.0	7,680.2	14.1	6,197.7	19.2	5,033.3
4.0	9,539.0	9.1	7,647.5	14.2	6,172.1	19.3	5,013.1
4.1	9,497.1	9.2	7,614.9	14.3	6,146.6	19.4	4,993.0
4.2	9,455.4	9.3	7,582.6	14.4	6,121.2	19.5	4,973.0
4.3	9,414.0	9.4	7,550.3	14.5	6,096.0	19.6	4,953.1
4.4	9,372.7	9.5	7,518.2	14.6	6,070.9	19.7	4,933.3
4.5	9,331.7	9.6	7,486.3	14.7	6,045.9	19.8	4,913.5
4.6	9,290.8	9.7	7,454.5	14.8	6,021.0	19.9	4,893.9
4.7	9,250.2	9.8	7,422.9	14.9	5,996.2	20.0	4,874.4
4.8	9,209.7	9.9	7,391.5	15.0	5,971.5	20.1	4,854.9
4.9	9,169.5	10.0	7,360.1	15.1	5,947.0	20.2	4,835.5
5.0	9,129.5	10.1	7,329.0	15.2	5,922.5	20.3	4,816.3

TABLE 1 SENSOR CHARACTERISTICS con't

Temp (°C)	R (Ω)	Temp (°C)	R (Ω)	Temp (°C)	R (Ω)	Temp (°C)	R (Ω)
20.4	4,797.1	23.0	4,327.5	25.6	3,909.9	28.2	3,537.9
20.5	4,778.0	23.1	4,310.5	25.7	3,894.8	28.3	3,524.5
20.6	4,758.9	23.2	4,293.6	25.8	3,879.7	28.4	3,511.1
20.7	4,740.0	23.3	4,276.8	25.9	3,864.8	28.5	3,497.7
20.8	4.721.2	23.4	4,260.0	26.0	3,849.9	28.6	3,484.4
20.9	4,702.4	23.5	4,243.4	26.1	3,835.0	28.7	3,471.2
21.0	4,683.7	23.6	4,226.8	26.2	3,820.2	28.8	3,458.0
21.1	4,665.1	23.7	4,210.2	26.3	3,805.5	28.9	3,444.9
21.2	4,646.6	23.8	4,193.8	26.4	3,790.9	29.0	3,431.8
21.3	4,628.2	23.9	4,177.4	26.5	3,776.3	29.1	3,418.8
21.4	4,609.9	24.0	4,161.1	26.6	3,761.8	29.2	3,405.9
21.5	4,591.6	24.1	4,144.9	26.7	3,747.3	29.3	3,393.0
21.6	4,573.4	24.2	4,128.7	26.8	3,732.9	29.4	3,380.1
21.7	4,555.3	24.3	4,112.6	26.9	3,718.6	29.5	3,367.3
21.8	4,537.3	24.4	4,096.6	27.0	3,704.3	29.6	3,354.6
21.9	4,519.4	24.5	4,080.7	27.1	3,690.1	29.7	3,341.9
22.0	4,501.6	24.6	4,064.8	27.2	3,676.0	29.8	3,329.3
22.1	4,483.8	24.7	4,049.0	27.3	3,661.9	29.9	3,316.8
22.2	4,466.1	24.8	4,033.3	27.4	3,647.9	30.0	3,304.3
22.3	4,448.5	24.9	4,017.6	27.5	3,633.9		
22.4	4,431.0	25.0	4,002.0	27.6	3,620.0		
22.5	4,413.5	25.1	3,986.5	27.7	3,606.2		
22.6	4,396.2	25.2	3,971.0	27.8	3,592.4		
22.7	4,378.9	25.3	3,955.6	27.9	3,578.7		
22.8	4,361.7	25.4	3,940.3	28.0	3,565.1		
22.9	4,344.6	25.5	3.925.1	28.1	3,551.5		

(b) Dissipation Constant, ie. the power required to raise the thermistor temperature 1°C

9.0 mW/C° in still water
10.0 mW/C° in moving water, 6m/s

(c) Time Constant, ie. the time required by the thermistor to change 63% of the difference between its initial and final temperature

1 second in still water
0.3 seconds in moving water, 6m/s

(d) Temperature measurement

Range 0 - 30°C
Accuracy ±0.1°C over the 0 - 30°C range
Stability ± 0.05°C per year change maximum

(e) Depth measurement

Range 0- 30m

Accuracy ±0.1m

In-board Instrumentation

A photograph of the inboard instrument is shown in Plate 1.

A full technical description of the instrumentation, including the software listings, as supplied by the manufacturer, is given in the Appendix to this report.

The basic components of the system comprise:

(a) a sensor energisation supply;

(b) a multiplexer which scans sequentially the five thermistor channels and the depth measuring channel;

(c) a real-time clock and calender;

(d) an Intel 8031 microprocessor which controls the whole unit and converts the measured sensor values into engineering units of temperature and depth by means of a programmed "lookup" table.

Each sensor channel has an individual four-decade liquid crystal display.

A hard-copy of the six data channels is obtained using a Citizen DP-505 dot-matrix printer. Each record contains the five temperature values, the depth value and real time. The record is updated at a selectable scan rate between 1 and 99 seconds. A printout of the date is made at the start of each record block.

A simultaneous "fix" indication is made at every print cycle. This comprises a momentary contact closure which may be used to synchronise the measured values with the vessel's positional data.

The sensor values may be displayed and printed either as an instantaneous value or as an average over the set scan interval. An RS 232C outlet port enables direct connection to a microcomputer for on-board logging and computation.

The unit operates from a 12V battery supply and incorporates reverse polarity protection.

3 FIELD TRIAL

Measurements in the thermal plume

Prior to carrying out a field trial of the thermal survey system the thermistor sensors were each calibrated in the laboratory using a thermostatically controlled, circulating water bath. A measurement accuracy and interchangeability of $\pm 0.1°C$ was confirmed.

In order to demonstrate the operation of the system under field conditions a short experiment was carried out in which measurements were taken of the thermal plume from the Fawley power station outfall (see Fig 1).

The Fawley power station is oil-fired and fortunately for us, because of the miner's dispute, was operating continuously and at near full power at the time chosen for the trial. It can be seen from Fig 1 that the cooling water is taken from Southampton Water and the outfall discharges to the Solent. Calshot Spit forms a natural barrier between intake and outfall.

The experiment was carried out on 20 March 1985 during the ebb tide period only. The predicted tidal range at Southampton was 3.5m (the mean spring and neap tidal ranges are 4.0 and 1.9m respectively).

The power station generating load was 1350 MW during the period of the trial. Weather conditions were ideal with a smooth sea and very light winds throughout the day.

Five thermistor sensors were attached to a common towing line which was held near-vertical by a 25kg streamlined weight. The measurement levels were chosen to be near-surface (within 10cm) and at depths of 1, 2, 3 and 4m. The array was towed at speeds of between 1 and 1.5m/s from a 12m long hired fishing vessel.

For position control, a Motorola Miniranger III position fixing system was set up with remote station sited at Stansore Point on the mainland and at Osborne House on the Isle of Wight. On the tracking vessel, the vessel-position data from the Motorola master unit were logged onto magnetic tape cassette using an Actif DL4 logger to enable the subsequent plotting of the vessel's course to be made using the HR mainframe computer. The fix output from the thermal survey equipment was logged simultaneously onto the cassette to enable a precise correlation to be made between the temperature measurements and the vessel's position.

For this experiment, a measurement time interval of 10 seconds was chosen which, at the towing speed of 1 to 1.5m/s represented a distance of between 10 and 15 metres between fixes.

During the course of the ebb tide several traverses were made through the thermal plume to distances of some 1.5km from the outfall. For illustrative purposes, the measured near-surface temperature distributions at three tidal states are shown in Figures 3, 4 and 5. The longitudinal temperature distribution at the five measurement levels during one measurement traverse are illustrated in Fig 6 and the lateral temperature distribution at the five levels on one cross-sectin are shown in Fig 7. At the present time the field logger and computer software which would allow computer plotting and manipulation of the temperature data, have not been developed. The illustrated results have therefore been hand plotted. The results represent a small proportion of the data collected during the short measurement period. A more exhaustive analysis of the results is beyond the scope of this development project.

Aerial photography of the plume

Whilst in the field, the opportunity was taken of evaluating the use of the "Stewkie" aerial photography system for photographing thermal plumes. The "Stewkie" seen being launched in Plate 2 is a $5m^2$ semi-sail kite. The kite is inflated with balloon gas to give a positive lift and its aerofoil section, together with twin control lines, enables it to be launched and manoeuvred easily. The kite may be operated by hand in very light wind conditions and by using a winching system may be operated in wind speeds up to 10m/s (20 knots). A radio-controlled camera, attached by gimbals to the underside of the kite, allows the operator to take photographs and advance the film from the ground.

For these tests the kite was launched from the deck of a second hired fishing vessel. In the very light wind conditions the launching and recovery of the kite proved to be relatively easy. Ordinary infra-red film as used in standard cameras does not have adequate sensitivity to define the relatively small temperature differences found in an outfall plume. We therefore adopted a technique of dye-enhancement of the plume in order to provide a contrast which could be photographed using a standard colour film. The vessel was moored at the outfall structure and a concentrated solution of fluorescein was pumped to a submerged outlet nozzle within the thermal plume.

Plate 3 is a black and white print of a photograph taken from a height of 100m and shows clearly the initial spreading of the buoyant plume. The original photograph was in colour and a better contrast than that shown in the black and white print was obtained. Plate 3 is a photograph showing the outfall structure, the moored vessel and the smaller tracking vessel traversing the plume.

The dye-enhanced plume was clearly seen by the tracking vessel at 1km from the outfall. It is likely therefore that given good visibility and by operating the kite at higher altitude the trajectory of the plume could be photographed from a fixed platform. Alternatively it is feasible that given good position control of the vessel a composite longitudinal picture could be built up from a series of photographs taken at lower altitude.

The initial promising performance was somewhat marred when at the end of the day an operator error caused the kite to go out of control and ditch with consequent irreparable damage to the non-waterproof camera!

4 CONCLUSIONS AND RECOMMENDATIONS

The development of instrumentation for the measurement in three-dimensions of temperatures within the thermal plume from power station outfalls has been successfully completed.

A short field trial of the system has demonstrated both the quality and quantity of the data produced.

Encouraging results were also obtained from a preliminary evaluation of a kite-mounted aerial photography system used to photograph a dye-enhanced thermal plume.

It is desirable before undertaking full-scale field projects that the logging and software development necessary to enable the temperature data to be processed by the HR mainframe computer is completed.

Further evaluation of the "Stewkie" kite, using a waterproof camera, is also recommended.

5 ACKNOWLEDGEMENTS

The development work was supervised by Mr C B Waters Head of the Field Services Section in Dr A J Brewer's Technical Services Department, of Hydraulics Research. The electronic design and construction of the in-board instrumentation was carried out by Cirtronic Instruments Ltd, Reading. Mr M F C Thorn was the Company's nominated project officer.

Thanks are due to the various members of the HR Field Services Section for carrying out the instrument calibrations and assisting in the field trials.

We are also very grateful to Mr W Wright, Station Manager and Messrs J Bridgeman and J Spencer of the CEGB Fawley Power Station for their advice and cooperation given prior to and during the successful field trials.

This report is published by permission of the Department of the Environment but any opinions expressed are not necessarily those of the Department.

Appendix

TECHNICAL DETAILS OF THE CIRTRONIC INSTRUMENTS LTD TSI THERMAL SURVEY SYSTEM

GENERAL DESCRIPTION

The TSI Thermal Survey System is a six channel transducer monitor instrument in which one channel (CH6) has been adapted to measure pressure and the remaining five channels measure temperature.

Each of the five temperature inputs accept a thermistor which has a resistance range of roughly 11k to 3k3 for a temperature variation of 0^oC to 30^oC.

The pressure input accepts the voltage output from a Druck pressure transducer and also supplies the voltage required to excite the transducer.

Each channel has its own four decade display which is continuously updated as long as the 'Start' switch is on.

A high speed printer is incorporated to enable a permanent record of all six channels to be made, together with the time of printout. The printer, which can be disabled if required, can printout at a rate varying between once per second to once per ninety_nine seconds, the rate being selected by means of a thumbwheel switch mounted on the front panel.

The system is built around three circuit cards:_

a. 803 Microprocessor Card

b. 80 Multiplexer Card

c. 80 Real Time Black Card

all of which are accessible by releasing and hinging down the front panel.

For ease of servicing and replacement of ribbon and paper, the printer is a plug in unit.

The system is designed to run from a 12V supply and is reverse connection protected as well as fused.

The system is contained in a standard 19" x 3U Euro card frame, housed in a metal cabinet.

Supply voltage:	11 - 14V (_VE earthed)
Current	1A peaking to 4A when printing
Transducers	
Thermistors (CH1 to CH5)	Fenwal Type GB 34 MM 132
Pressure	Druck
Displays	6 x 4 decade L.C.D.
Inputs CH1 - CH5	2 pole jack plug (both poles isolated from earth.) Sleeve _VE Supply Tip Output
CH6	4 pole jock plug (all poles isolated from earth.) RD +VE supply BL -VE supply GN -VE out WH +VE out
Controls	
Supply	3 pole SKT +VE Pin 3 -VE Pin 1
	2 pole heavy duty toggle switch in bottom left hand corner
System Control	Toggle 'Start' - 'Stop' in upper left hand corner
Timing	2 decade thumbwheel switch (controls printout rate 1_99 seccs.) adjacent to 'Start' switch
Printer	Toggle 'ON' - 'OFF' beneath timing switch
Printer Reset	Combined printer reset and paper feed. Mounted on printer

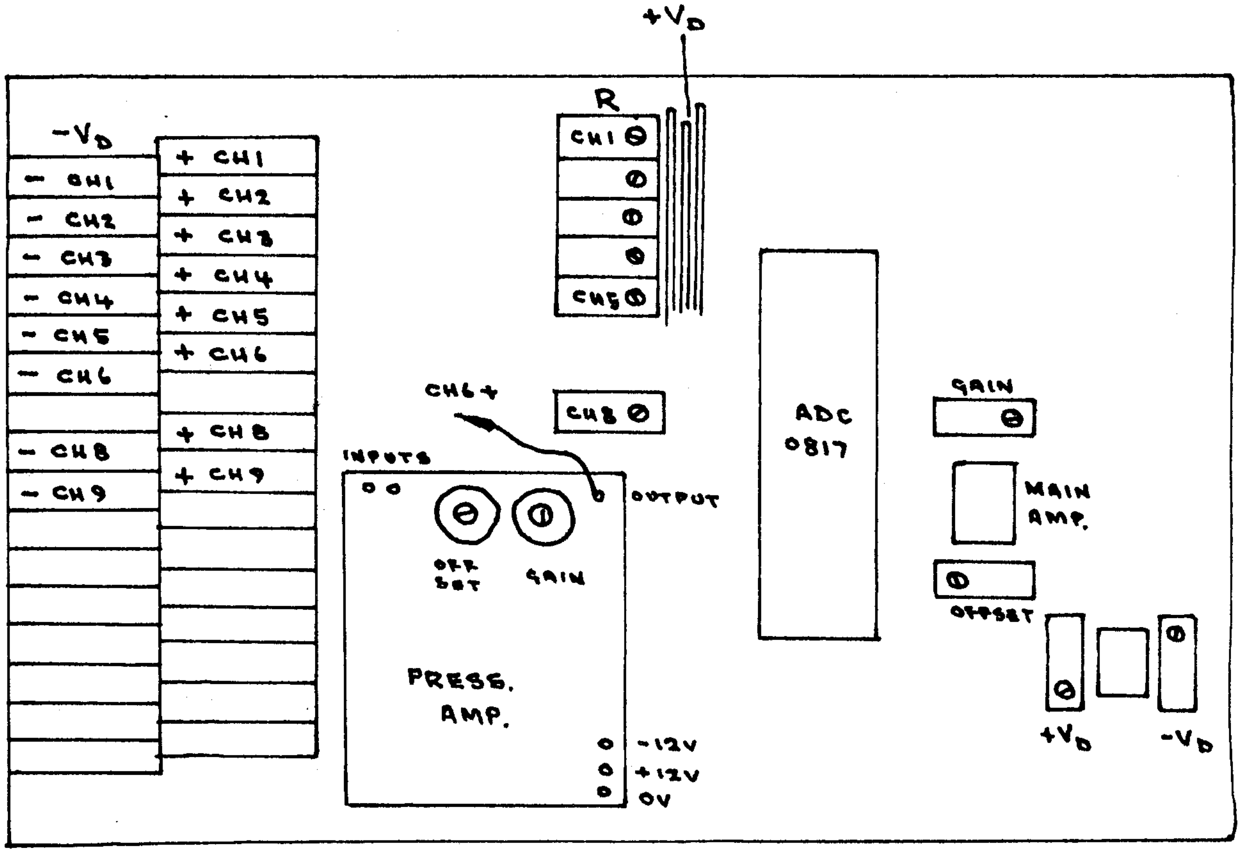
PRESSURE

The thermistor calibration must be checked before proceeding

Amplifier offset

1. With transducer disconnected, short amplifier input leads to 0V
2. Monitoring amplifier output adjust offset to give 0V output
3. Wind CH6 front panel trim fully clockwise and then wind anti clockwise 5 turns
4. Connect pressure transducer
5. Carefully adjust CH8 R until display just changes to 00.00 (fine adjustment may be made using front panel trim).
6. With a known pressure applied adjust pressure amplifier to give desired reading
7. Repeat 5. and 6.

The front panel trim may now be used to introduce a pressure offset.



CH8
PRESS. TRANS.
SUPPLY

CH9
PRESS. TRANS.
OUTPUTS

805 MULTIPLEXER LAYOUT.

THERMAL SURVEY SOFTWARE

The software is contained in a 2k ROM located in the rearmost socket on board the 803 microprocessor card. It consists of a main routine and a number of sub_routines which are called from it.

The main routine first of all initialised the 8031, enabling External Interrupt 1 and on board timer 0. Timer 0 is configured to an auto reload mode which counts 2Hz timing pulses generated by the Real Time black card 806.

In the auto reload mode the 16 bit Timer 0 counts the 2Hz pulses in its low byte and, when it overflows, reloads to the value held in its high byte. At the same time an internal interrupt (INTZ) is generated which vectors the program to location 000BH which in turn calls the Printout Routine.

After initialising, the program tests the Real Time Clock VRT but to confirm that the clock card is present and/or running. If it is not, the program write 'HELP' to the display and waits for the user to set the clock. This is achieved by generating an external interrupt (INT1) via the 'SET' switch on the clock control panel.

After setting the clock and pressing 'START' the program runs into a continuous loop which first checks the control switch, via Port 6 on the card. If the switch is off the 2Hz square wave is disabled, the timer switched off and the switch tested again.

As soon as a switch closure is detected the program jumps to a routine to read the thumbwheel switch setting, load the appropriate reload value into the high byte of Timer 0, start the 2Hz clock pulses and the timer.

Before looping to wait for the timer to overflow a call is made to the Printout routine. If the Printer switch is open an immediate return to the main program is made. If the switch is closed the full date and time are printed before the return.

The rest of the program sets the data pointer to the first channel of the multiplexer, reads it, increments the data pointer and writes to that location to initiate a conversion and then, whilst the conversion is in progress, converts the previous reading to data, via a look-up table, and stores it in consecutive locations in RAM, starting at 30H, to be read by the display.

The sequence then repeats until all six channels have been read. The only exception to this is the sixth channel (Pressure Transducer) where the data is calculated rather than looked up.

When all six channels have been read a check is made to see how many times the sequence has been performed and when this number reaches a value stored in TEMP3 a call is made to the Display routine to write the information stored in the display buffers.

Having updated the displays the program loops back to check the control switch and repeat the process.

803 MICROPROCESSOR

This board is based on the INTEL 8031 µp and contains 2 - 8 bit port expanders, driven from Port 1 of the 8031. There is provision for on board memory in the form of a max 4k ROM and 4k RAM.

In addition the board contains an 8 bit addressable latch which is memory mapped into the top of program memory, giving the facility of being able to set any latch on or off by LCALing a particular address. Three of these latches are used to control the port expenders and are the serial (RS232) ports of which there are two.

The four remaining latches are brought out to the rear connector, one of them being used to enable the printer.

A summary of the instruction set for the 8031 is included in this manual together with a complete listing of the software which is contained in a 2k on board ROM.

806 REAL TIME CLOCK

This card is mapped into memory at locations FF00H to FF0DH.

The card contains address decoding, the RTC and a battery for back-up purposes. The battery is continuously trickle charged all the time the system is switched on, and should be able to retain charge for a minimum of 7 - 8 days.

The clock I.C. will maintain time keeping as long as the battery voltage is maintained at the required level.

PRINTER 807

This unit is assembled from a CITIZEN DP575R mechanism and CBM-505-HF12 interface card.

Control of the print functions is performed by writing the required codes to the memory location the printer is mapped to.

In addition to printing the unit contains a small circuit to momentarily close a relay every time the printer is addressed, providing a time marker.

In operation the printer is addressed by operating latch on the microprocessor board, enabling the printer. Data is then written to the interface by using an unused address (AA00H).

All the data to be printed is sent, in a single stream, to the interface print buffer and printing is initiated by sending a single character (CR = 0DH).

MUX 805 CCT OPERATION

The 805 Multiplexer is a 16 channel data acquisition system designed around the National ADC 0816/7. The chip contains a full 16 input multiplexer together with an 8 bit ADC. It is fully microprocessor compatable in that the data is accessible via an 8 bit data bus and channel selection can be made via a 4 bit address bus.

The ADC 0816 is a ratiometric device and is therefore ideally suited to the measurement of voltages across simple resistor networks. To this end the 805 Multiplexer incorporates a variable gain DC amplifier and a positive and negative adjustable drive voltage circuit.

In operation one of the 16 channels is selected by applying the appropriate code to the address input and taking ALE high to latch it. After a suitable settling time has elapsed the START input is taken high and when taken low again initiates conversion in the ADC.

The time taken for conversion is dependent upon the frequency of the on board oscillator and is of the order of 100 _ 120μS. At the end of that period the data is available at the DATA pins and can be read out onto the system bus by strobing the READ input.

The multiplexer output is available separately on the chip as is the ADC input to enable an amplifier to be incorporated between the two halves of the system (Fig. 1) and this, together with adjustable drive voltages and reference levels enables a wide range of inputs and levels to be accommodated.

SYSTEM

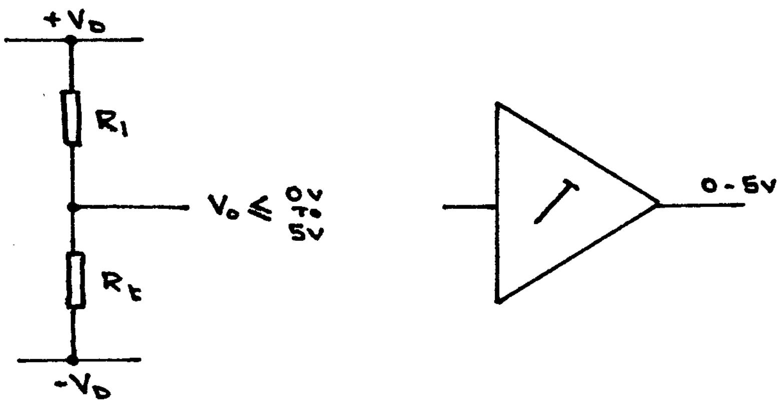
The system requirements for the TS1 are for five channels of temperature measurement, via thermistors, and one of pressure measurement.

TEMPERATURE

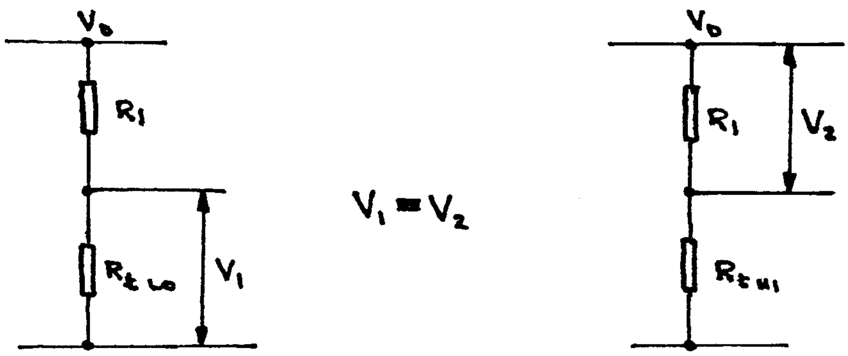
All five temperature channels are treated in the same way by connecting each thermistor in series with a fixed resistor, applying a constant voltage across the chain and measuring the voltage across the thermistor.

Since the input range of the ADC is 0 to 5V and the thermistors have a range of 3.3 to 11.4k it is necessary to drive the chain with a negative and positive voltage in order to obtain a zero output when the thermistor is at its lowest value.

At the high end (RT - 11.4k) the derived voltage must not exceed +5V and so the combination of fixed resistor and drive voltages must be chosen carefully to ensure the ADC is not over or under driven.



Since the output voltage from the chain has got to swing equally about the centre voltage of the ADC reference inputs (+2.5V) the value for R1 can be calculated as follows:-



$$V_1 = \frac{R_{LO}}{R_1 + R_{LO}} \times V_{DD}$$

$$V_2 = \frac{R_{HI}}{R_1 + R_{HI}} \times V_{DD}$$

But $V_1 = V_2$

Therefore: $$\frac{R_{LO}}{R_1 + R_{LO}} = \frac{R_1}{R_1 + R_{HI}}$$

Or $$R_1 (R_1 + R_{LO}) = R_{LO} (R_1 + R_{HI})$$

$$= \quad R_1^2 + R_1 R_{LO} = R_{LO} R_1 + R_{LO} R_{HI}$$

Therefore: $$R_1^2 = R_{LO} R_{HI}$$

and. $$R_1 = R_{LO} R_{HI}$$

The known values of R_T are

a. R_{TLO} = 3304.3R @ 30° C

b. R_{THI} = 11400 R @ 0° C

Therefore: R_1 = 3.304.3 X 11.4 = 6.1375k

R_1 in fact comprises a fixed resistor (4k7) and a variable (2k) and so the exact value can be set by applying a known voltage across the chain and substituting a fixed, accurate, resistor for R_T (say 3k3). It is then only necessary to calculate the value of V_1 and adjust the variable resistor to obtain that voltage across the 3k3 resistor.

$$V_1 = \frac{3.3V}{3.3 + 6.1375} = .3496V$$

i.e. if V is set to 2V the voltage across the 3k3 resistor should be adjusted to 0.6992V.

Now, by setting the positive drive voltage to a fixed value it is only necessary to adjust $-V_D$ to give a zero volt output (wrt 0V) and, since the resistor values are in the correct ratio, the full scale range can be set by adjusting the amplifier gain.

PRESSURE

The pressure transducer used requires an excitation voltage to drive it and produces a differential output centred about the mid point of the drive voltage.

The method employed in the TSI System is to use the ∓ 12V lines to excite the transducer via a series resistor and then to feed the outputs into a differential input, single ended output, amplifier connected into one of the channel inputs.

Since the output of the transducer varies with excitation voltage, fine adjustment of zero output can be obtained by adjusting the series resistor (the ratio arm of the thermistor circuits, R_1).

Full scale adjustment is then made by adjusting the on board amplifier gain.

SETTING UP

The first step is to adjust the resistors in series with each thermistor to a given value and ensure that channels 1 - 5 are identical

Equipment required:-

- 1 - DVM minimum impedance 10M
- 1 - resistance box, range 3k to 12k minimum with 2 pole jack plug connected.
- 1 - small trim tool

Procedure (refer to layout of 805 Multiplexer)

Switch on and allow unit 10 minutes to stabilise.

THERMISTORS

1. Monitor the $-V_D$ line with respect to 0V and adjust to approximately -0.5V
2. Monitor $+V_D$ line with respect to $-V_D$ and adjust $+V_D$ to give value (V).
3. Plug resistance box into CH2 and set value to 3304R.
4. Monitor voltage across resistance box and adjust R until it =

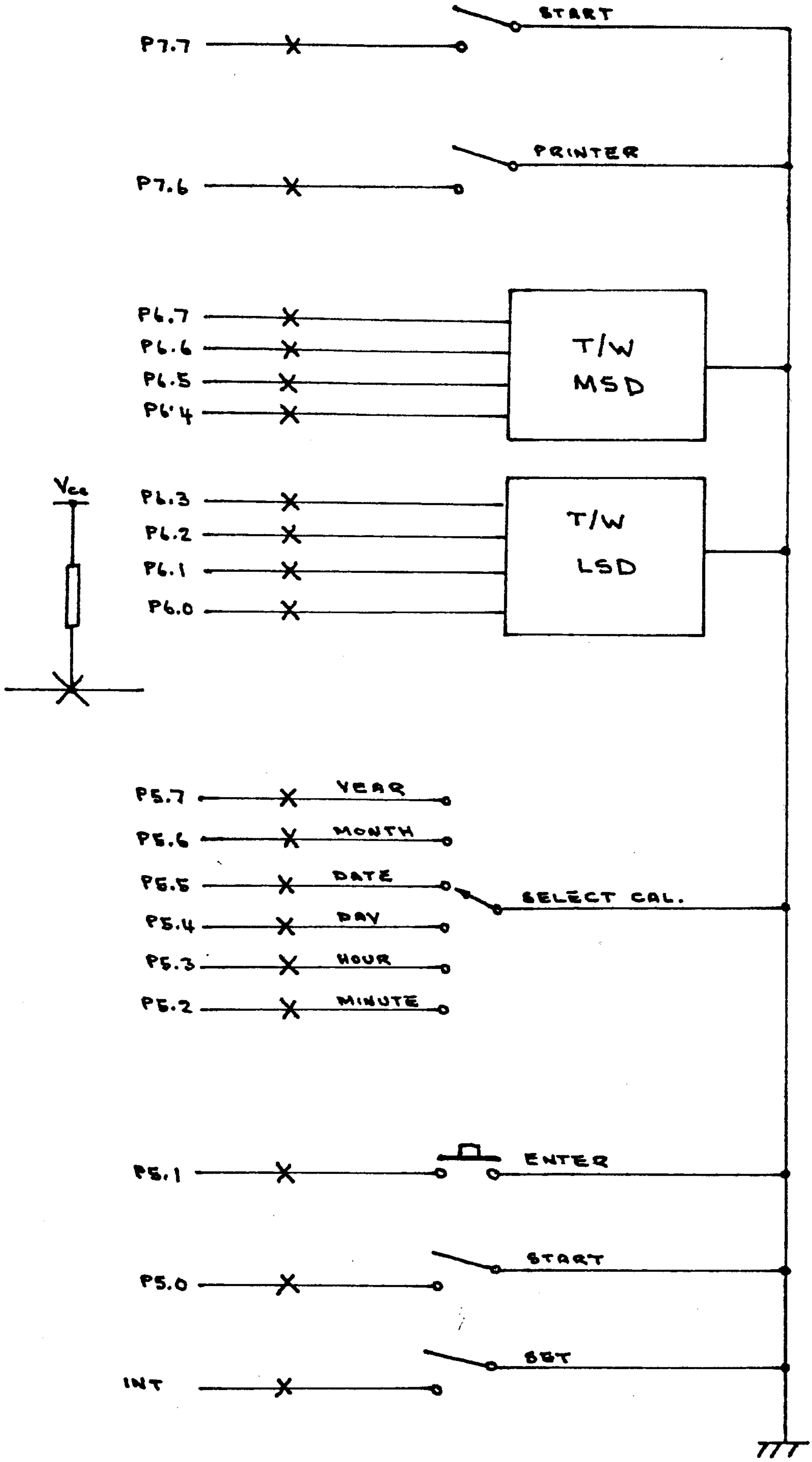
$$\left(\frac{3.304}{3.304 + 6.1375} \right) \times V \quad \text{i.e.} \quad 0.3499\ V$$

5. Adjust $-V_D$ until display reads less than 30.00 then gradually adjust back up to 30.00
6. Alter resistance to 11400R and adjust main amplifier gain to just give a display reading of 00.00
7. Repeat 5. and 6. until no changes are necessary
8. Set resistance box to give a steady display reading and then connect to CH1
9. Adjust CH1 R to give the same display reading
10. Repeat for CH3 - 5

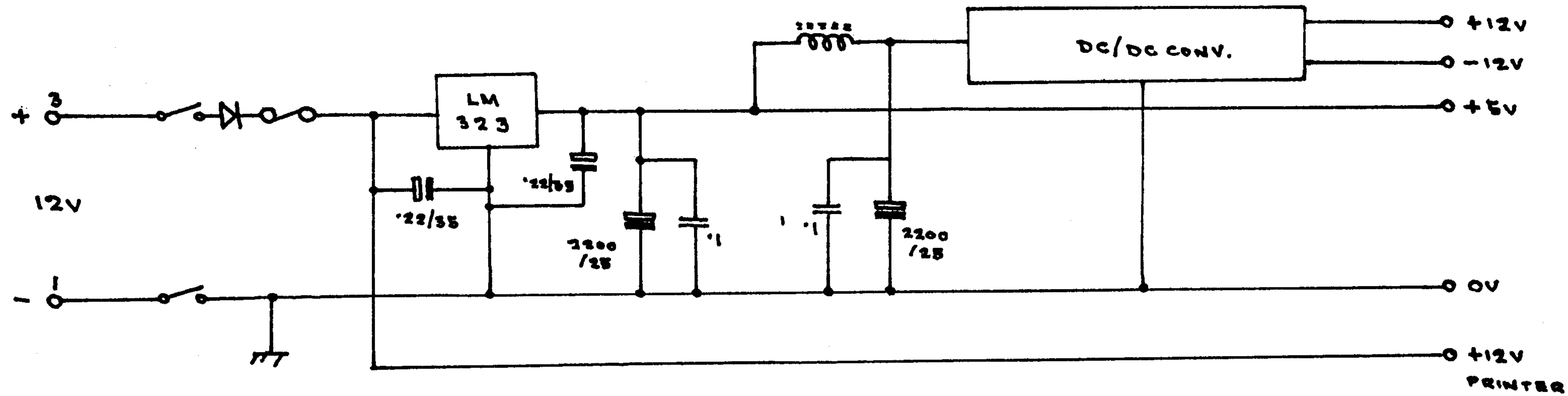
SETTING CLOCK

Switch on the system, but do not start it. Release the two screws retaining the front panel and hinge it down, revealing the clock controls. Select the required setting (Year, Month, etc.) by means of the rotary switch and set the value on the front panel thumbwheel switches. Pressing 'ENTER' will load the clock which will then be read back onto the display. This procedure should be repeated for all required settings.

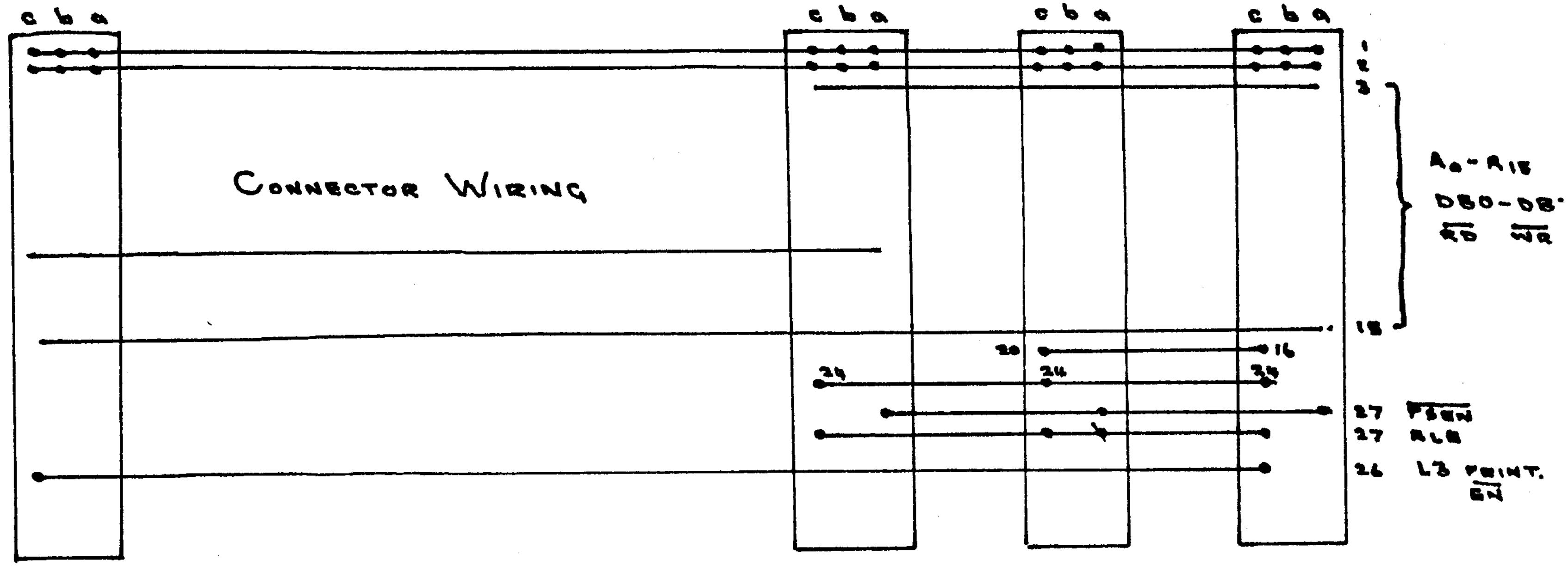
When setting minutes choose a value ahead of real time, since the clock will only start running when 'START' is operated and will clock seconds (starting at 00) from the time 'START' is pressed. The system may now be operated normally.



THERMAL SURVEY SWITCH CONNECTIONS.



Power Supply.



Connector Wiring

ADC0816, ADC0817 8-Bit μP Compatible A/D Converters with 16-Channel Multiplexer

General Description

The ADC0816, ADC0817 data acquisition component is a monolithic CMOS device with an 8-bit analog-to-digital converter, 16-channel multiplexer and microprocessor compatible control logic. The 8-bit A/D converter uses successive approximation as the conversion technique. The converter features a high impedance chopper stabilized comparator, a 256R voltage divider with analog switch tree and a successive approximation register. The 16-channel multiplexer can directly access any one of 16-single-ended analog signals, and provides the logic for additional channel expansion. Signal conditioning of any analog input signal is eased by direct access to the multiplexer output, and to the input of the 8-bit A/D converter.

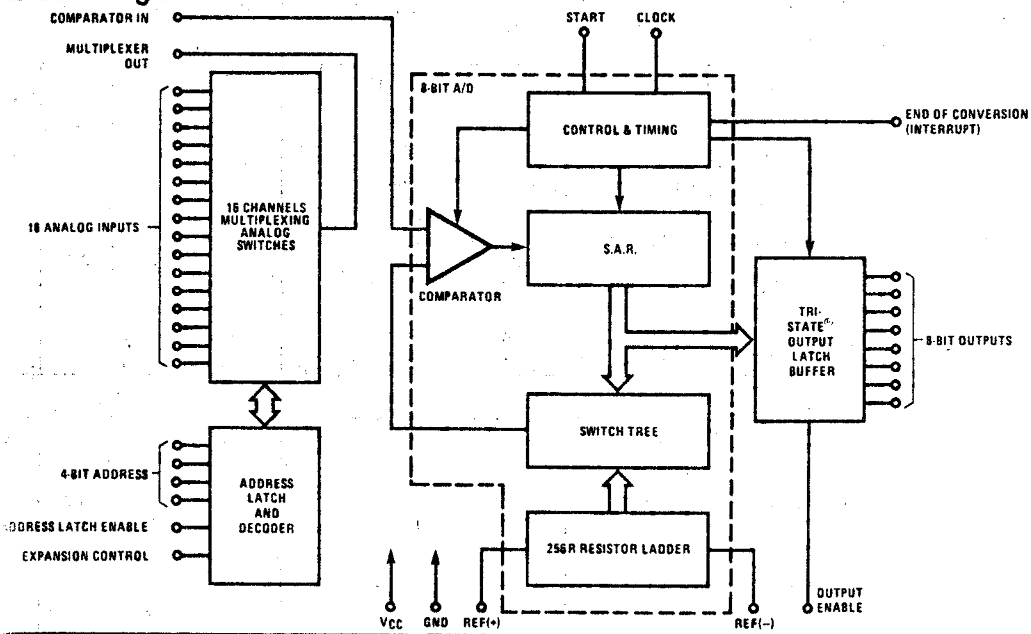
The device eliminates the need for external zero and full-scale adjustments. Easy interfacing to microprocessors is provided by the latched and decoded multiplexer address inputs and latched TTL TRI-STATE® outputs.

The design of the ADC0816, ADC0817 has been optimized by incorporating the most desirable aspects of several A/D conversion techniques. The ADC0816, ADC0817 offers high speed, high accuracy, minimal temperature dependence, excellent long-term accuracy and repeatability, and consumes minimal power. These features make this device ideally suited to applications from process and machine control to consumer and automotive applications. For similar performance in an 8-channel, 28-pin, 8-bit A/D converter, see the ADC0808, ADC0809 data sheet. (See AN-258 for more information.)

Features

- Resolution — 8-bits
- Total unadjusted error — ± 1/2 LSB and ± 1 LSB
- No missing codes
- Conversion time — 100 μs
- Single supply — 5 V_{DC}
- Operates ratiometrically or with 5 V_{DC} or analog span adjusted voltage reference
- 16-channel multiplexer with latched control logic
- Easy interface to all microprocessors, or operates "stand alone"
- Outputs meet T^2L voltage level specifications
- 0V to 5V analog input voltage range with single 5V supply
- No zero or full-scale adjust required
- Standard hermetic or molded 40-pin DIP package
- Temperature range −40°C to +85°C or −55°C to +125°C
- Low power consumption — 15 mW
- Latched TRI-STATE® output
- Direct access to "comparator in" and "multiplexer out" for signal conditioning

Block Diagram



8

A 16

Functional Description

Multiplexer: The device contains a 16-channel single-ended analog signal multiplexer. A particular input channel is selected by using the address decoder. Table I shows the input states for the address line and the expansion control line to select any channel. The address is latched into the decoder on the low-to-high transition of the address latch enable signal.

TABLE I

SELECTED ANALOG CHANNEL	ADDRESS LINE D	C	B	A	EXPANSION CONTROL
IN0	L	L	L	L	H
IN1	L	L	L	H	H
IN2	L	L	H	L	H
IN3	L	L	H	H	H
IN4	L	H	L	L	H
IN5	L	H	L	H	H
IN6	L	H	H	L	H
IN7	L	H	H	H	H
IN8	H	L	L	L	H
IN9	H	L	L	H	H
IN10	H	L	H	L	H
IN11	H	L	H	H	H
IN12	H	H	L	L	H
IN13	H	H	L	H	H
IN14	H	H	H	L	H
IN15	H	H	H	H	H
All Channels OFF	X	X	X	X	L

X = don't care

Additional single-ended analog signals can be m plexed to the A/D converter by disabling all the multipl inputs using the expansion control. The additional ex nal signals are connected to the comparator input and device ground. Additional signal conditioning (i prescaling, sample and hold, instrumentation ampli tion, etc.) may also be added between the analog in signal and the comparator input.

CONVERTER CHARACTERISTICS

The Converter

The heart of this single chip data acquisition system i 8-bit analog-to-digital converter. The converter is desig to give fast, accurate, and repeatable conversions ov wide range of temperatures. The converter is partitio into 3 major sections: the 256R ladder network, the s cessive approximation register, and the comparator. converter's digital outputs are positive true.

The 256R ladder network approach (*Figure 1*) was cho over the conventional R/2R ladder because of its inher monotonicity, which guarantees no missing digital co Monotonicity is particularly important in closed loop fe back control systems. A non-monotonic relationship c cause oscillations that will be catastrophic for system. Additionally, the 256R network does not ca load variations on the reference voltage.

The bottom resistor and the top resistor of the lad network in *Figure 1* are not the same value as remainder of the network. The difference in th resistors causes the output characteristic to be s metrical with the zero and full-scale points of the trans curve. The first output transition occurs when the ana signal has reached + 1/2 LSB and succeeding ou transitions occur every 1 LSB later up to full-scale.

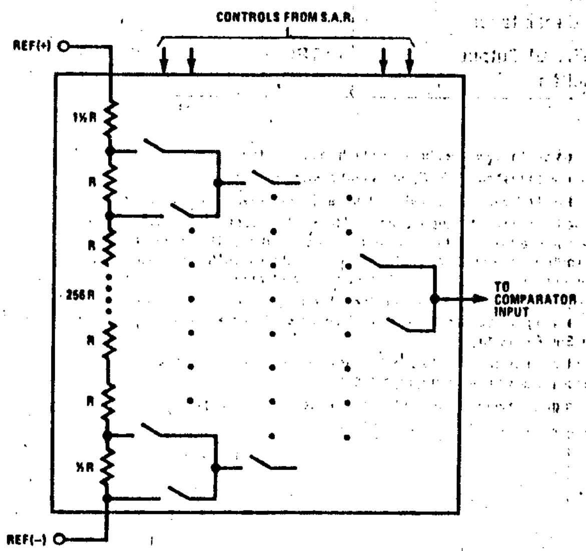


FIGURE 1. Resistor Ladder and Switch Tree

A 17

The successive approximation register (SAR) performs 8 iterations to approximate the input voltage. For any SAR type converter, n-iterations are required for an n-bit converter. *Figure 2* shows a typical example of a 3-bit converter. In the ADC0816, ADC0817, the approximation technique is extended to 8 bits using the 256R network.

The A/D converter's successive approximation register (SAR) is reset on the positive edge of the start conversion (SC) pulse. The conversion is begun on the falling edge of the start conversion pulse. A conversion in process will be interrupted by receipt of a new start conversion pulse. Continuous conversion may be accomplished by tying the end-of-conversion (EOC) output to the SC input. If used in this mode, an external start conversion pulse should be applied after power up. End-of-conversion will go low between 0 and 8 clock pulses after the rising edge of start conversion.

The most important section of the A/D converter is the comparator. It is this section which is responsible for the ultimate accuracy of the entire converter. It is also the comparator drift which has the greatest influence on the repeatability of the device. A chopper-stabilized comparator provides the most effective method of satisfying all the converter requirements.

The chopper-stabilized comparator converts the DC input signal into an AC signal. This signal is then fed through a high gain AC amplifier and has the DC level restored. This technique limits the drift component of the amplifier since the drift is a DC component which is not passed by the AC amplifier. This makes the entire A/D converter extremely insensitive to temperature, long term drift and input offset errors.

Figure 4 shows a typical error curve for the ADC0816 as measured using the procedures outlined in AN-179.

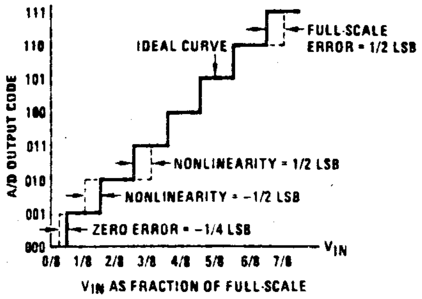


FIGURE 2. 3-Bit A/D Transfer Curve

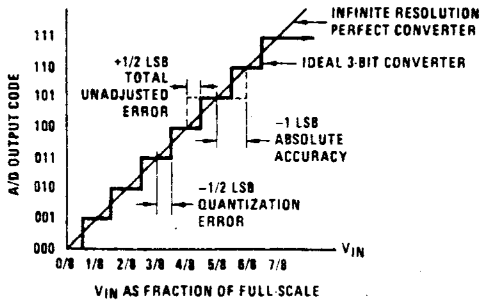


FIGURE 3. 3-Bit A/D Absolute Accuracy Curve

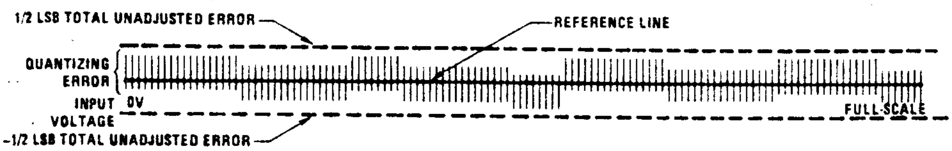
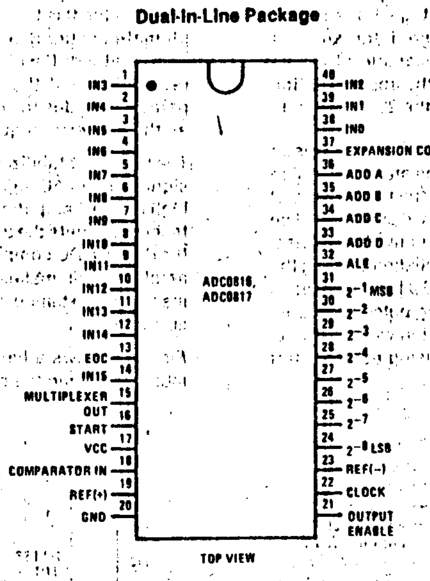


FIGURE 4. Typical Error Curve

8

A-18

Connection Diagram



Timing Diagram

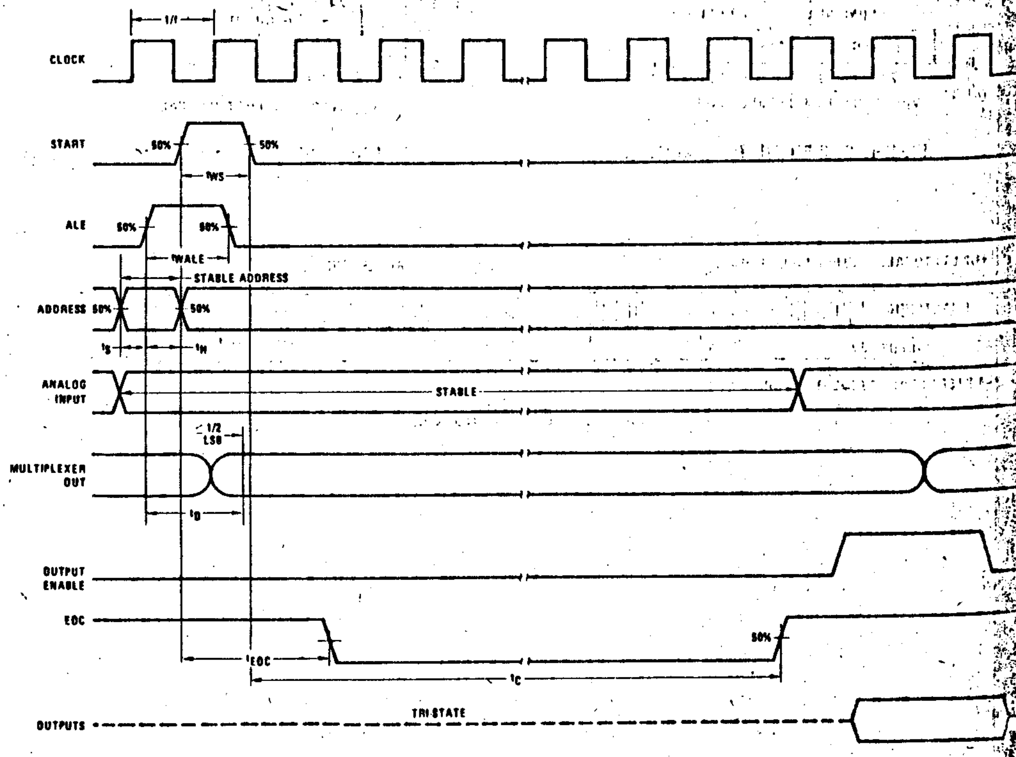


FIGURE 5

A.9

Applications Information

OPERATION

1.0 Ratiometric Conversion

The ADC0816, ADC0817 is designed as a complete Data Acquisition System (DAS) for ratiometric conversion systems. In ratiometric systems, the physical variable being measured is expressed as a percentage of full-scale which is not necessarily related to an absolute standard. The voltage input to the ADC0816 is expressed by the equation

$$\frac{V_{IN}}{V_{fs} - V_Z} = \frac{D_X}{D_{MAX} - D_{MIN}} \qquad (1)$$

V_{IN} = Input voltage into the ADC0816
V_{fs} = Full-scale voltage
V_Z = Zero voltage
D_X = Data point being measured
D_{MAX} = Maximum data limit
D_{MIN} = Minimum data limit

A good example of a ratiometric transducer is a potentiometer used as a position sensor. The position of the wiper is directly proportional to the output voltage which is a ratio of the full-scale voltage across it. Since the data is represented as a proportion of full-scale, reference requirements are greatly reduced, eliminating a large source of error and cost for many applications. A major advantage of the ADC0816, ADC0817 is that the input voltage range is equal to the supply range so the transducers can be connected directly across the supply and their outputs connected directly into the multiplexer inputs, *(Figure 9)*.

Ratiometric transducers such as potentiometers, strain gauges, thermistor bridges, pressure transducers, etc., are suitable for measuring proportional relationships; however, many types of measurements must be referred to an absolute standard such as voltage or current. This means a system reference must be used which relates the full-scale voltage to the standard volt. For example, if $V_{CC} = V_{REF} = 5.12V$, then the full-scale range is divided into 256 standard steps. The smallest standard step is 1 LSB which is then 20 mV.

2.0 Resistor Ladder Limitations

The voltages from the resistor ladder are compared to the selected input 8 times in a conversion. These voltages are coupled to the comparator via an analog switch tree which is referenced to the supply. The voltages at the top, center and bottom of the ladder must be controlled to maintain proper operation.

The top of the ladder, Ref(+), should not be more positive than the supply, and the bottom of the ladder, Ref(−), should not be more negative than ground. The center of the ladder voltage must also be near the center of the supply because the analog switch tree changes from N-channel switches to P-channel switches. These limitations are automatically satisfied in ratiometric systems and can be easily met in ground referenced systems.

Figure 10 shows a ground referenced system with a separate supply and reference. In this system, the supply must be trimmed to match the reference voltage. For instance, if a 5.12V reference is used, the supply should be adjusted to the same voltage within 0.1V.

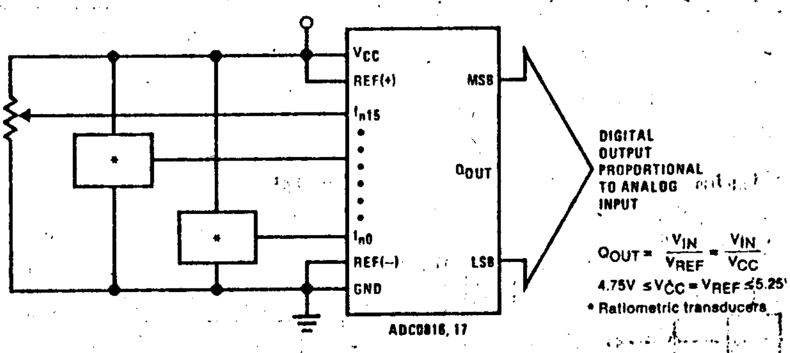


FIGURE 9. Ratiometric Conversion System

A20

The ADC0816 needs less than a milliamp of supply current so developing the supply from the reference is readily accomplished. In *Figure 11* a ground referenced system is shown which generates the supply from the reference. The buffer shown can be an op amp of sufficient drive to supply the milliamp of supply current and the desired bus drive, or if a capacitive bus is driven by the outputs a large capacitor will supply the transient supply current as seen in *Figure 12*. The LM301 is overcompensated to insure stability when loaded by the 10 μF output capacitor.

The top and bottom ladder voltages cannot exceed V_{CC} and ground, respectively, but they can be symmetrically less than V_{CC} and greater than ground. The center of the ladder voltage should always be near the center of the supply. The sensitivity of the converter can be increased, (i.e., size of the LSB steps decreased) by using a symmetrical reference system. In *Figure 13*, a 2.5V reference is symmetrically centered about $V_{CC}/2$ since the same current flows in identical resistors. This system with a 2.5V reference allows the LSB to be half the size of the LSB in a 5V reference system.

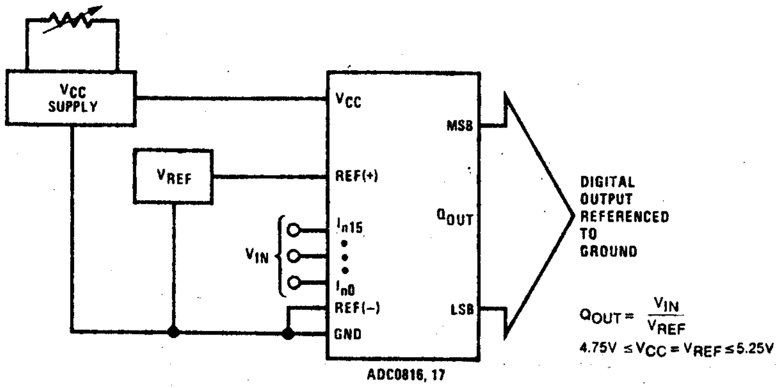


FIGURE 10. Ground Referenced Conversion System Using Trimmed Supply

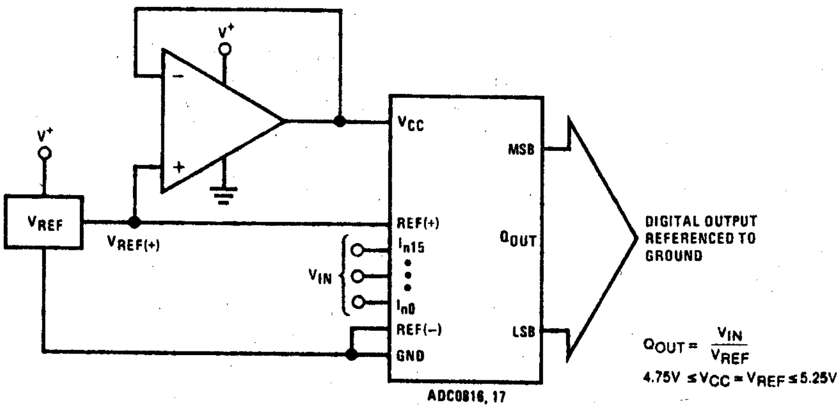


FIGURE 11. Ground Referenced Conversion System with Reference Generating V_{CC} Supply

Applications Information (Continued)

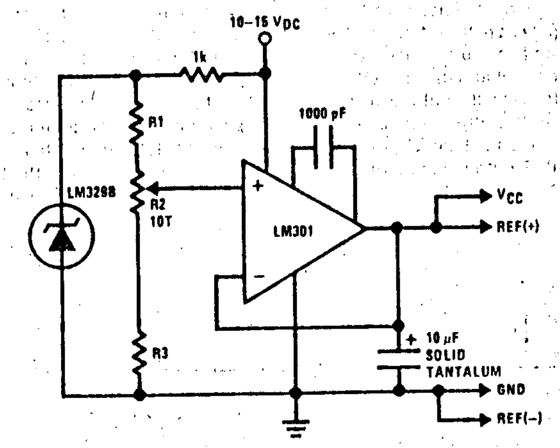


FIGURE 12. Typical Reference and Supply Circuit

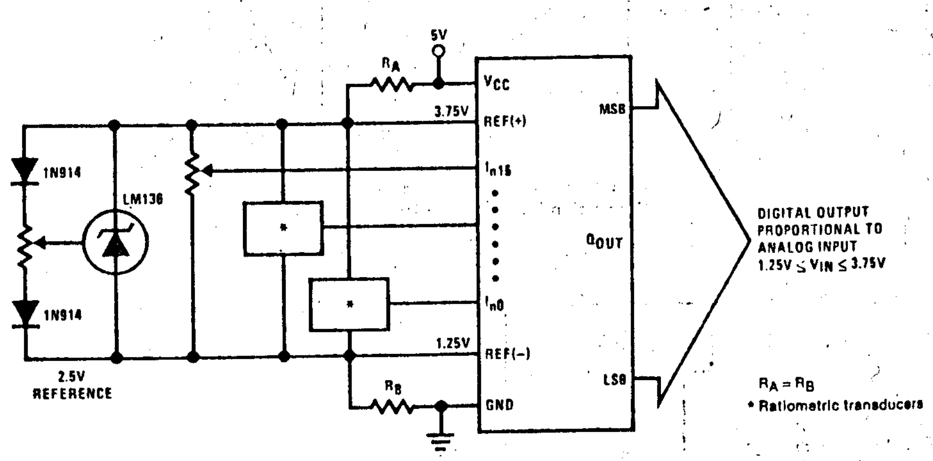


FIGURE 13. Symmetrically Centered Reference

3.0 Converter Equations

The transition between adjacent codes N and N+1 is given by:

$$V_{IN} = \left\{ \left(V_{REF(+)} - V_{REF(-)}\right) \left[\frac{N}{256} + \frac{1}{512}\right] \pm V_{TUE} \right\} + V_{REF(-)} \quad (2)$$

The center of an output code N is given by:

$$V_{IN} = \left\{ \left(V_{REF(+)} - V_{REF(-)}\right) \left[\frac{N}{256}\right] \pm V_{TUE} \right\} + V_{REF(-)} \quad (3)$$

The output code N for an arbitrary input are the integers within the range:

$$N = \frac{V_{IN} - V_{REF(-)}}{V_{REF(+)} - V_{REF(-)}} \times 256 \pm \text{Absolute Accuracy}$$

where: V_{IN} = Voltage at comparator input
$V_{REF(+)}$ = Voltage at Ref(+)
$V_{REF(-)}$ = Voltage at Ref(−)
V_{TUE} = Total unadjusted error voltage (typically $V_{REF(+)} \div 512$)

A22

Table 4. MCS-51™ Instruction Set Description

ARITHMETIC OPERATIONS

Mnemonic		Description	Byte	Cyc
ADD	A,Rn	Add register to Accumulator	1	1
ADD	A,direct	Add direct byte to Accumulator	2	1
ADD	A,@Ri	Add indirect RAM to Accumulator	1	1
ADD	A,#data	Add immediate data to Accumulator	2	1
ADDC	A,Rn	Add register to Accumulator with Carry	1	1
ADDC	A,direct	Add direct byte to A with Carry flag	2	1
ADDC	A,@Ri	Add indirect RAM to A with Carry flag	1	1
ADDC	A,#data	Add immediate data to A with Carry flag	2	1
SUBB	A,Rn	Subtract register from A with Borrow	1	1
SUBB	A,direct	Subtract direct byte from A with Borrow	2	1
SUBB	A,@Ri	Subtract indirect RAM from A w/ Borrow	1	1
SUBB	A,#data	Subtract immed. data from A w/ Borrow	2	1
INC	A	Increment Accumulator	1	1
INC	Rn	Increment register	1	1
INC	direct	Increment direct byte	2	1
INC	@Ri	Increment indirect RAM	1	1
DEC	A	Decrement Accumulator	1	1
DEC	Rn	Decrement register	1	1
DEC	direct	Decrement direct byte	2	1
DEC	@Ri	Decrement indirect RAM	1	1
INC	DPTR	Increment Data Pointer	1	2
MUL	AB	Multiply A & B	1	4
DIV	AB	Divide A by B	1	4
DA	A	Decimal Adjust Accumulator	1	1

LOGICAL OPERATIONS

Mnemonic		Destination	Byte	Cyc
ANL	A,Rn	AND register to Accumulator	1	1
ANL	A,direct	AND direct byte to Accumulator	2	1
ANL	A,@Ri	AND indirect RAM to Accumulator	1	1
ANL	A,#data	AND immediate data to Accumulator	2	1
ANL	direct,A	AND Accumulator to direct byte	2	1
ANL	direct,#data	AND immediate data to direct byte	3	2
ORL	A,Rn	OR register to Accumulator	1	1
ORL	A,direct	OR direct byte to Accumulator	2	1
ORL	A,@Ri	OR indirect RAM to Accumulator	1	1
ORL	A,#data	OR immediate data to Accumulator	2	1
ORL	direct,A	OR Accumulator to direct byte	2	1
ORL	direct,#data	OR immediate data to direct byte	3	2
XRL	A,Rn	Exclusive-OR register to Accumulator	1	1
XRL	A,direct	Exclusive-OR direct byte to Accumulator	2	1
XRL	A,@Ri	Exclusive-OR indirect RAM to A	1	1
XRL	A,#data	Exclusive-OR immediate data to A	2	1
XRL	direct,A	Exclusive-OR Accumulator to direct byte	2	1
XRL	direct,#data	Exclusive-OR immediate data to direct	3	2
CLR	A	Clear Accumulator	1	1
CPL	A	Complement Accumulator	1	1
RL	A	Rotate Accumulator Left	1	1
RLC	A	Rotate A Left through the Carry flag	1	1
RR	A	Rotate Accumulator Right	1	1
RRC	A	Rotate A Right through Carry flag	1	1
SWAP	A	Swap nibbles within the Accumulator	1	1

DATA TRANSFER

Mnemonic		Description	Byte	Cyc
MOV	A,Rn	Move register to Accumulator	1	1
MOV	A,direct	Move direct byte to Accumulator	2	1
MOV	A,@Ri	Move indirect RAM to Accumulator	1	1
MOV	A,#data	Move immediate data to Accumulator	2	1
MOV	Rn,A	Move Accumulator to register	1	1
MOV	Rn,direct	Move direct byte to register	2	2
MOV	Rn,#data	Move immediate data to register	2	1
MOV	direct,A	Move Accumulator to direct byte	2	1
MOV	direct,Rn	Move register to direct byte	2	2
MOV	direct,direct	Move direct byte to direct	3	2
MOV	direct,@Ri	Move indirect RAM to direct byte	2	2
MOV	direct,#data	Move immediate data to direct byte	3	2
MOV	@Ri,A	Move Accumulator to indirect RAM	1	1
MOV	@Ri,direct	Move direct byte to indirect RAM	2	2
MOV	@Ri,#data	Move immediate data to indirect RAM	2	1
MOV	DPTR,#data16	Load Data Pointer with a 16-bit constant	3	2

DATA TRANSFER (cont.)

Mnemonic		Description	Byte	Cyc
MOVC	A,@A+DPTR	Move Code byte relative to DPTR to A	1	2
MOVC	A,@A+PC	Move Code byte relative to PC to A	1	2
MOVX	A,@Ri	Move External RAM (8-bit addr) to A	1	2
MOVX	A,@DPTR	Move External RAM (16-bit addr) to A	1	2
MOVX	@Ri,A	Move A to External RAM (8-bit addr)	1	2
MOVX	@DPTR,A	Move A to External RAM (16-bit addr)	1	2
PUSH	direct	Push direct byte onto stack	2	2
POP	direct	Pop direct byte from stack	2	2
XCH	A,Rn	Exchange register with Accumulator	1	1
XCH	A,direct	Exchange direct byte with Accumulator	2	1
XCH	A,@Ri	Exchange indirect RAM with A	1	1
XCHD	A,@Ri	Exchange low-order Digit ind. RAM w A	1	1

BOOLEAN VARIABLE MANIPULATION

Mnemonic		Description	Byte	Cyc
CLR	C	Clear Carry flag	1	1
CLR	bit	Clear direct bit	2	1
SETB	C	Set Carry flag	1	1
SETB	bit	Set direct Bit	2	1
CPL	C	Complement Carry flag	1	1
CPL	bit	Complement direct bit	2	1
ANL	C,bit	AND direct bit to Carry flag	2	2
ANL	C,/bit	AND complement of direct bit to Carry	2	2
ORL	C,bit	OR direct bit to Carry flag	2	2
ORL	C,/bit	OR complement of direct bit to Carry	2	2
MOV	C,bit	Move direct bit to Carry flag	2	1
MOV	bit,C	Move Carry flag to direct bit	2	2

PROGRAM AND MACHINE CONTROL

Mnemonic		Description	Byte	Cyc
ACALL	addr11	Absolute Subroutine Call	2	2
LCALL	addr16	Long Subroutine Call	3	2
RET		Return from subroutine	1	2
RETI		Return from interrupt	1	2
AJMP	addr11	Absolute Jump	2	2
LJMP	addr16	Long Jump	3	2
SJMP	rel	Short Jump (relative addr)	2	2
JMP	@A+DPTR	Jump indirect relative to the DPTR	1	2
JZ	rel	Jump if Accumulator is Zero	2	2
JNZ	rel	Jump if Accumulator is Not Zero	2	2
JC	rel	Jump if Carry flag is set	2	2
JNC	rel	Jump if No Carry flag	2	2
JB	bit,rel	Jump if direct Bit set	3	2
JNB	bit,rel	Jump if direct Bit Not set	3	2
JBC	bit,rel	Jump if direct Bit is set & Clear bit	3	2
CJNE	A,direct,rel	Compare direct to A & Jump if Not Equal	3	2
CJNE	A,#data,rel	Comp. immed. to A & Jump if Not Equal	3	2
CJNE	Rn,#data,rel	Comp. immed. to reg. & Jump if Not Equal	3	2
CJNE	@Ri,#data,rel	Comp. immed. to ind. & Jump if Not Equal	3	2
DJNZ	Rn,rel	Decrement register & Jump if Not Zero	2	2
DJNZ	direct,rel	Decrement direct & Jump if Not Zero	3	2
NOP		No operation	1	1

Notes on data addressing modes:

- Rn — Working register R0-R7
- direct — 128 internal RAM locations, any I/O port, control or status register
- @Ri — Indirect internal RAM location addressed by register R0 or R1
- #data — 8-bit constant included in instruction
- #data16 — 16-bit constant included as bytes 2 & 3 of instruction
- bit — 128 software flags, any I/O pin, control or status bit

Notes on program addressing modes:

- addr16 — Destination address for LCALL & LJMP may be anywhere within the 64-Kilobyte program memory address space.
- addr11 — Destination address for ACALL & AJMP will be within the same 2-Kilobyte page of program memory as the first byte of the following instruction.
- rel — SJMP and all conditional jumps include an 8-bit offset byte. Range is +127/−128 bytes relative to first byte of the following instruction.

3. INSTRUCTION SET AND ADDRESSING MODES

The 8051 instruction set is extremely regular, in the sense that most instructions can operate with variables from several different physical or logical address spaces. Before getting deeply enmeshed in the instruction set proper, it is important to understand the details of the most common data addressing modes. Whereas Table 4 summarizes the instructions set broken down by functional group, this chapter starts with the addressing mode classes and builds to include the related instructions.

Data Addressing Modes

MCS-51 assembly language instructions consist of an operation mnemonic and zero to three operands separated by commas. In two operand instructions the destination is specified first, then the source. Many byte-wide data

8031 ASSEMBLY LISTING FOR THERMSURVEY16

```
; INTERNAL RAM LOCATIONS
; P0          =       0080
; SP          =       0081
; DPL         =       0082
; DPH         =       0083
; TCON        =       0088
; TMOD        =       0089
; TL0         =       008A
; TL1         =       008B
; TH0         =       008C
; TH1         =       008D
; P1          =       0090
; SCON        =       0098
; SBUF        =       0099
; P2          =       00A0
; IE          =       00A8
; P3          =       00B0
; IP          =       00B8
; PSW         =       00D0
; ACC         =       00E0
; A           =       00E0
; B           =       00F0
; DH1         =       0030
; TEMP1       =       003C
; TEMP2       =       003D
; TEMP3       =       003E
; TEMP4       =       003F
; FLAG        =       0020
; MUXADD      =       FD00
; DISPADD     =       FEF0
; DIGSTB4     =       0040
; DIGSTB3     =       0041
; DIGSTB2     =       0042
; DIGSTB1     =       0043
;
; PROG. LABEL LOCATIONS
; ER0         SET     0003
; IT/C0       SET     000B
; ER1         SET     0013
; IT/C1       SET     001B
; ISP         SET     0023
; START       SET     0000
; INT2        SET     000B
; INT1        SET     0013
; INIT        SET     0100
; CLKSET      SET     0200
; PRINTOUT    SET     0400
; PRESSURE    SET     0500
; READTWS     SET     05B0
; DISPINIT    SET     05D0
; DATAMSB     SET     0600
; DATALSB     SET     0700
; LCB         SET     FF88
```

```
; LDE          SET    FF0E
; PRINT-EN     SET    FF6E
; PRINT-DIS    SET    FFEE
; ZERODISP     SET    0133
; CLKCHECK     SET    013B
; WAIT         SET    014F
; CHECKSW      SET    0154
; LOADTHO      SET    0174
; WAITDF       SET    019B
; RUN          SET    01A0
; FIRST-CH     SET    01A3
; READ         SET    01AE
; NEXT         SET    01B2
; NEXTHERM     SET    01BE
; NEXTCH       SET    01CD
; DELAY        SET    01D5
;
; DATA LABELS
; DS4          DATA   0000
; DS3          DATA   0010
; DS2          DATA   0020
; DS1          DATA   0030
;


;
;
;
;
;THIS ROUTINE IS DESIGNED TO READ 6 CHANNELS OF THE 805 MUX. & CONVERT
;EACH 8 BIT RESULT INTO 2 BYTES OF DATA VIA A L-U TABLE (THE DATA BEING
;CONVERSION TO TEMP. OF A THERMISTOR). THE DATA IS THEN STORED IN RAM
;STARTING AT LOCATION 40H. THE MUX IS ADDRESSED AS MEMORY LOCATED AT
;FD00H.
;
LOC.   OBJ.      LABEL      MN.          OPERAND                COMMENT

0000  21 00     START      AJMP  INIT
000B  91 00     INT2       ACAL  PRINTOUT
000D  32                   RETI
0013  51 00     INT1       ACAL  CLKSET
0015  32                   RETI
0100  75 81 0B  INIT       MOV   SP,#0BH                       ; SET STACK PNTR.
0103  75 40 00             MOV   DIGSTB4,#DS4
0106  75 41 10             MOV   DIGSTB3,#DS3
0109  75 42 20             MOV   DIGSTB2,#DS2
010C  75 43 30             MOV   DIGSTB1,#DS1
010F  75 A8 86             MOV   IEC,#10000110B                ; ENABLE EXT.INT1 & T0
0112  75 B8 04             MOV   IPC,#00000100B                ; HIGH PRIOR.
0115  75 88 00             MOV   TCON,#00000000B               ; T0 OFF.INT1 LEVEL ACT.
0118  75 89 26             MOV   TMOD,#00100110B               ; SET T1 & T0 AUTO-RELOAD
011B  75 98 40             MOV   SCON,#01000000B               ; FOR FUTURE USE
011E  12 FF EB             LCAL  PRINT-DIS                     ; DISABLE PRINTER
0121  C2 20                CLR   FLAG.0
0123  C2 21                CLR   FLAG.1
0125  C2 22                CLR   FLAG.2
0127  C2 23                CLR   FLAG.3
0129  C2 24                CLR   FLAG.4
012B  C2 25                CLR   FLAG.5
012D  C2 26                CLR   FLAG.6
012F  C2 27                CLR   FLAG.7
0131  78 30                MOV   R0,#CH1                       ;
0133  76 00     ZERODISP   MOV   @R0,#00H                      ; ZERO DISPLAY
0135  08                   INC   R0                            ; REGISTERS
```

```
LOC.  OBJ.      LABEL      MN.        OPERAND                 COMMENT

0136  B8 3C FA             CJNE  R0,#3CH,ZERODISP
0139  B1 D0                ACAL  DISPINIT                     ;
013B  90 FF 0D  CLKCHECK   MOV   DPTR,#FF0DH                  ; POINT TO CLK REG.D
013E  E0                   MOVX  A,@DPTR                      ; READ REG.D
013F  20 E7 12             JB    ACC.7,CHECKSW                ; IS BATT. FLAT?
;
;COMPACT 'HELP' INTO 2 BYTES
;
0142  78 30                MOV   R0,#CH1                      ; YES! SHOUT 'HELP'
0144  74 CB                MOV   A,#CBH                       ; LOAD 'H' & 'E' TO CH1
0146  F6                   MOV   @R0,A                        ; & STORE IN BUFFER
0147  08                   INC   R0
0148  74 DE                MOV   A,#DEH                       ; LOAD 'L' & 'P' TO CH1+1
014A  F6                   MOV   @R0,A
014B  B1 D0                ACAL  DISPINIT                     ; WRITE TO DISPLAY
014D  D2 21                SETB  FLAG.1
014F  20 21 FD  WAIT       JB    FLAG.1,WAIT                  ; WAIT FOR INT. (SET)
0152  80 E7                SJMP  CLKCHECK                     ; TRY AGAIN
0154  75 90 22  CHECKSW    MOV   P1,#22H                      ; CODE TO READ P6
0157  12 FF B8             LCAL  LCR
015A  75 90 FF             MOV   P1,#FFH                      ; SET P1 TO READ
015D  E5 90                MOV   A,P1
015F  12 FF 0B             LCAL  LDB
0162  64 FF                XRL   A,#FFH                       ; INVERT A
0164  20 E7 0D             JB    ACC.7,LOADTH0                ; START SWITCH CLOSED
0167  C2 21                CLR   FLAG.1                       ; NO. STOP EVERYTHING
0169  90 FF 0B             MOV   DPTR,#FF0BH                  ;
016C  E0                   MOVX  A,@DPTR                      ;
016D  C2 E3                CLR   ACC.3                        ; STOP SQ.WAVE
016F  F0                   MOVX  @DPTR,A
0170  C2 8C                CLR   TCON.4                       ; STOP TIMER 0
0172  80 E0                SJMP  CHECKSW                      ; TRY AGAIN
0174  20 21 29  LOADTH0    JB    FLAG.1,RUN                   ; IS THIS FIRST CYCLE?
0177  B1 B0                ACAL  READTWS                      ; YES! READ TWS
0179  75 F0 10             MOV   B,#16                        ;
017C  84                   DIV   AB                           ;
017D  85 F0 3F             MOV   TEMP4,B                      ; CONVERT PACKED BCD
0180  75 F0 0A             MOV   B,#10                        ; TO BINARY
0183  A4                   MUL   AB                           ;
0184  25 3F                ADD   A,TEMP4                      ;
0186  23                   RL    A                            ; DOUBLE READING
0187  64 FF                XRL   A,#FFH                       ; & COMPLIMENT
0189  24 01                ADD   A,#01H
018B  F5 8C                MOV   TH0,A                        ; RELOAD VALUE IN TIMER
018D  75 8A FF             MOV   TL0,#FFH                     ; FILL CNTR.
0190  D2 20                SETB  FLAG.0                       ; & SET FLAG
0192  D2 8C                SETB  TCON.4                       ; START TIMER
0194  90 FF 0B             MOV   DPTR,#FF0BH                  ;
0197  E0                   MOVX  A,@DPTR                      ; READ CLK.REG.B
0198  D2 E3                SETB  ACC.3                        ; SET SQ.WAVE EN.
019A  F0                   MOVX  @DPTR,A                      ; & WRITE BACK
019B  20 20 FD  WAITCP     JB    FLAG.0,WAITCP                ; WAIT FOR CLK.PULSE
019E  D2 21                SETB  FLAG.1                       ; & FLAG
01A0  75 3E FF  RUN        MOV   TEMP3,#FFH                   ; DISPLAY UPDATE CNTR.
01A3  78 30     FIRST-CH   MOV   R0,#CH1                      ; START
01A5  90 FD 00             MOV   DPTR,#MUXADD                 ; PNT TO MUX
01A8  E0        READ       MOVX  A,@DPTR                      ; READ CHANN.
01A9  64 FF                XRL   A,#FFH                       ; INVERT
```

```
LOC.  OBJ.      LABEL      MN.            OPERAND                 COMMENT

01AB  A3                   INC   DPTR                      ; READY FOR NEXT CHANN.
01AC  B8 3A 03             CJNE  R0,#3AH,NEXT              ; IS IT LAST CHANN?
01AF  90 FD 00             MOV   DPTR,#MUXADD              ; YES,START AGAIN
01B2  F0        NEXT       MOVX  @DPTR,A                   ; START MUX CONVERSION
01B3  C0 82                PUSH  DPL                       ;
01B5  C0 83                PUSH  DPH                       ; SAVE DPTR
01B7  B8 3A 04             CJNE  R0,#3AH,NEXTHERM          ; IS THIS LAST THERM?
01BA  B1 00                ACAL  PRESSURE                  ; YES,COMPUTE PRESSURE
01BC  80 0F                SJMP  NEXTCH
01BE  90 0E 00  NEXTHERM   MOV   DPTR,#DATAMSB             ; PNT.TO MSB L-U TABLE
01C1  F5 3C                MOV   TEMP1,A                   ; SAVE A
01C3  93                   MOVC  A,@A+DPTR                 ; FETCH MSB DATA
01C4  F6                   MOV   @R0,A                     ; & SAVE
01C5  08                   INC   R0                        ; POINT TO NEXT CH-STORE
01C6  90 17 00             MOV   DPTR,#DATALSB             ; POINT TO LSB L-U TABLE
01C9  E5 3C                MOV   A,TEMP1                   ; RESTORE A
01CB  93                   MOVC  A,@A+DPTR                 ; FETCH LSB DATA
01CC  F6                   MOV   @R0,A                     ; & SAVE
01CD  08        NEXTCH     INC   R0                        ; READY FOR NEXT CHANN.
01CE  D0 83                POP   DPH                       ;
01D0  D0 82                POP   DPL                       ; RESTORE DPTR.
01D2  75 3D 70             MOV   TEMP2,#70H                ; LOAD DELAY
01D5  D5 3D FD  DELAY      DJNZ  TEMP2,DELAY               ; CONVERSION DELAY
01D8  B8 3C CD             CJNE  R0,#3CH,READ              ; IS IT LAST CHANN?
01DB  D5 3E C5             DJNZ  TEMP3,FIRST-CH            ; YES, WRITE DISP.YET?
01DE  B1 D0                ACAL  DISPINIT                  ; YES,UPDATE DISPLAY & RE-
01E0  21 54                AJMP  CHECKSW                   ; START

END
```

8031 ASSEMBLY LISTING FOR PRINTOUT3

```
; INTERNAL RAM LOCATIONS
; P0              =       0080
; SP              =       0081
; DPL             =       0082
; DPH             =       0083
; TCON            =       0088
; TMOD            =       0089
; TL0             =       008A
; TL1             =       008B
; TH0             =       008C
; TH1             =       008D
; P1              =       0090
; SCON            =       0098
; SBUF            =       0099
; P2              =       00A0
; IE              =       00A8
; P3              =       00B0
; IP              =       00B8
; PSW             =       00D0
; ACC             =       00E0
; A               =       00E0
; B               =       00F0
; FLAG            =       0020
;
; PROG. LABEL LOCATIONS
; EP0            SET      0003
; IT/C0          SET      000B
; ER1            SET      0013
; IT/C1          SET      001B
; ISP            SET      0023
; PRINTOUT       SET      0400
; PRINT-EN       SET      FF6B
; PRINT-DIS      SET      FFEB
; LCP            SET      FF8B
; LDB            SET      FF0B
; UPDATE         SET      0400
; PR-DATE        SET      0400
; GAP            SET      0400
; PR-DATA        SET      0400
; NEXTNIB        SET      0400
; SPACE          SET      0400
; PR-TIME        SET      0400
; TIME           SET      0400
; BUSY           SET      0400
; RESTORE        SET      0400
;
; DATA LABELS
;                DATA     0000
;

;THIS ROUTINE PRINTS THE FULL DATE & STARTING TIME FOR THE HRS THERMAL
;SURVEY SYSTEM ON THE FIRST PASS & DATA & TIME ON ALL SUBSEQUENT PASSES.
;THE CALEDAR DATE & TIME ARE FETCHED FROM A RTC AT LOC.FF00-FF0DH.
;THE DATA IS STORED IN INTERNAL RAM LOC.30H-3BH (POINTED TO BY R1)
;
```

A20

```
;
;
LOC.  OBJ.      LABEL     MN.    OPERAND              COMMENT

0400  C0 E0     PRINTDLT  PUSH   ACC                  ;
0402  C0 82               PUSH   DPL                  ;
0404  C0 83               PUSH   DPH                  ;
0406  C0 F0               PUSH   B                    ; SAVE VARIABLES
0408  C0 90               PUSH   P1                   ; ON STACK
040A  E8                  MOV    A,R0                 ;
040B  C0 E0               PUSH   ACC                  ;
040D  E9                  MOV    A,R1                 ;
040E  C0 E0               PUSH   ACC                  ;
0410  90 FF 0A            MOV    DPTR,#FF0AH          ; POINT TO CLK.UPDATE REG.
0413  75 90 22            MOV    P1,#22H              ; CODE TO READ P6
0416  12 FF BE            LCAL   LCB
0419  75 90 FF            MOV    P1,#FFH              ; SET P1 TO READ (P6)
041C  E5 90               MOV    A,P1
041E  12 FF 0B            LCAL   LDB
0421  64 FF               XRL    A,#FFH               ; INVERT
0423  20 E6 02            JB     ACC.6,UPDATE         ; IS PRINT SWITCH ON?
0426  81 AE               AJMP   RESTORE              ; YES. JUMP
0428  E0        UPDATE    MOVX   A,@DPTR              ; READ REG.
0429  20 E7 FC            JB     ACC.7,UPDATE         ; IF U/D SET LOOP UNTIL CLR
042C  30 20 23            JNB    FLAG.0,PR-DATA       ; IS THIS FIRST PASS?
042F  90 FF 07            MOV    DPTR,#FF07H          ; POINT TO DATE
0432  78 4B               MOV    R0,#4BH              ; POINT TO PRINT BUFFER
0434  E0        PR-DATE   MOVX   A,@DPTR              ; READ DATE
0435  75 F0 10            MOV    B,#16
0438  84                  DIV    AB                   ; SPLIT INTO NIBBLES
0439  44 30               ORL    A,#30H               ; ADD CHR.SET MASK
043B  F6                  MOV    @R0,A                ; STORE IN BUFFER
043C  08                  INC    R0
043D  C5 F0               XCH    A,B                  ; 2ND NIBBLE
043F  44 30               ORL    A,#30H
0441  F6                  MOV    @R0,A
0442  08                  INC    R0
0443  76 20               MOV    @R0,#20H             ; 'SPACE'
0445  08                  INC    R0
0446  A3                  INC    DPTR
0447  B8 51 EA            CJNE   R0,#51H,PR-DATE
044A  76 20     GAP       MOV    @R0,#20H
044C  08                  INC    R0
044D  B8 66 FA            CJNE   R0,#66H,GAP
0450  80 25               SJMP   PR-TIME
0452  79 30     PR-DATA   MOV    R1,#30H              ; POINT TO DATA
0454  78 4B               MOV    R0,#4BH              ; POINT TO PR.BUFFER
0456  C2 22               CLR    FLAG.2
0458  E7        NEXTNIB   MOV    A,@R1                ; FETCH BYTE OF DATA
0459  75 F0 10            MOV    B,#16
045C  84                  DIV    AB                   ; SPLIT INTO NIBBLES
045D  44 30               ORL    A,#30H               ; & MASK 1ST NIBBLE
045F  F6                  MOV    @R0,A                ; MOVE TO BUFFER
0460  08                  INC    R0
0461  C5 F0               XCH    A,B                  ; 2ND NIBBLE
0463  44 30               ORL    A,#30H
0465  F6                  MOV    @R0,A                ; STORE
0466  08                  INC    R0
0467  09                  INC    R1                   ; BUMP POINTER
0468  20 22 04            JB     FLAG.2,SPACE
```

```
LOC.   OBJ.       LABEL      MN.          OPERAND                    COMMENT

046B  D2 22                  SETB  FLAG.2
046D  80 E9                  SJMP  NEXTNIB
046F  76 20      SPACE       MOV   @R0,#20H
0471  08                     INC   R0
0472  C2 22                  CLR   FLAG.2                     ; SPACE INSERTED
0474  B8 66 E1               CJNE  R0,#66H,NEXTNIB
0477  90 FF 04   PR-TIME     MOV   DPTR,#FF04H                ; POINT TO CLK.(HRS)
047A  E0         TIME        MOVX  A,@DPTR                    ; READ TIME
047B  75 F0 10               MOV   B,#10
047E  84                     DIV   AB                         ; SPLIT
047F  44 30                  ORL   A,#30H
0481  F6                     MOV   @R0,A
0482  08                     INC   R0
0483  C5 F0                  XCH   A,B
0485  44 30                  ORL   A,#30H
0487  F6                     MOV   @R0,A
0488  08                     INC   R0
0489  76 20                  MOV   @R0,#20H
048B  08                     INC   R0
048C  15 82                  DEC   DPL
048E  15 82                  DEC   DPL
0490  B8 6F E7               CJNE  R0,#6FH,TIME
0493  18                     DEC   R0
0494  76 0D                  MOV   @R0,#0DH                   ; PRINT COMMAND
0496  90 AA 00               MOV   DPTR,#AA00H                ; PRINTER ADD.
0499  78 48                  MOV   R0,#48H                    ; PRINT BUFFER
049B  12 FF 6B               LCAL  PRINT-EN                   ; ENABLE PRINTER
049E  74 11                  MOV   A,#11H                     ; INIT. CODE
04A0  F0                     MOVX  @DPTR,A
04A1  E0         BUSY        MOVX  A,@DPTR                    ; IS PRINTER BUSY?
04A2  20 E0 FC               JB    ACC.0,BUSY                 ; YES, TRY AGAIN
04A5  E6                     MOV   A,@R0                      ; READ BUFFER
04A6  08                     INC   R0
04A7  F0                     MOVX  @DPTR,A                    ; SEND TO PRINTER
04A8  B8 6F F6               CJNE  R0,#6FH,BUSY
04AB  12 FF EB               LCAL  PRINT-DIS                  ; DISABLE PRINTER
04AE  D0 E0      RESTORE     POP   ACC                        ;
04B0  F9                     MOV   R1,A                       ;
04B1  D0 E0                  POP   ACC                        ;
04B3  F8                     MOV   R0,A                       ;
04B4  D0 90                  POP   P1                         ; RESTORE VARIABLES
04B6  D0 F0                  POP   B                          ; FROM STACK
04B8  D0 83                  POP   DPH                        ;
04BA  D0 82                  POP   DPL                        ;
04BC  D0 E0                  POP   ACC                        ;
04BE  D2 A9                  SETB  IEC.1                      ; RESET INT.
04C0  C2 20                  CLR   FLAG.0                     ; FIRST PRINT DONE
04C2  22                     RET

END
```

8031 ASSEMBLY LISTING FOR HRSPRESSURE1

```
; INTERNAL RAM LOCATIONS
; P0          =      0080
; SP          =      0081
; DPL         =      0082
; DPH         =      0083
; TCON        =      0088
; TMOD        =      0089
; TL0         =      008A
; TL1         =      008B
; TH0         =      008C
; TH1         =      008D
; P1          =      0090
; SCON        =      0098
; SBUF        =      0099
; P2          =      00A0
; IEC         =      00A8
; P3          =      00B0
; IPC         =      00B8
; PSW         =      00D0
; ACC         =      00E0
; A           =      00E0
; B           =      00F0
; TEMP4       =      003F
;
; PROG. LABEL LOCATIONS
; EX0         SET    0003
; IT0         SET    000B
; EX1         SET    0013
; IT1         SET    001B
; SER         SET    0023
; PRESSURE    SET    0500
;
; DATA LABELS
;             DATA   0000
;

;THIS ROUTINE TAKES THE READING FROM CHANNEL 6 (PRESSURE) IN THE ACCUMU-
;LATOR & DIVIDES IT BY 8 TO GIVE A MAXIMUM READING OF 31. THE REMAINDER
;IS STORED IN THE B REG. THE ACC. READING IS CONVERTED TO PACKED BCD &
;STORED IN DISPLAY REGISTER 3AH. THE REMAINDER (B) IS THEN MULTIPLIED
;BY 14 TO GIVE A MAXIMUM READING OF 98 (.98), COVERTED TO PACKED BCD &
;STORED IN REGISTER 3BH.
;
;
;
LOC.  OBJ.      LABEL      MN.        OPERAND              COMMENT

0500  64 FF     PRESSURE   XRL   A,#FFH                    ; INVERT ACC.
0502  75 F0 08             MOV   B,#08H
0505  84                   DIV   AB                        ; DIVIDE INTO 8'THS
0506  85 F0 3F             MOV   TEMP4,B                   ; STORE REMAINDER
0509  75 F0 0A             MOV   B,#0AH
050C  84                   DIV   AB                        ; SPLIT INTO 10'S & UNITS
050D  C4                   SWAP  A                         ; MOVE TO MSN
050E  45 F0                ORL   A,B                       ; ADD MSN
0510  F6                   MOV   @R0,A                     ; & STORE
0511  08                   INC   R0                        ; BUMP PNTR TO DISPLAY REG.
```

```
LOC   OBJ        LABEL      OP         OPERAND              COMMENT

0512  E5 7F                 MOV   A,TEMP4                   ; FETCH REMAINDER
0514  75 F0 0E              MOV   B,#0EH
0517  A4                    MUL   AB                        ; MULTIPLY BY 14
0518  75 F0 0A              MOV   B,#0AH
051B  84                    DIV   AB                        ; SPLIT INTO 10'S & UNITS
051C  C4                    SWAP  A                         ; MOVE TO MSN
051D  45 F0                 ORL   A,B                       ; ADD MSN
051F  F6                    MOV   @R0,A                     ; & STORE
0520  22                    RET                             ; BACK TO PROGRAM

END
```

8031 ASSEMBLY LISTING FOR READTWS

```
; INTERNAL RAM LOCATIONS
; P0              =       0080
; SP              =       0081
; DPL             =       0082
; DPH             =       0083
; TCON            =       0088
; TMOD            =       0089
; TL0             =       008A
; TL1             =       008B
; TH0             =       008C
; TH1             =       008D
; P1              =       0090
; SCON            =       0098
; SBUF            =       0099
; P2              =       00A0
; IEC             =       00A8
; P3              =       00B0
; IPC             =       00B8
; PSW             =       00D0
; ACC             =       00E0
; A               =       00E0
; B               =       00F0
;
; PROG. LABEL LOCATIONS
; ER0             SET     0003
; IT/C0           SET     000B
; ER1             SET     0013
; IT/C1           SET     001B
; ISP             SET     0023
; LCB             SET     FF8B
; LDB             SET     FF0B
; READTWS         SET     05B0
;
; DATA LABELS
;                 DATA    0000
;


;
;
LOC.   OBJ.       LABEL      MN.          OPERAND                 COMMENT

05B0  75 90 33  READTWS     MOV   P1,#33H                         ; CONTROL CODE READ P7
05B3  12 FF 8B              LCAL  LCB
05B6  75 90 FF              MOV   P1,#FFH                         ; SET P1 TO READ
05B9  E5 90                 MOV   A,P1                            ; READ P7
05BB  12 FF 0B              LCAL  LDB
05BE  64 FF                 XRL   A,#FFH                          ; INVERT
05C0  22                    RET
```

END

2031 ASSEMBLY LISTING FOR HRSDISPLAY1

```
; INTERNAL RAM LOCATIONS
; P0          =      00B0
; SP          =      00B1
; DPL         =      00B2
; DPH         =      00B3
; TCON        =      00BB
; TMOD        =      00B9
; TL0         =      00BA
; TL1         =      00BB
; TH0         =      00BC
; TH1         =      00BD
; P1          =      0090
; SCON        =      009B
; SBUF        =      0099
; P2          =      00A0
; IE0         =      00AB
; P3          =      00B0
; IP0         =      00BB
; PSW         =      00D0
; ACC         =      00E0
; A           =      00E0
; B           =      00F0
;
; CODE LABEL LOCATIONS
; ER0         SET    0003
; IT/EX0      SET    000B
; ER1         SET    0013
; IT/EX1      SET    001B
; ISP         SET    0023
; DISPINIT    SET    05D0
; NEXTDISP    SET    05D0
; MASK        SET    05D0
; DISPLAY     SET    05D0
;
; DATA LABELS
;             DATA   0000
;

;THIS ROUTINE IS DESIGNED TO DRIVE 6 LC DISPLAYS. EACH DISPLAY OF 4
;DIGITS IS UPDATED FROM 12 REGISTERS (CH-STORE) IE 2 BYTES FOR EACH
;DISPLAY (THE REGISTERS INITIALLY UPDATED FROM A L-U TABLE).
;EACH BYTE IS SEQUENTIALLY READ, SPLIT INTO NIBBLES, MASKED WITH A DIGIT
;STROBE & THEN WRITTEN TO A DISPLAY POINTED TO BY THE DPTR, STARTING AT
;LOCATION FEF0H.
;THE DS MASKS ARE LOCATED IN RAM AT 50-53H & ARE THE MSN OF THE DATA
;WRITTEN TO THE DISPLAY.
;
;
;
;
LOC.   OBJ.      LABEL       MN.          OPERAND                  COMMENT

05D0   90 FE F0  DISPINIT    MOV    DPTR,#FEF0H                    ; POINT TO DISPLAY 1
05D3   78 30                 MOV    R0,#30H                        ; POINT TO CH-STORE 1
05D5   80 01                 SJMP   MASK
05D7   A3        NEXTDISP    INC    DPTR                           ; NEXT DISPLAY
05D8   79 40     MASK        MOV    R1,#40H                        ; POINT TO DS1
```

LOC.	OBJ.	LABEL	MN.	OPERAND	COMMENT
05DA	E6	DISPLAY	MOV	A,@R0	; READ 1ST BYTE
05DB	75 F0 10		MOV	B,#16	
05DE	84		DIV	AB	; MSN IN A, LSN IN B
05DF	47		ORL	A,@R1	; PRE-FIX DS MASK
05E0	F0		MOVX	@DPTR,A	; WRITE TO DISPLAY
05E1	C5 F0		XCH	A,B	; LSN TO A
05E3	09		INC	R1	; NEXT MASK
05E4	47		ORL	A,@R1	; PRE-FIX IT
05E5	F0		MOVX	@DPTR,A	; & WRITE TO DISPLAY
05E6	08		INC	R0	; 2ND BYTE
05E7	09		INC	R1	; NEXT MASK
05E8	B9 44 EF		CJNE	R1,#44H,DISPLAY	; IS IT LAST DIGIT?
05EB	B8 3C EF		CJNE	R0,#3CH,NEXTDISP	; YES.IS IT LAST DISPLAY
05EE	22		RET		; YES.RETURN TO PROGRAM

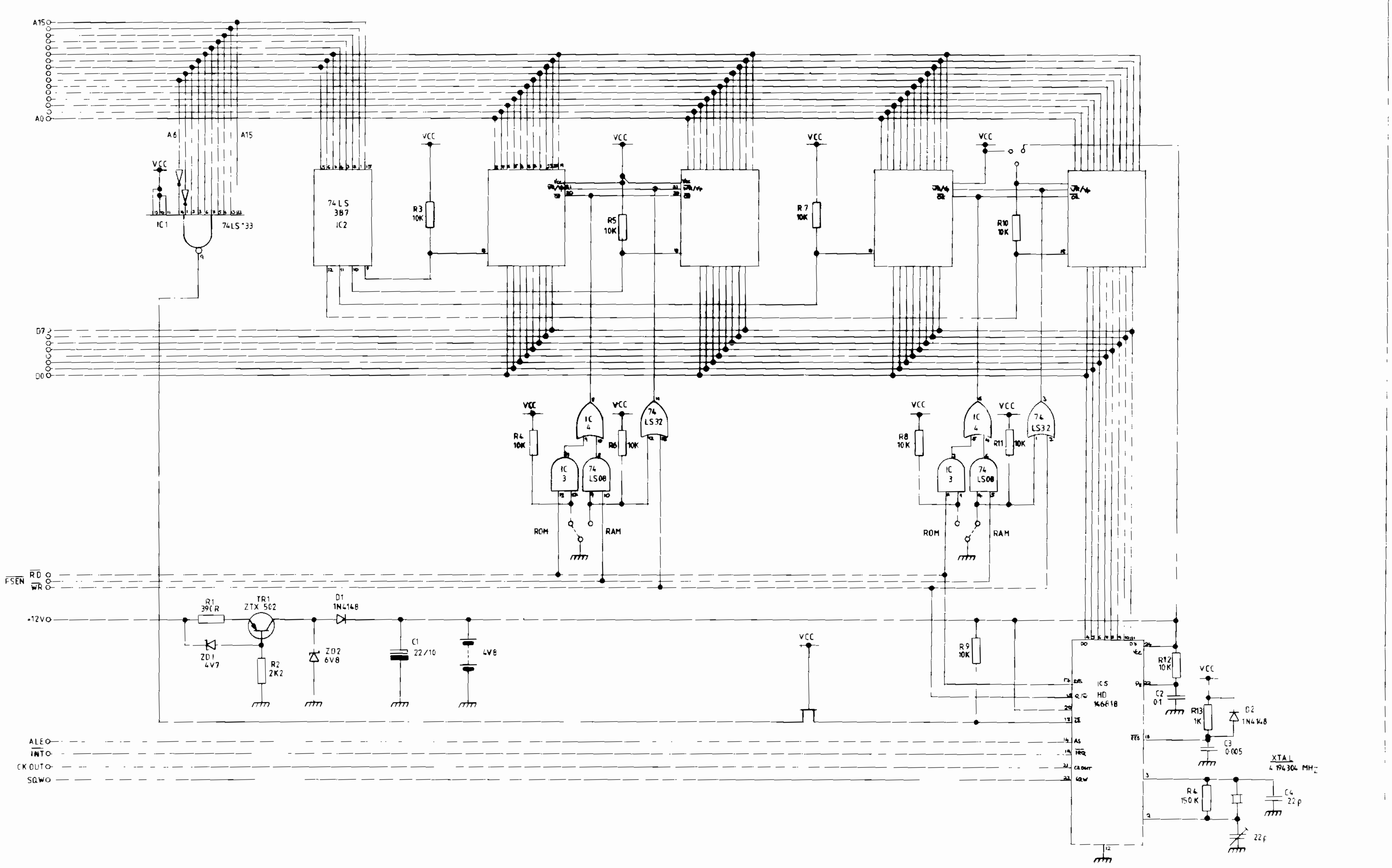
END

8051 ASSEMBLY LISTING FOR HRSCLKSET5

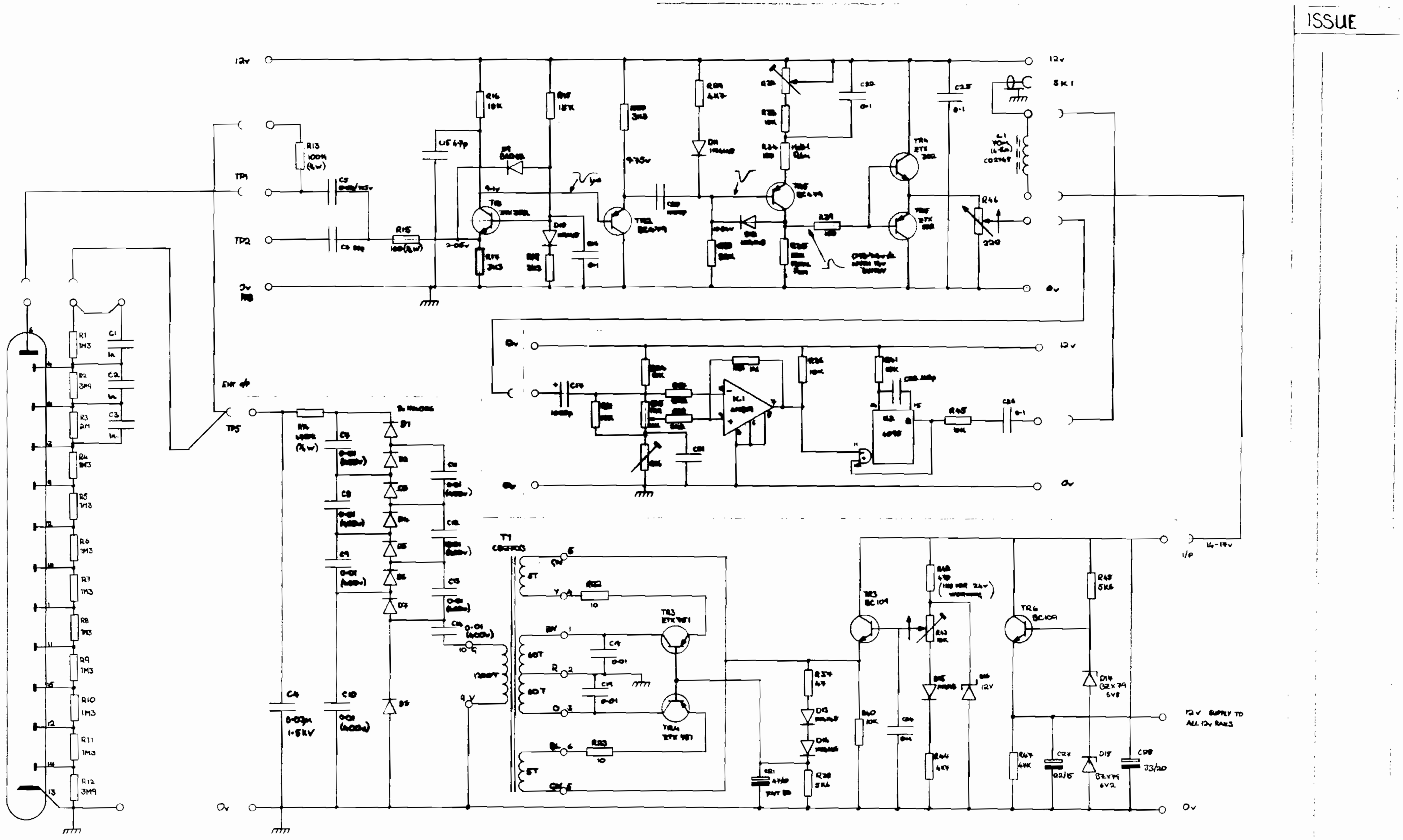
```
; INTERNAL RAM LOCATIONS
; P0          =       0080
; SP          =       0081
; DPL         =       0082
; DPH         =       0083
; TCON        =       0088
; TMOD        =       0089
; TL0         =       008A
; TL1         =       008B
; TH0         =       008C
; TH1         =       008D
; P1          =       0090
; SCON        =       0098
; SBUF        =       0099
; P2          =       00A0
; IEC         =       00A8
; P3          =       00B0
; IPC         =       00B8
; PSW         =       00D0
; ACC         =       00E0
; A           =       00E0
; B           =       00F0
; TEMP1       =       003C
; DH1         =       0030
; FLAG        =       0020
; DIGSTB0     =       0040
; DIGSTB1     =       0041
; DIGSTB2     =       0042
; DIGSTB3     =       0043
;
; PROG. LABEL LOCATIONS
; EX0        SET      0003
; IT/C0      SET      000B
; EX1        SET      0013
; IT/C1      SET      001B
; ISR        SET      0023
; CLKSET     SET      0200
; LCD        SET      FFB2
; LCE        SET      FF0B
; DISPINIT   SET      0500
; READTME    SET      05B0
; ZERO       SET      0212
; STEP       SET      021F
; CHECK1     SET      022A
; CHECK2     SET      022F
; SWITCH     SET      0234
; YEAR       SET      024A
; MONTH      SET      0252
; DATE       SET      025A
; DAY        SET      0262
; HOUR       SET      026A
; MINUTE     SET      0272
; READ       SET      027A
```

```
; CLKSTART      SET       02EE
;
; DATA LABELS
; DS4           DATA      0000
; DS3           DATA      0010
; DS2           DATA      0020
; DS1           DATA      0030
;

;THIS ROUTINE IS FOR INITIALLISING & SETTING THE RTC. IT USES A SMALL
;SUB-ROUTINE TO READ 2 THUMBWHEEL SWITCHES CONNECTED TO P7 OF THE BOD
;& LOAD THEIR SETTING INTO THE LOCATIONS FOR YEAR, MONTH, DATE, DAY,
;HOUR & MINUTE. SELECTION OF PERIOD IS MADE BY A ROTARY SWITCH CONNECTED
;TO P5 (BITS 7 - 2). BITS 1 & 0 ARE CONNECTED TO 2 PB SWITCHES TO
;'ENTER' & 'START' DATA & CLOCK RESPECTIVELY.
;
;
;
;THE ROUTINE MAKES USE OFINTERNAL RAM LOCATIONS 0030H TO 003EH TO STORE
;THE CALENDAR/CLOCK DATA FROM WHICH THE DISPLAYS WILL BE UPDATED.
;LOCATIONS 0040 TO 0043H CONTAIN THE MASK DATA FOR SELECTING THE REQU-
;IRED DIGITS ON EACH DISPLAY.
;
;
LOC.   OBJ.      LABEL     MN.          OPERAND                 COMMENT

0200   78 30     CLKSET    MOV    R0,#30H                      ; SET UP
0202   76 00     ZERO      MOV    @R0,#00H                     ; TO ZERO DISPLAY
0204   08                  INC    R0                           ; REGISTERS
0205   B8 3C FA            CJNE   R0,#3CH,ZERO
0208   B1 D0               ACAL   DISPINIT                     ; ZERO DISPLAY
020A   90 FF 0D            MOV    DPTR,#FF0DH                  ; PNT TO REG D
020D   E0                  MOVX   A,@DPTR                      ; TO SET VRT
020E   90 FF 0B            MOV    DPTR,#FF0BH                  ; PNT TO REG B
0211   74 83               MOV    A,#10000011B                 ; STOP UPDATE,DISABLE INT &
0213                                                           ; SELECT 24HR & DAY'LT SAVE
0213   F0                  MOVX   @DPTR,A                      ; WRITE TO REG B
0214   90 FF 0A            MOV    DPTR,#FF0AH                  ; PNT TO REG A
0217   74 70               MOV    A,#01110000B                 ; RESET DIV
0219   F0                  MOVX   @DPTR,A                      ; WRITE TO REG A
021A   90 FF 09            MOV    DPTR,#FF09H                  ; PNT. TO CLK.
021D   78 31               MOV    R0,#31H
021F   E0        STEP      MOVX   A,@DPTR                      ; READ CLK.
0220   F6                  MOV    @R0,A                        ; & STORE IN BUFFER
0221   08                  INC    R0
0222   08                  INC    R0
0223   15 82               DEC    DPL
0225   B8 3B 02            CJNE   R0,#3BH,CHECK1
0228   15 82               DEC    DPL
022A   B8 39 02  CHECK1    CJNE   R0,#39H,CHECK2
022D   15 82               DEC    DPL
022F   B8 3D ED  CHECK2    CJNE   R0,#3DH,STEP
0232   B1 D0               ACAL   DISPINIT
0234   75 90 11  SWITCH    MOV    P1,#11H                      ;
0237   12 FF B8            LCAL   LCB                          ; READ P5
023A   75 90 FF            MOV    P1,#FFH                      ; SET P1 TO READ
023D   E5 90               MOV    A,P1                         ; READ SWITCH SETTINGS
023F   12 FF 08            LCAL   LDB                          ; SWITCH PORT OFF
0242   64 FF               XRL    A,#FFH                       ; INVERT
0244   20 E0 3F            JB     ACC.0,CLKSTART               ; IS IT START?
0247   30 E1 EA            JNB    ACC.1,SWITCH                 ; NO! IS IT ENTER?
024A   30 E7 05  YEAR      JNB    ACC.7,MONTH                  ; IS P5 YEAR?
024D   75 82 09            MOV    DPL,#09H                     ; YES! SAVE LOW ADD.
```

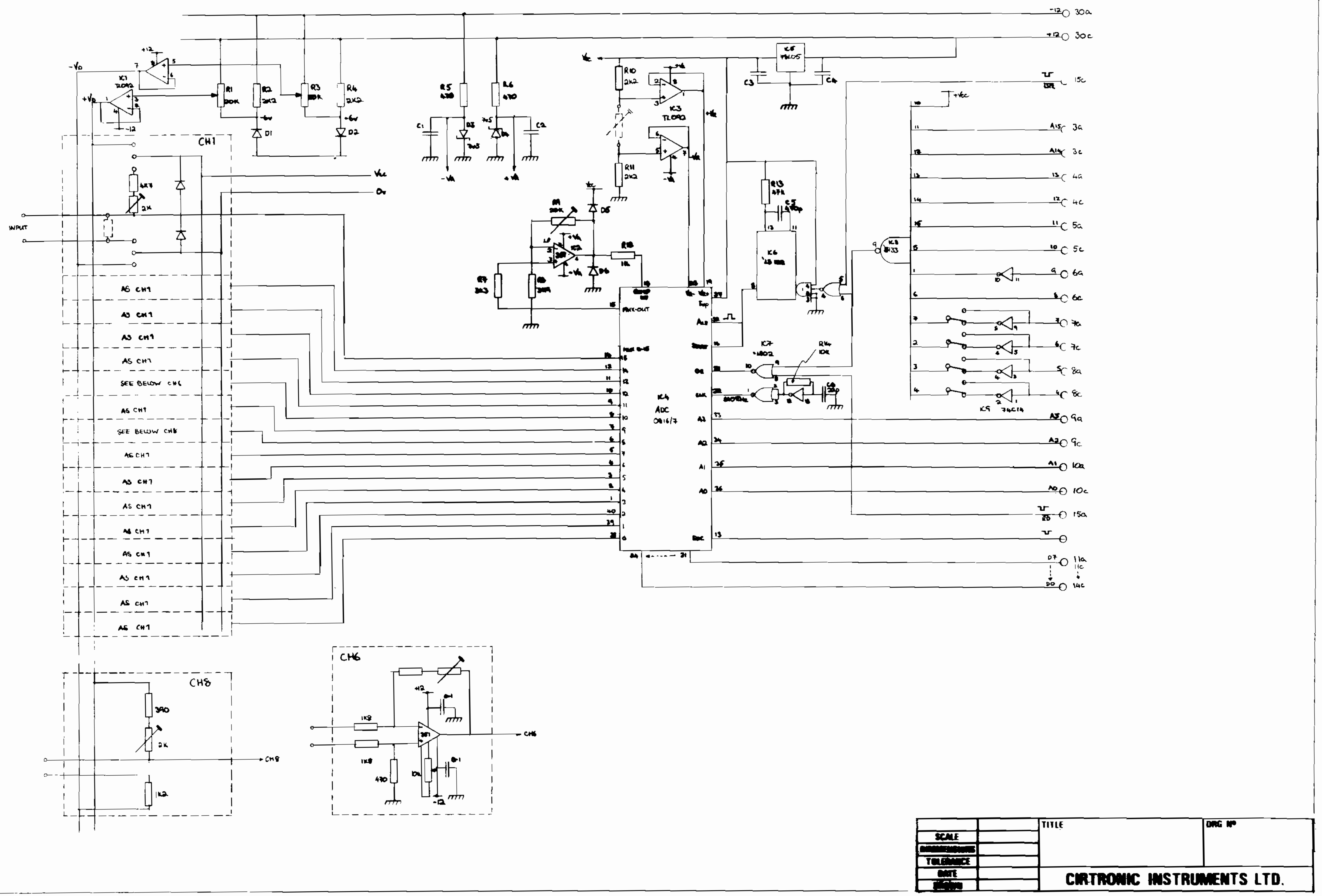
```
LOC   OBJ.        LABEL      MN.     OPERAND                  COMMENT

0250  78 31                  MOV     R0,#31H                  ; PNT.TO DISPLAY BUFFER
0252  30 E6 05   MONTH       JNB     ACC.6,DATE               ; IS P5 MONTH?
0255  75 82 0B               MOV     DPL,#0BH                 ; ETC.
0258  78 33                  MOV     R0,#33H                  ; ETC.
025A  30 E5 05   DATE        JNB     ACC.5,DAY
025D  75 82 07               MOV     DPL,#07H
0260  78 35                  MOV     R0,#35H
0262  30 E4 05   DAY         JNB     ACC.4,HOUR
0265  75 82 06               MOV     DPL,#06H
0268  78 37                  MOV     R0,#37H
026A  30 E3 05   HOUR        JNB     ACC.3,MINUTE
026D  75 82 04               MOV     DPL,#04H
0270  78 39                  MOV     R0,#39H
0272  30 E2 05   MINUTE      JNB     ACC.2,READ
0275  75 82 02               MOV     DPL,#02H
0278  78 3B                  MOV     R0,#3BH
027A  75 83 FF   READ        MOV     DPH,#FFH
027D  B1 B0                  ACAL    READTWS                  ; READ TW SWITCH
027F  F0                     MOVX    @DPTR,A                  ; WRITE SW TO CLK
0280  E0                     MOVX    A,@DPTR                  ; READ LOC FOR CHECK
0281  F6                     MOV     @R0,A                    ; & STORE
0282  B1 D0                  ACAL    DISPINIT                 ; WRITE TO DISPLAY
0284  41 34                  AJMP    SWITCH                   ; NEXT
0286  90 FF 0A   CLKSTART    MOV     DPTR,#FF0AH              ; PNT TO REG A
0289  74 2F                  MOV     A,#00101111B             ; SET 32KHZ & 2HZ SQW
028B  F0                     MOVX    @DPTR,A
028C  90 FF 0B               MOV     DPTR,#FF0BH              ; PNT TO REG B
028F  74 03                  MOV     A,#00000011B             ; SET UPDATE,NO INT'S,SQWE,
028F                                                          ; 24HR CLK,DAYLT SAVE
0291  F0                     MOVX    @DPTR,A
0292  C2 21                  CLR     FLAG.1                   ; FIRST CF RECEIVED
0294  D2 AA                  SETB    IEO.2                    ; RESET TO INT.
0296  22                     RET                              ; BACK TO PROGRAM

END
```



		TITLE 806 MEMORY and RTC	DRG Nº
SCALE			
DIMENSIONS			
TOLERANCE			
DATE	15/03/85	CIRTRONIC INSTRUMENTS LTD.	
DRAWN	PM		



		TITLE	DRG Nº
SCALE		BORE HOLE PROBE	
DATE	15/3/85	CIRTRONIC INSTRUMENTS LTD.	
	PM		



CIRTRONIC INSTRUMENTS LTD.
TITLE
DRG No
SCALE
TOLERANCE
DATE
CH1
CH6
CH8
INPUT
ADC
AS CH1
SEE BELOW CH6
SEE BELOW CH8

Figures

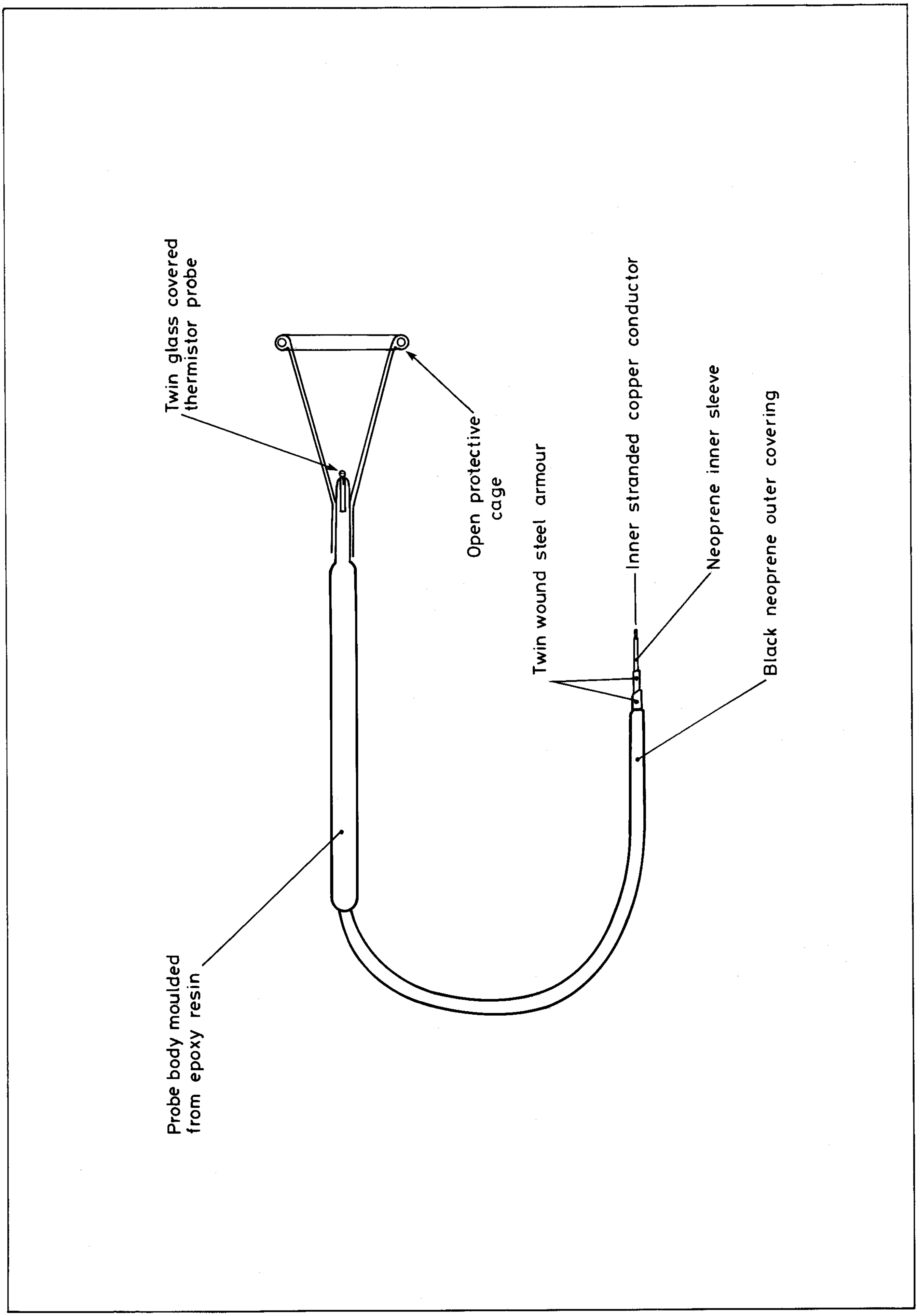


Fig 1 Thermistor assembly

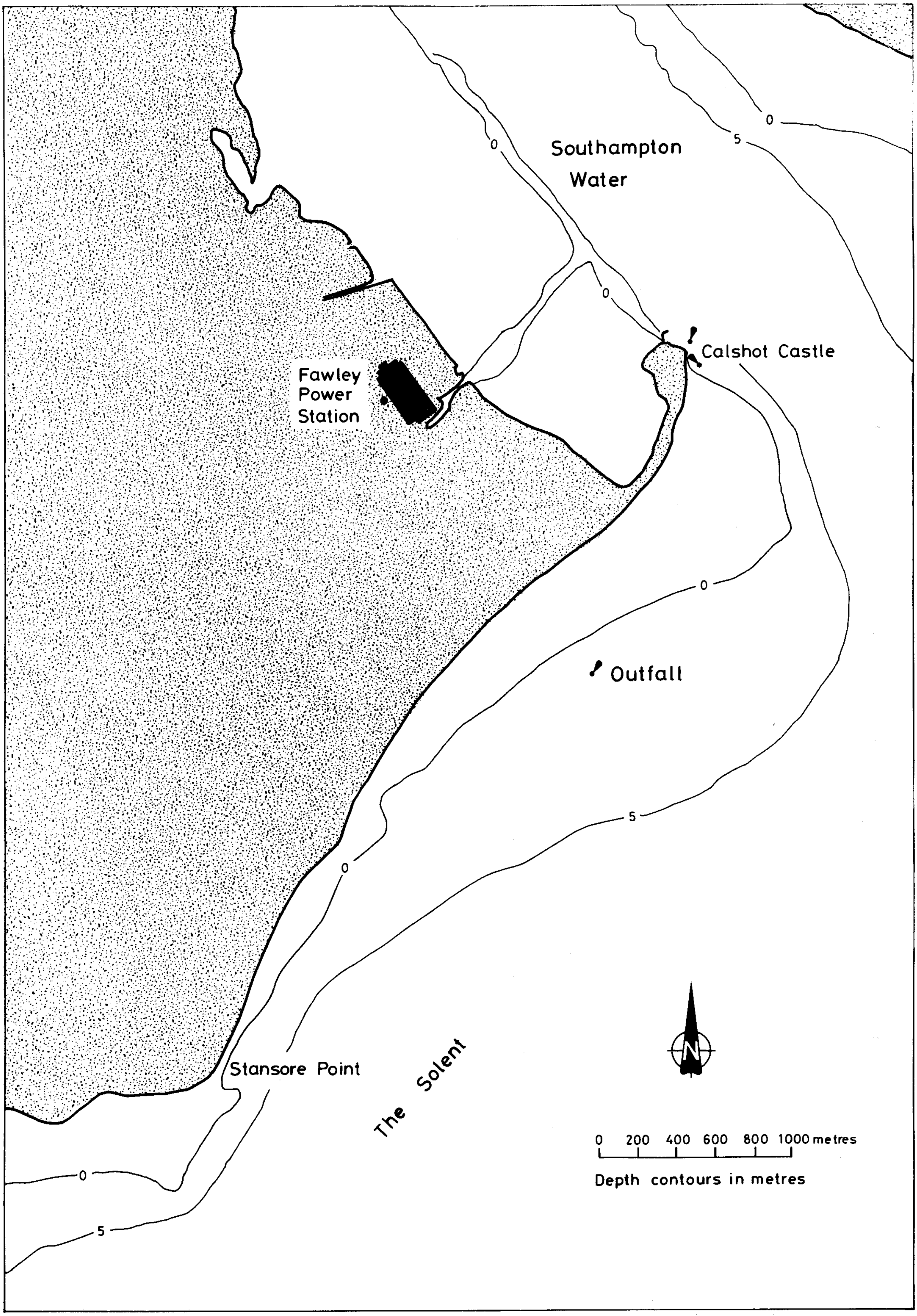


Fig 2 Plan of experimental area showing outfall position

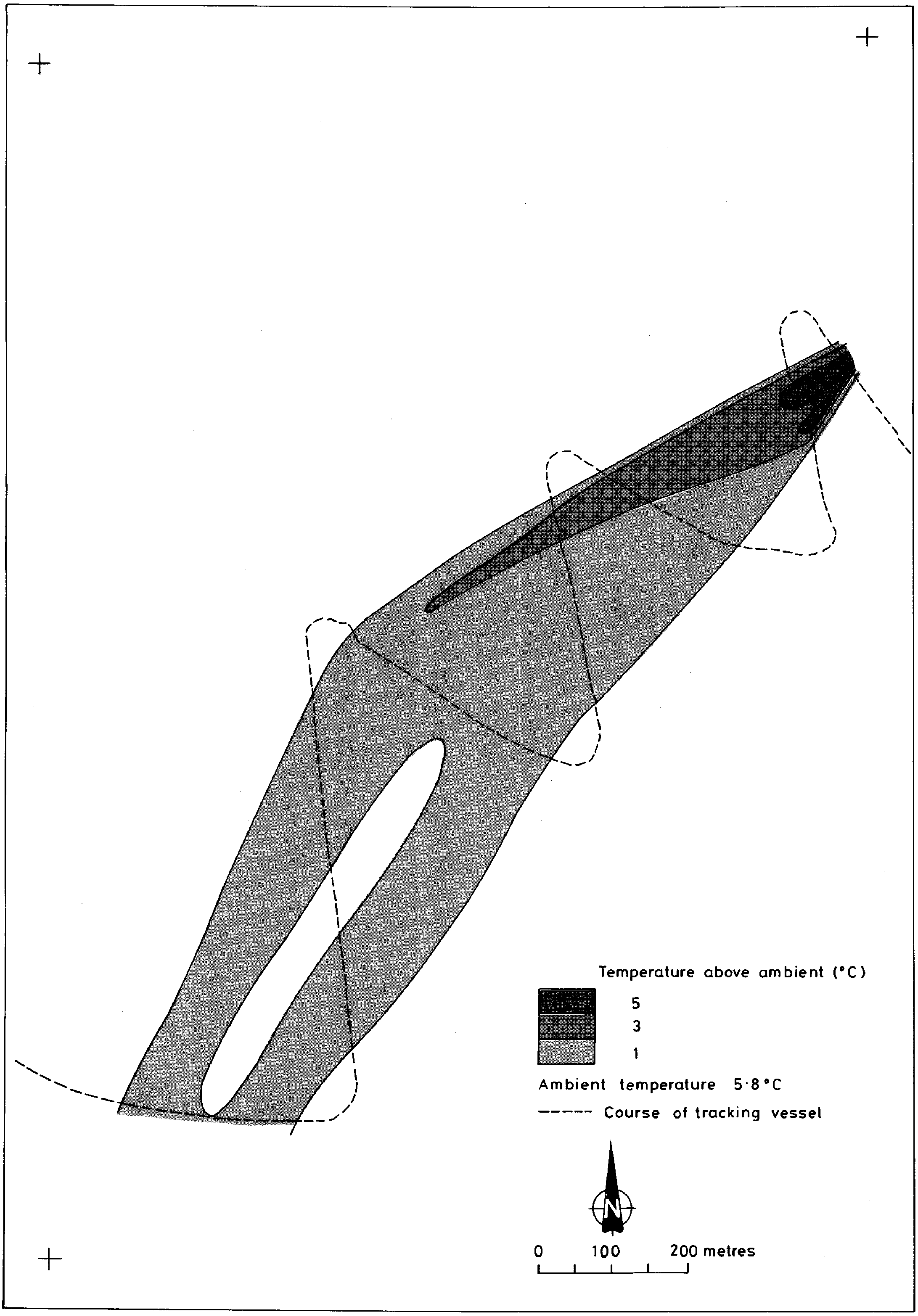


Fig 3 Fawley outfall 20·3·85 Near-surface temperature distribution HW + 1 hr to HW + 1·5 hrs

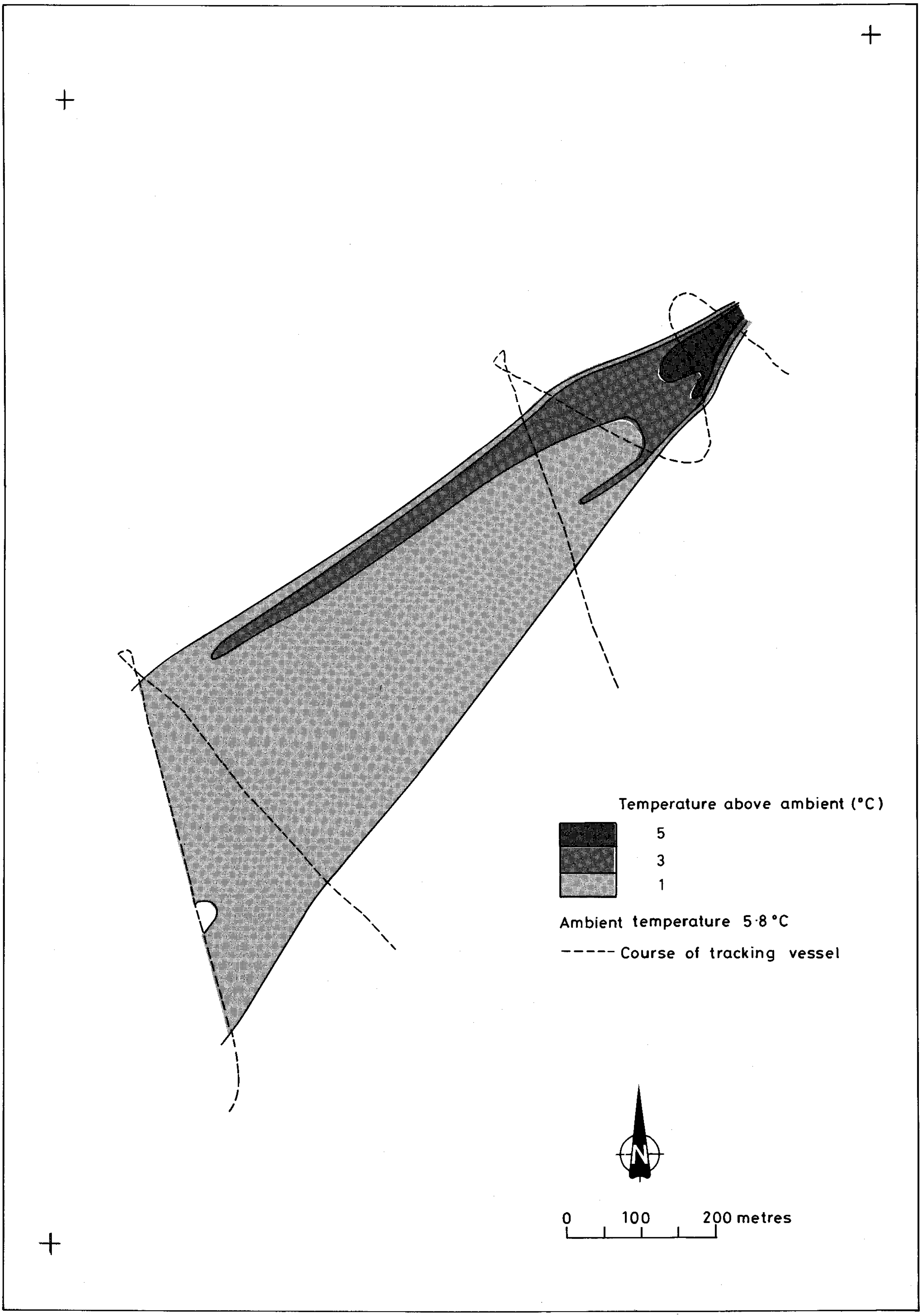


Fig 4 Fawley outfall 20·3·85 Near-surface temperature distribution HW + 2·3 hrs to HW + 3 hrs

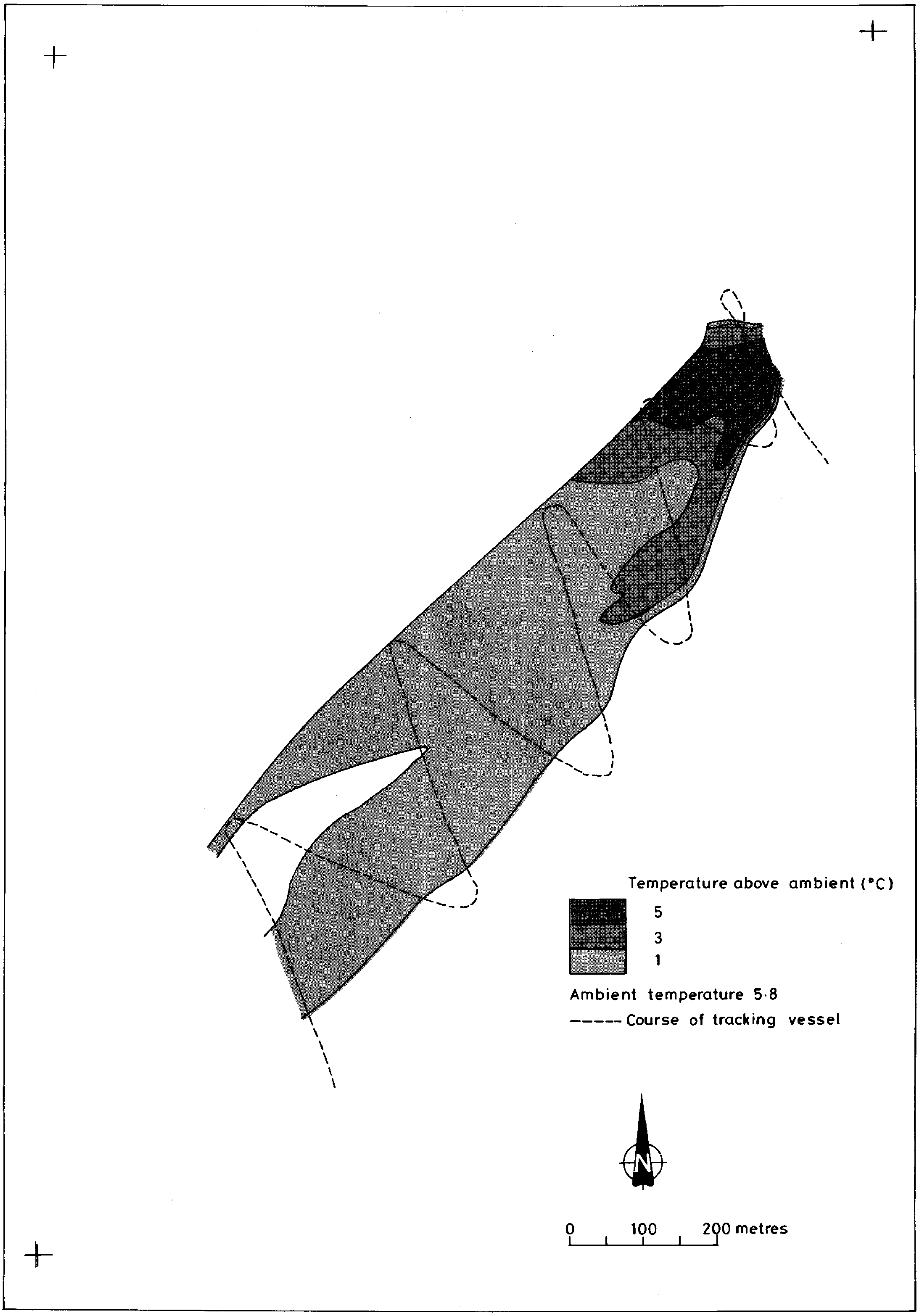


Fig 5 Fawley outfall 20·3·85 Near-surface temperature distribution HW + 3·5 hrs to HW + 4·3 hrs

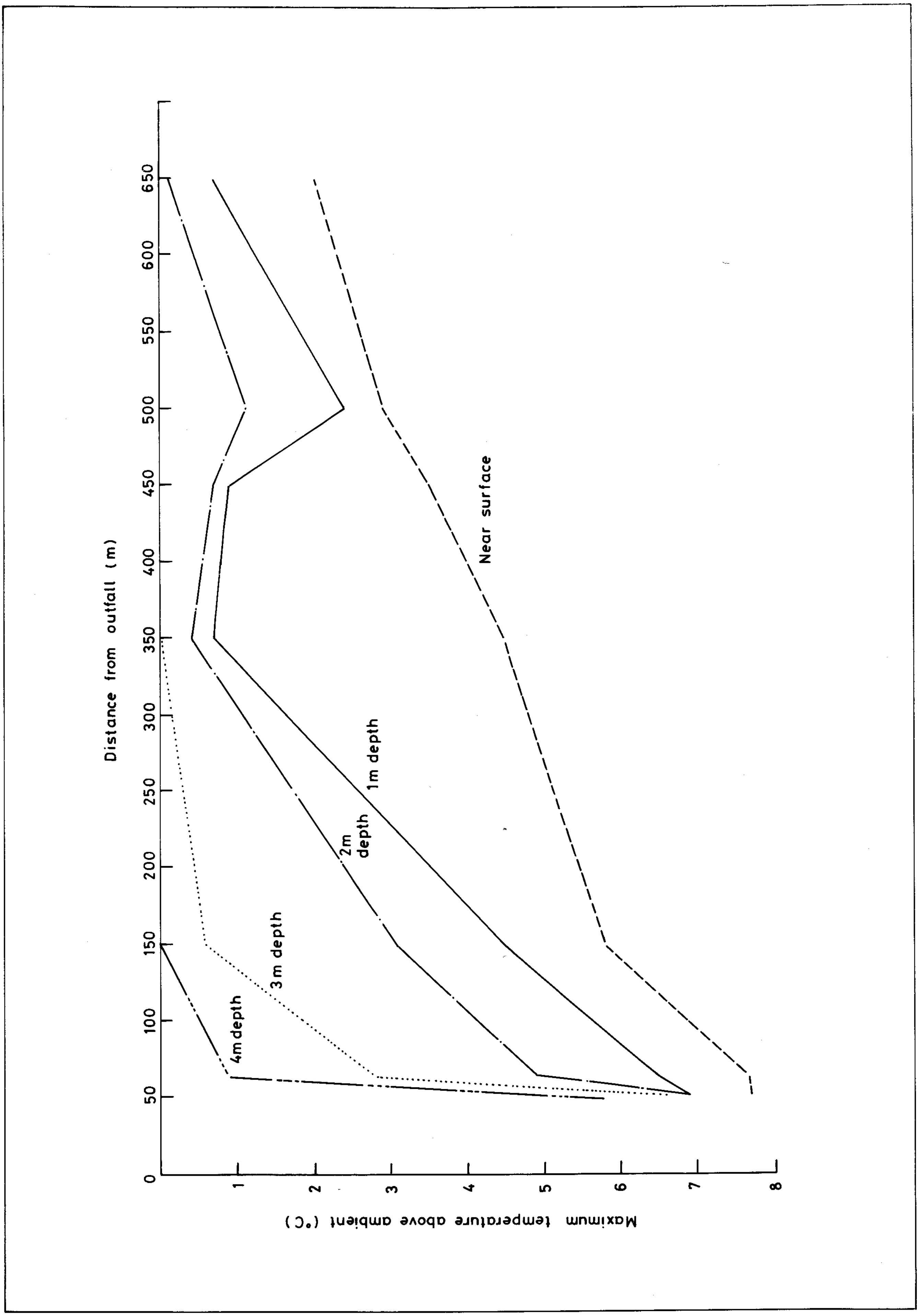


Fig 6 Longitudinal variation of temperature during period HW + 3·5 hrs to HW + 4·3 hrs

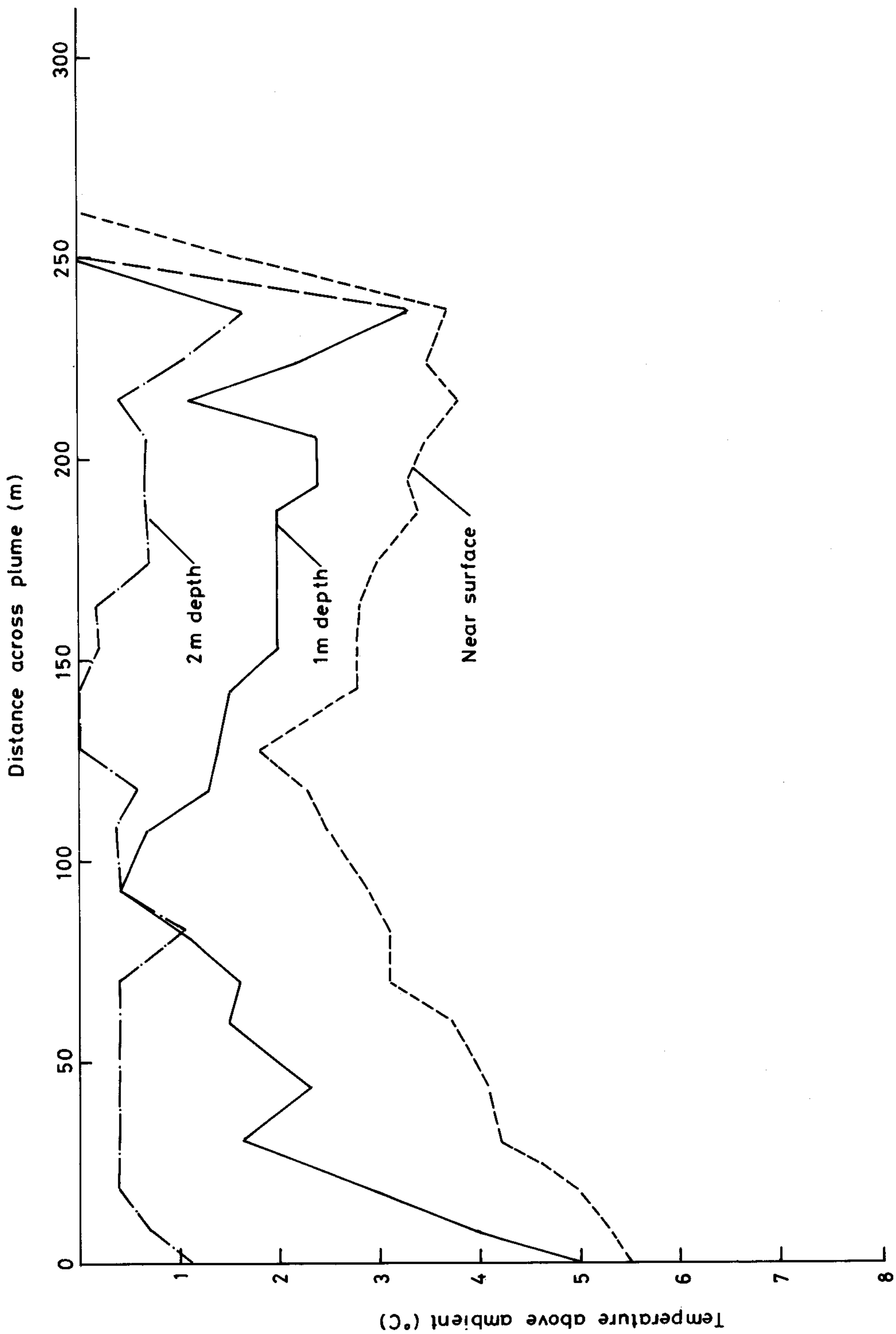


Fig 7 Lateral variation of temperature 300m from outfall at HW + 3·5 hrs

Plates

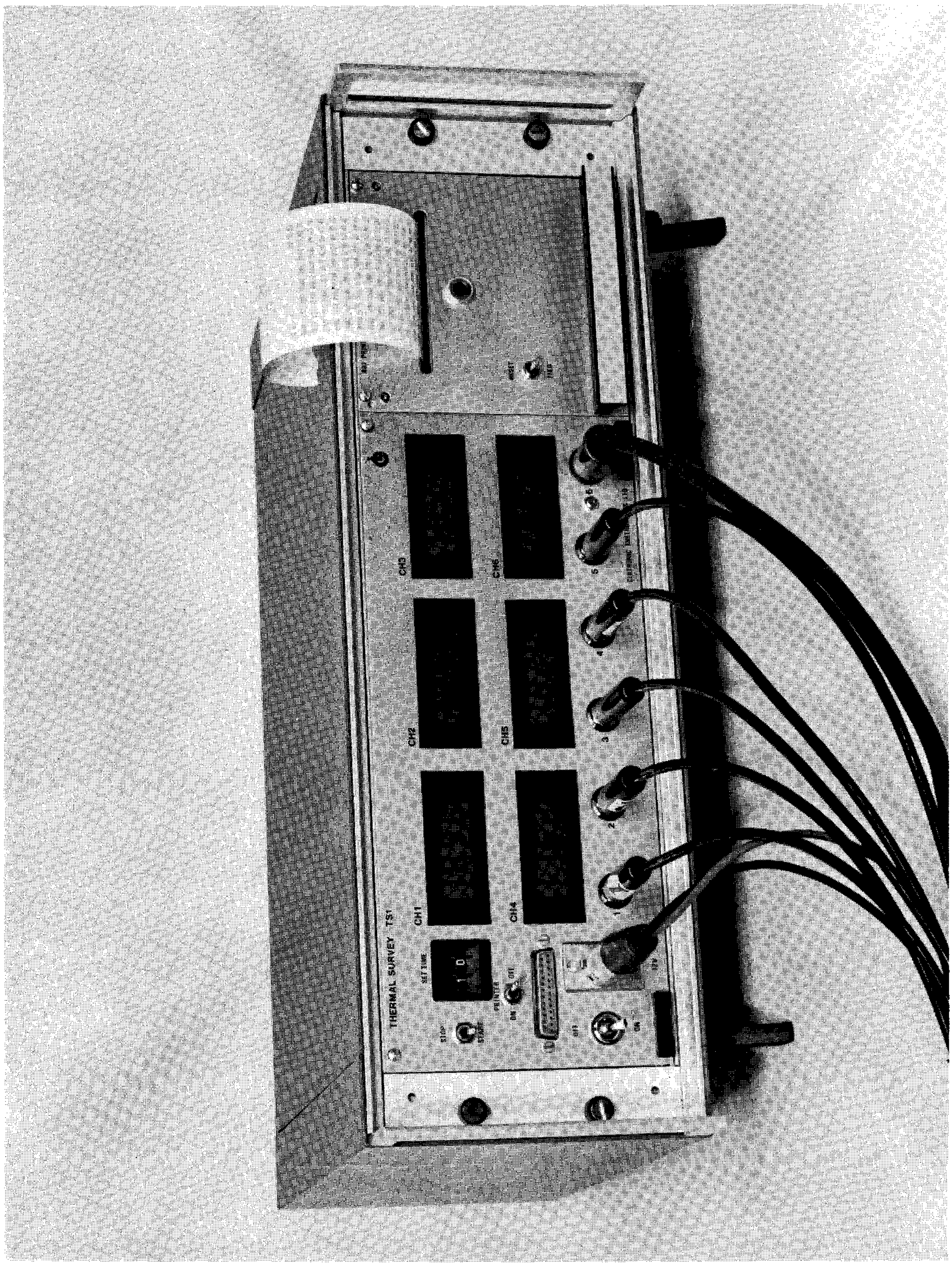


PLATE 1 Inboard instrumentation

PLATE 2 The "Stewkie" Kite being launched from the moored vessel

PLATE 3 Photograph of the dye-enhanced thermal plume

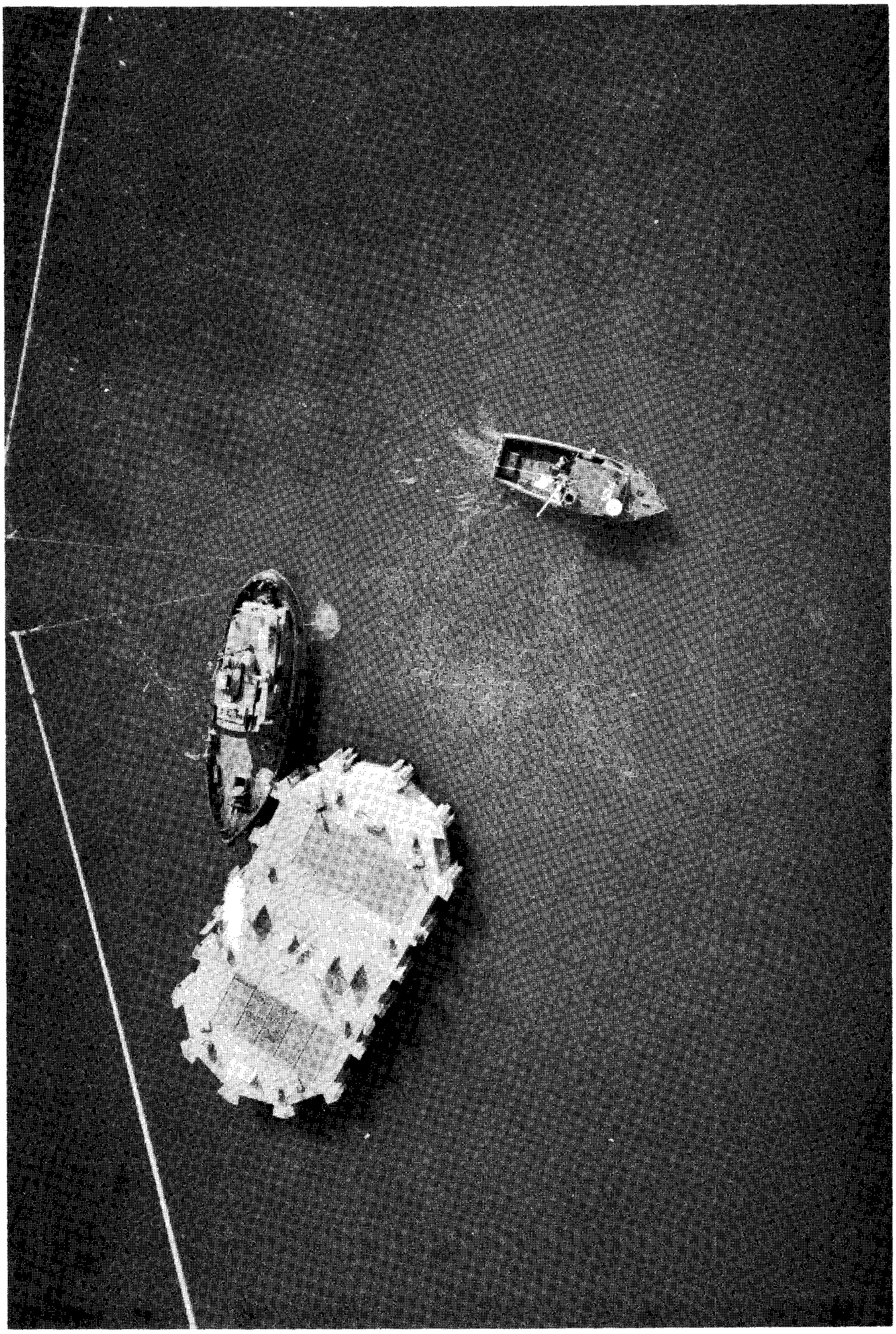


PLATE 4 Aerial photograph showing the outfall structure, the moored vessel and the tracking vessel.