DEVELOPMENT AND PERFORMANCE OF THE

C.C.I.W. FIXED TEMPERATURE PROFILING SYSTEM

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ABSTRACT

The C.C.I.W. Fixed Temperature-Profiling System is described in terms of its engineering development and evolution. It is a moored, self-recording, 18-channel temperature monitoring system capable of digitally recording 180,000 water temperature samples, accurate to ±0.03°C, sensed by a vertical thermistor array 100m. long. System operating environment is the Great Lakes, and operating endurance 50 days. The report reviews system design, equipment performance during test, and initial operating experience gained during the 1972 IFYGL field season.

CONTENTS

FIGURES

1. INTRODUCTION AND PURPOSE OF THE SYSTEM

Study of the limnological environment is a multidisciplined effort involving physics, chemistry, biology, geology, etc. Consequently many types of measurements must be taken to gain overall insight into the nature and behaviour of a given body of water. One common parameter which affects most limnological processes is temperature. Accordingly, for its program in the Great Lakes System, C.C.I.W. utilizes varied equipment to make temperature measurements; including reversing thermometers, electronic bathy-thermographs (EBT's), mechanical BT's, towed thermistor arrays, remote IR detectors, and surface temperature sensors, both towed and fixed. However, none of these systems provide long-term continuous temperature profiling capability at a given point in a lake. Such a moored or "fixed" system could help to determine the lake thermal energy content and overall heat budget, obtain increased insight into the characteristics of long wave-length internal waves and seiches in lake basins, and provide valuable data about such variations in lake thermal structure as thermal bar development. Thus, the requirement for the C.C.I.W. Fixed Temperature Profiling (FTP) System was made clear.[1]

The basic design approach uses thermistor-array technology,[2-5] with data obtained by recording the output of several thermistors placed at known depths. Eighteen levels was considered adequate to characterize a temperature profile at any particular time. The actual evolutionary cycle of the FTP system through development and into operation was somewhat abreviated due to the pressing requirements of the IFYGL program, i.e. the need to get an array of working systems into Lake Ontario for the 1972 field season. An associated program objective was that nearly two million initial samples gained from system field experience were to become part of the IFYGL data bank, for subsequent scientific analysis and processing.

2. CONFIGURATION OF THE MOORED BUOY SYSTEM

The physical arrangement of the complete FTP system as moored is shown in Figure 1, and with its scientific moored buoy, groundline, and separate marker float is typical of CCIW's "U" shaped moorings. The active part of the system is contained in and below the main buoy, and is composed of three basic elements, namely, 18 thermistor sensors, the telemetering cable assembly and the digitizing/recording electronics. The surface buoy functions effectively as a spar, comprised of a double truncated cone shell constructed of fibreglass skin filled with polyurethane foam, together with a heavy concrete keel for vertical stability. The mooring is designed to be a relatively simple, semi-taut, "self-compensating" system trimmed by a section of chain at the anchor to minimize vertical excursions of the cable assembly and maintain depth constancy with seasonal changes in lake level. The mooring configuration is designed for expected lake current-values up to one knot, or for current shears in local layers due to baroclinic jets of up to two knots magnitude. As shown in the figure the main mooring stress cable is separate from the effectively-unstressed sensor cable so that the moldings, connectors, etc. are not subject to the full environmentally-induced buoy forces. Buoy and cable dynamic motions occurring at relatively-high frequencies are averaged out due to the long sensor time-constants provided.

As shown in figure 1 the ground line and auxiliary anchor/marker line assembly provide for two alternate recovery procedures. In the event of a lost surface buoy, the system can be recovered via the marker line and ground line. If both buoy and marker are gone, the ground line may be retrieved by dragging, and thus the system recovered.

Some appreciation of the size, shape, etc. of the FTP surface buoy, and handling arrangements during deployment can be gained from the views of figure 3.

3. TEMPERATURE SENSORS AND CABLE ASSEMBLY

After considerable review of different types of probes, it was decided that the system temperature sensors would be thermistors, (Fenwal Type K2284), ordered to a nominal interchangeability of 1% and a resistance at 25°C. of nominally 4KΩ. Improved accuracy would then be obtained by individual calibration of each unit. These thermistors are mounted in a two pin Marsh and Marine connector housing, incorporated in neoprene moldings, which are part of the cable assembly. Figure 4 shows views of this complete FTP sensor assembly. (The faired configuration of the molding derives from earlier towed thermistor-chain designs.)

The basic probe in its metal housing has a time constant (or nominal response time) of about 80 seconds, which is unduly rapid in relation to the 10 minute sampling interval of the system. Accordingly, a neoprene boot is affixed to the probe, which increases the time constant to 4 minutes in still water. Figure 5 shows measured response curves with and without the boot, as well as the cross sectional view of the thermistor assembly.[9]

These thermistor sensors are geometrically spaced in the vertical water column at locations which result in a hybrid log/linear sensor array. At shallow depths (to 30 m) linear spacing at 4 m. intervals is used to give finer coverage in the active thermocline region. From 30 to 100 metres logarithmic spacing is adequate, with any excess array length at shallow stations doubled back in the mooring. (Fig. 1)

Table 1 below shows actual sensor depths along the complete 100 metre array.

TABLE #1

SENSOR NO.	DEPTH (METERS)	SENSOR NO.	DEPTH (METERS)
1	0.2	10	30
2	1.0	11	35
3	3.0	12	40
4	6.0	13	46
5	10	14	55
6	14	15	64
7	18	16	74
8	22	17	86
9	26	18	100
Effectively-linear Section		Logarithmic Section	

The temperature information (resistance variations) produced by the thermistors is effectively telemetered to the digitizer via the special molded multi-conductor electrical cable 100 metres in length. The cable assembly made by BIW (Canada) to CCIW specification,[12] is a two-part system, incorporating both a 7/32" stainless-steel strain member with a break strength of 4100 lb, and a 22-conductor neoprene-jacketted electrical cable, designed to the standards of mil specification MIL-C-915C. At some 40 intervals down the assembly (as set by the sensor spacings shown above) there are stress relief mouldings joining the strain member and the electrical cable. (Figure 4). The strain member itself is in three sections, joined by swaged fittings, allowing terminable cable lengths of 65, 75 and 100 metres or more to suit varying on-station depths. The upper end of the electrical cable is terminated in a multipin water-proof connector, which mates directly with the digitizer. The lower end of the cable is capped with a water-proof seal.

(Earlier versions of the FTP cable utilized a braided stainless steel strain member, but good bonding between the rubber moulding and the braid could not be maintained over the required period due to working of the cable under the varying load of the mooring, and leakage at the temperature sensors became a significant problem.)

4. ELECTRONIC DIGITIZER/RECORDER UNIT

In this system, temperature sensor data is processed by purely digital techniques, using the standard multiplexer A/D converter, digital encoder, and incremental recorder approach. (Figure 2 shows the functional block diagram). The digitizer, manufactured by EG & G Inc., [10] is a complete, self-powered resistance sampling, digitizing, and recording instrument, whose physical arrangement is shown in Figure 6. At preselected sampling intervals (usually ten minutes), the digitizer scans, measures and records the 18 input channels in an overall scan time of 6 seconds for all channels. During the 250 milliseconds each channel is connected, a successive-approximation analog to digital conversion is performed, by means of 12 switched-in precision resistors, and a 12 bit digital word corresponding to the resulting combination of resistors is recorded on 1/4" magnetic tape.

A resistive bridge network with differential comparator is used as the sensing circuit, as shown in the schematics of figures 7 and 8. Bridge DC excitation at 0.7V is adequately low to result in negligible thermistor self-heating during digitization.

In addition to the 18 channels of temperature information, a time reference, an instrument identity word, and a fixed resistance reference are recorded. The time reference is obtained from a quartz crystal oscillator operating at 65,536Hz. This frequency is divided down and provides all the basic timing including .125pps pulse train. These pulses are counted by a binary counter and result in a five digit (14 bit) time word, which decrements by one number every eight seconds. The operation of the digitizer can be monitored and controlled via a 6 pin test socket, using a special test unit or Digital Display Monitor (DDM...also shown in Figure 6). Using this test unit, any data word of a given scan may be displayed on 16 lights. By putting the instrument into the continuous mode, correct operation of all 18 sensor channels and time, reference, and identity can be verified in a few minutes.

In terms of electronics technology, the digitizer compares well with other contemporary units of a similar nature and purpose. Table 2 below shows electronic component complement:-

TABLE 2

Discrete Active Devices	678
Discrete Passive Devices	503
Monolithic Integrated Circuits	10
Hybrid Thick-Film Circuits	86
Miscellaneous Discrete Electromechanical Components	35
TOTAL:	1,312

5. SYSTEM PERFORMANCE AND MEASUREMENT ACCURACY

The FTP system performance target in terms of the salient parameters temperature, time, depth and capacity is as follows:-

Temperature Measurement-Range:	-2° to +30°C
Temperature Measurement-Accuracy:	0.1°C total RMS error (max.)
System On-Station Endurance:	50 days (minimum)
System Data Capacity:	Up to 180,000 digital temperature samples. (i.e. 10^4 scans)
Sensor Depth Accuracy:	0.5m based on the averaging effect of the thermistors in relation to the size of the surface waves.

With respect to the temperature measurement process in the FTP system, this can be considered divided into 2 steps; one physical, the other electronic. The first step depends on the fundamental temperature/resistance transfer characteristic of the thermistor itself, as illustrated in figure 9. For the thermistors selected for this system (Fenwal Type K2284), this characteristic was not available in a closed mathematical form, but rather as a table of empirical "iso-curve" values.[8] This table, provided by Fenwal, represents the mean characteristics of a large population of thermistors but can be represented in a closed form as follows:

Using the basic thermistor equation:

$$R=R_o e^{\beta(1/T-1/To)} \qquad (1)$$

with 25°C baseline values

$$(R_o=4002\Omega \text{ and } T_o=298.16°K)$$

and substituting iso-values from the table to determine β, the resulting simple exponential form of the equation becomes:

$$R=4002e^{3385(1/T-1/298.16)} \qquad (2)$$

Equation (2) matches the table of iso-values only to within ±90 ohms over the range -2 to +30°C. This is not adequate, and therefore a polynomial was fitted to the error curve resulting in the final equation:

$$R=4002e^{3385(1/T-1/298.16)}+87.6-1.48T-0.17T^2+.0035T^3 \qquad (3)$$

which corresponds to the Fenwall Table within ±2 ohms over the range -2 to +30°C, and thus gives fully-adequate representation of these sensors, and is shown in figure 9. This is further confirmed diagrammatically in Figure 10, which summarizes the situation in relation to the FTP system thermistor population. Here the temperature axis represents the initial empirical iso-values. The deviations inherent in using equation 3 as a representation are seen to be negligible in comparison with both the 1% procurement tolerance limits to which the sensors were obtained, and the population histograms (based on CCIW temperature bath calibrations) which themselves are clearly well within tolerance.

The electronic step in the measurement process is the successive approximation analog to digital conversion of resistance performed by the digitizer. Due to the non-linear nature of the thermistor characteristic (figure 9), the transfer characteristic of the chosen digitizing circuit (shown in figure 8) is inversely non-linear in order to compensate, and produce quasi-linear overall operation. In this situation the digitizing network of figure 8 can be represented exactly by the function:

$$D_o=2^{11}.5000\left[\frac{4}{R_t+4000}-\frac{1}{4166.6}\right]\pm 0.5 \qquad (4)$$

where D_o is an integral digital number in the range 0 to 4095 and Rt is the thermistor resistance in ohms.

Although the equation is exact, the resolution is limited in the first place to the 12 binary bits used in the actual circuit. A further limitation is the the equipment error (due to accumulated tolerances) which limits the accuracy to one bit overall, in realistic equipment operating conditions of temperature, voltage, etc. Combining equations (3) and (4) results in the overall FTP-system transfer function (shown in figure 11), fairly linear over the temperature range -2 to 40°C. For accurate, quantitative, work however, a valid mathematical representation is required. Accordingly a curve-fitting routine was applied to 45 discrete points, to obtain the final performance equation:

$$D_o = 123.4 + 101.74T - 78.97\left[\frac{T}{17.817} - 1\right]^3 \pm 1 \text{ BIT} \text{———} (5)$$

where T is °C.

<u>This equation represents the overall temperature/digital transfer function of the FTP system within its operating measurement range, valid for all temperature sensors.</u>

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Discussion thus far has emphasized the measurement/recording operation of the FTP system.[6] Equally important is the inverse data-reduction process (from D_o to T), where we have available both digital numbers on tape, and multipoint calibration data for individual thermistors. Here the method is to use the standard D_o to T transfer function.

$$T = -2.324 + 0.0163D_o + -9.5598\times10^{-7}D_o^2 + 1.65\times10^{-10}D_o^3 + \varepsilon \text{—} (6)$$

which is obtained using the same data as eqn (5), then adding a correction term based on the deviation of each individual thermistor from the standard curve. The correction equation is of the form

$$\varepsilon = A + B.D_o + C.D_o^2 \text{———} (7)$$

This form of equation dictates a minimum of three calibration points, and in fact CCIW calibrates the thermistors at four temperatures. 0°C, 10°, 15° and 25°C. 0°, 10° and 25° are used to solve for the constants and 15°C is used as a check.

For the FTP temperature-measurement system it is also possible to construct a realistic measurement-error budget, whose separate elements are shown tabulated below:

. Electronic Digitizer Resolution (±1 bit)	±10 millidegrees C
. Calibration Error for Individual Temperature Sensors	±15 millidegrees
. Cable Loop Resistance Variations	<-5 millidegrees
. Thermistor Self-Heating Error	<+0.5 millidegrees
. Thermistor pressure coefficient (1500psi/°C)	1 milligree max.
. Thermistor Aging and Drift Effect	<6 millidegree/year[1]

Totalising all these sources of error indicates that final operational temperature-measurement error is of the order ±30 millidegrees, which is well within the original design objective in this area. (Figure 12 shows the error distribution diagrammatically).

With respect to depth error, discrepancies result from vertical excursions of the assembly due to wave action, and horizontal movement due to sub-surface currents. It was calculated that with waves less then ∿1.5 metres and currents less than 1 knot, the average depth could be determined within ±0.5 metres. On the rare occasion, when larger waves are encountered, the averaging affect of the thermistors (response time >3 min.) negates the effect of wave action. Elapsed time errors result purely from the instability of the quartz crystal clock which is known to be within ±10 sec./day.

1. Quantitative population histograms for premooring & postmooring calibrations are given in figure 19, and characteristic drift histograms in figure 20. Note that the mean drift is well within the calibration error.

6. SYSTEM TEST PROGRAM AND INITIAL FIELD EXPERIENCE

Although CCIW's IFYGL committments somewhat abreviated the overall development and evaluation cycle, a two-part development and testing program was carried out in the months prior to the beginning of the 1972 IFYGL field season. The first phase was the development of the cable assembly. The decision was made to use a separate strain member to avoid the problems inherent with molding around an external braided strain member, and concurrently more emphasis was placed on precisely detailing the Q.C. requirements and the certification of test results; thus insuring consistent quality of the cable assemblies. Tests applied included insulation break-down; insulation resistance; conductivity tests, X-rays of all key areas in the cable; and hydrostatic pressure testing on a 100% sampling ratio basis. A typical X-ray for Q.C. purposes is shown in figure 13. Selected TDR tests were also performed. In addition to the above production-type tests of the special FTP cable, cable performance on the prototype FTP mooring (see below) was satisfactory. The cable used was still operating, after 7 months moored deployment.

The test program for the FTP digitizers comprised a series of environmental and burn-in tests designed to thoroughly stress the instruments at their operating limits to identify all possible problem areas, and also to be sure that any component infant mortalities occurred before going into the field. The test program included nominally:

(1) Acceptance Tests
(2) 200 Hr. at R.T.
(3) 300 Hr. at 4°C
(4) 300 Hr. at 40°C
(5) 300 Hr. at -10°C

All five instruments were subjected to the above testing as well as extensive bench tests and detailed physical examination. Eight faults which could have caused digitizer failures in the field were revealed. Table 4 on page 14 summarises these problems, and shows a reasonable incidence and distribution of problem areas for the complexity of the instrument (See Table 2).

On the basis of the above results, supplemented by a successful prototype system mooring early in the field season, an array of 4 FTP moorings was made operational for IFYGL. The selected locations for these moorings in Lake Ontario is shown in figure 14.

A summary of the overall status of these moored FTP systems for the 1972 field season is presented in figure 15. Chief emphasis was placed on data recovery during the 3 IFYGL active periods shown, and the plan was to recover data (and digitizers) at the end of each period, leaving the balance of the moored system (figure 1) deployed. In the event, as shown by the status summary, a data-recovery factor of 73% was achieved, but as shown in the notes to the status chart, rather more system problems and other unscheduled events were encountered than had been hoped for, although this is not unusual with most accelerated moored-buoy programs. Table 3 summarises these various unserviceabilities and shows the specific problem areas.

TABLE 3

- Cable-assembly conductor open-circuits due to torsional flexing immediately below the surface-float assembly. (Qty. 8 occurrences)
- System inoperative due to flooded monitor connector (Qty.1)
- Digitizer malfunction caused by prematurely-exhausted battery (Qty. 1)
- Digitizer Records with abnormal format due to turn-on transient (Qty. 2)
- Unsuccessful mooring attempt with loss of reserve buoyancy due to water entry into float (Qty. 1)
- Cable interface problems between digitizer and test box (Qty. 2)
- Magnetic tape tangled about recorder capstan. (Qty. 2) Data were not lost in either case because of concurrent cable problems.
- Cable physically broken (Qty. 2) One near the lower end (entire system was eventually recovered), the other near the surface buoy and resulting from hydrodynamic action on a rather large repair splice.

TABLE 4

F.T.P. PROJECT: SUMMARY OF ELECTRONIC PROBLEMS/FAILURES IN GEODYNE DIGITIZERS #775-25

(POPULATION TESTED -5 UNITS)

Item	Date	Serial #	Total Test Hr. Accum-ulated/Unit	Test Type	Problem/Fault Symptoms	Board Type and Function	Fault Diagnosis and Corrective Action	Comments or Implications	Notes
1	29/4/71	003	5	Acceptance Test	No data recorded on track B	Tape recorder	Record head open circuit. (replaced).	16 other manufacturing faults (the result of poor workmanship) were found and corrected; however, these bear little significance in regard to future modifications.	
2	9/71	--	24	Routine Maintenance	Digitizer functions but unable to monitor data with DDM	Control logic & monitor clock signal buffer (LOG-7D)	Faulty transistor in buffer amplifier Z9 (replaced component)	Single occurrence. No recommended action.	
3	20/12/71	001	335	Test Mooring #2	In situ monitor attempt unsuccessful	Monitor plug (P2)	Water between pins of P2 caused digitizer to stop functioning (used moisture displacer to dry plug as described in Field Manual)	Contrary to CCIW Spec. which states "digitizer must operate with monitor plug flooded".	Monitor extension cable added to improve drainage and access to plug.
4	21/12/71	001	360	Test Mooring #2	Reference word wrong, but "bit" checks apparently successful.	As in item 2, LOG-7D	F-Chip (Z6) Faulty causing repetition of 4 MSB (replaced component and change bit check test to M--sequence to overcome symmetry of original check)	Indication of low reliability of F-Chips when related to failures on CM's.	Extensive burn-in tests to minimize chance of fault recurrence.
5	5/1/72	005	25	Pre-test preparation	Digitizer will not initiate a scan under any circumstances.	Turn-on delays & timing pulse generation.	Signals to Ko, Kx not present, differentiating capacitor C9 open circuit.	Capacitor of good quality and ample rating for circuit.	
6	7/3/72	DDM #3	1	Delivery check-out	No display with inputs applied	counter board CTR-2	2 faulty F-chips in counter	considered infant mortality faults	
7	23/3/72	004	1100	Final Test Spec.	All input channels reading about 20 octal bits high	Switch resistor array SSD-1-M	Faulty control flip-flop for fifth LSB.	F-chip failure	
8	11/4/72	001	1300	Cold Test -10°C.	Digitizer will not initiate scan.	Tape control card TAP-7.	Faulty transistor (Q2) relay driver.	First occurrence.	
9	30/5/72	002	700	Cold Test -10°C.	Readings 7777 for all channels including reference.	Error amplifier AMP-6 (AMP-12).	- wrong board - uncoated with several replaced components.	Manufacturing fault - returned board to E G & G.	
10	22/5/72	005	1200	Moored at Sta. 72-0T 11A.	Erratic readings.	-	- battery failure - spread board contacts - water in D. G. O'Brien and M. & M. connectors.	- cause of varied faults still a mystery. - see dump of data tape dated 6/6/72.	
11	5/7/72	002	1000	Moored at Sta. 72-0T 11A.	Tape Tangled	-	Tape splice Stuck on capstan drive.	- check quality of tape	
12	16/8/72	DDM #3	100	Field use	Rapid blinking of display	Display enable Buf-6E	Faulty transistor (o/c Base/emitter Junction)		
13	5/9/72	004 005	2500 2500	72-0T-6A 72-0T-9A	One or two bits written in the inter record gaps during turn-on transient.	Head driver Tap-9D	Enabled write head with a slow turn-on signal	- design weakness	

The chief problem mechanism is seen to be due to excessive cable flexing, effected through the specific physical configurations of the buoy/cable interface, the faired shaped of the thermistor housing, and the coupling technique between the two cable members. (Figure 16 shows the end result with a over-flexed cable, and figure 17 illustrates a possible future source of cable unserviceability).

7. POST-MOORING DATA PROCESSING

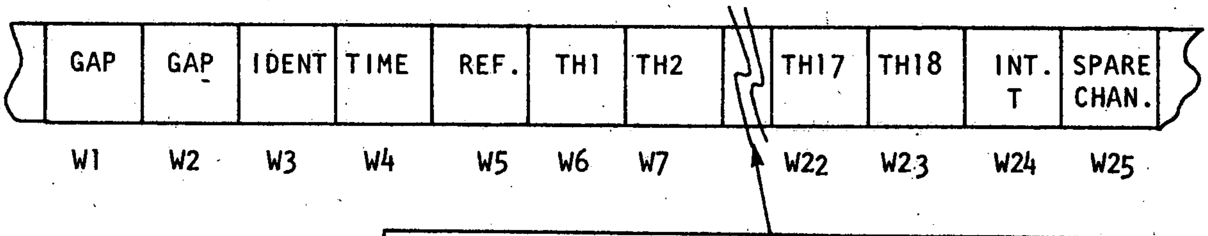
Following digitizer retrieval from a mooring, the data tape (figure 6) is passed for data-reduction to the C.C.I.W. Computer Services Section where the raw data is copied and reformatted from the 1/4" cartridge format to 1/2" computer-compatible format under the active control of a PDP-8 computer system, in a special C.C.I.W. data-translation system.[11] These initial and final formats are tabulated on the next page.

The raw data on the 1/2" tape is in external BCD, and when printed is as shown in figure 18. Actual translation of these digitizer numbers into temperatures takes place later in a program which inserts the calibration constants for each thermistor, performs thorough error checking and correlates time data with the time checks during the monitor exercises. The temperature data is then matched with the dimensionally measured depth data and the resulting time series profiles are made available for scientific purposes.[7]

During the 1972 IFYGL program, use of these four FTP systems is scheduled to produce $\sim$2 M samples of valid fully-checked temperature/depth data, for subsequent scientific analysis for overall scientific objectives described in section 1.

F.T.P. RAW AND TRANSLATED DATA TAPE FORMATS

(A) RAW DATA FORMAT One digitizer record or frame consists of 24 sixteen-bit words of serial RZ binary data recorded on 1/4" magnetic tape in an endless-loop cartridge. The data storage capacity of the instrument on 2 tracks of tape 390 ft. long (at 512 bit/in.) is 4.8 megabits (10,000 scans)



Bit usage for each word.

BIT NO.	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	B_{16}
IDENTITY	X	X	X	X	X	X	X	X	X	X	X	I_3	I_2	I_1	X	X
TIME	X	X	T_{14}	T_{13}	T_{12}	T_{11}	T_{10}	T_9	T_8	T_7	T_6	T_5	T_4	T_3	T_2	T_1
REF.	X	X	0	1	1	0	0	1	1	1	0	0	1	1	X	X
TEMP.	X	X	θ_{12}	θ_{11}	θ_{10}	θ_9	θ_8	θ_7	θ_6	θ_5	θ_4	θ_3	θ_2	θ_1	X	X

(B) TRANSLATED DATA FORMAT One translated record consists of 24 five-character 6 bit words (+ parity) of "external" B.C.D. coded data on 7-track tape. The capacity of one 10 1/2" reel of 1/2" tape 2,400 ft. long (at 800 characters/in.) is 150,000 records.

. . .

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0
0	0	0	0	0	0	0	X	X	X	X	0	0	0	0	0
0	0	0	0	I_3	0	0	T	T	T	T	0	1	1	0	0
0	0	0	0	I_2	0	T	T	T	T	T	0	1	0	1	0
0	0	0	0	I_1	0	T	T	T	T	T	1	0	1	0	0
1	0	0	0	P	1	P	P	P	P	P	1	0	0	1	1
	IDENTITY						TIME				REFERENCE				

. . .

NOTES

(1) X - "Don't Care"

(2) T - Time Word Bit

(3) P - Parity Bit

8. CONCLUSIONS AND PROJECTIONS

After the first season in the field, a number of strengths and weaknesses of the system have become apparent. On the positive side, the system sensor-suit (thermistor probes) and the system electronics (digitizer/recorder assembly) have produced consistent and quite reliable results. Only one system unserviceability can be attributed to electronic circuit problems, even though, as shown in Table 2 and Figure 7, the electronics are quite complex. The achieved data-recovery factor (73%) has produced an extensive amount of valid longterm temperature-profile data not hitherto available at C.C.I.W. At time of writing, this data is undergoing post-IFYGL processing for the scientific objectives stated in the introduction.

As a consequence of various system unserviceabilities encountered during the 1972 field season, certain specific problem areas have been identified. To remedy these, improvement programs are anticipated in the areas of cable flexure performance, surface-float buoyancy and handling characteristics, and test unit interfacing. System reconfiguration for winter operation under-ice is also a possibility. On the basis that the FTP project is an ongoing C.C.I.W. project with planned multi-year application, implementation of such an improvement program should produce a reliable, accurate, easy-to-use remote temperature-profiling system for seasons to come.

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NO	DATE	REVISION DESCRIPTION	DRWN BY	APPD BY

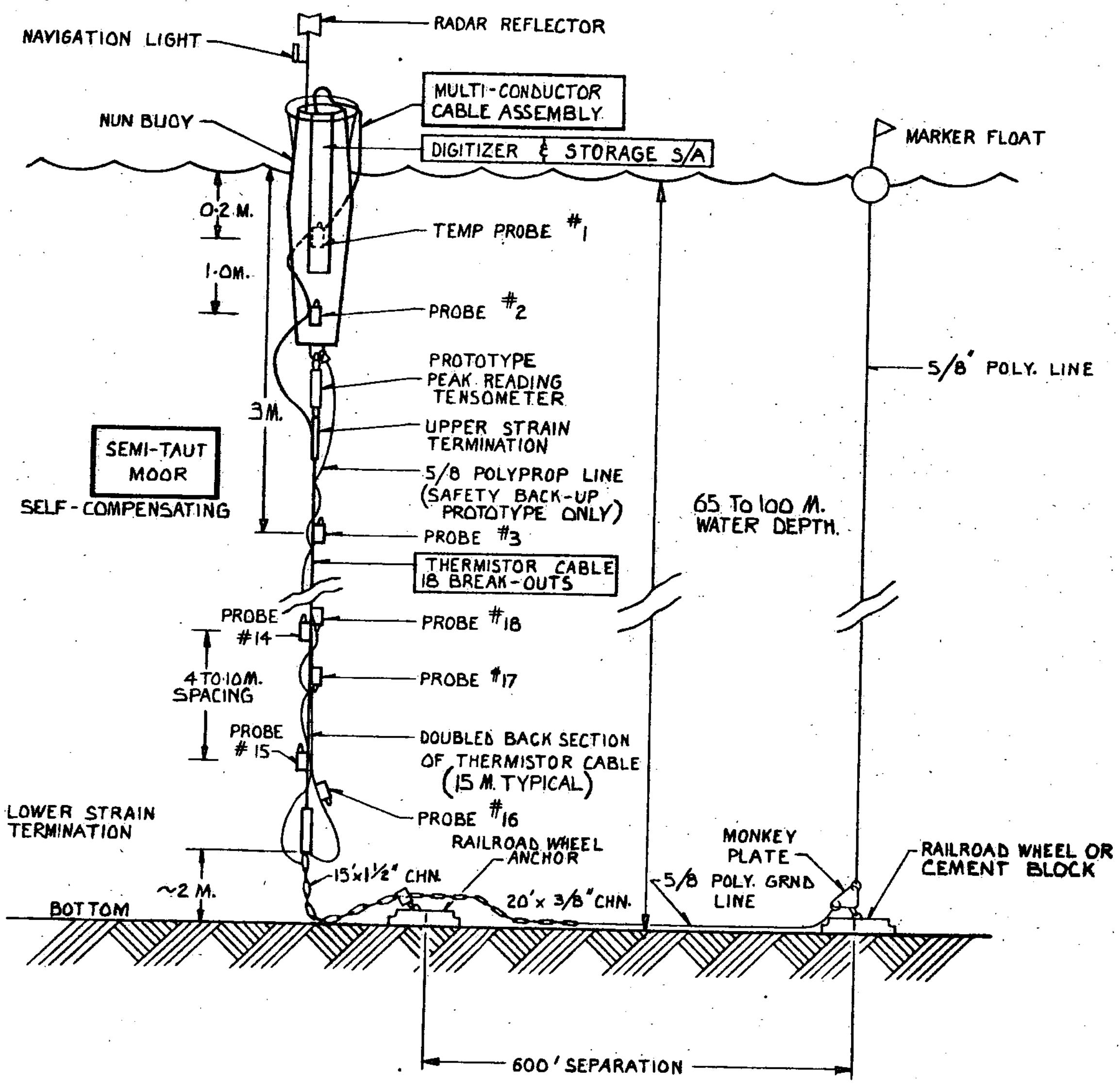


FIGURE 1

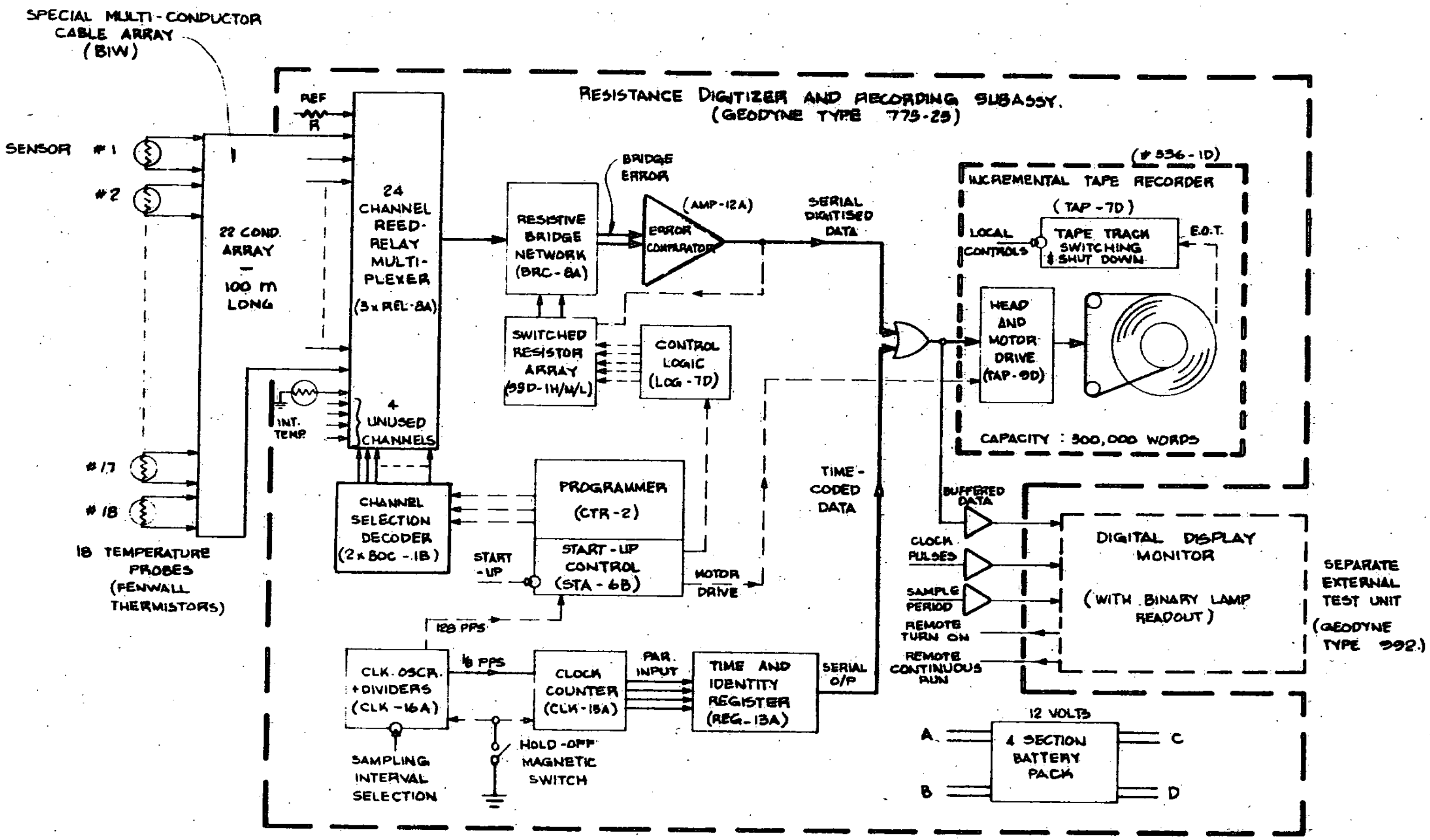
CANADA CENTRE FOR INLAND WATERS
BURLINGTON • ONTARIO

DEPARTMENT: ENGINEERING

TITLE: GENERAL ARRANGEMENT OF MOORED F.T.P. SYSTEM WITH INSTRUMENTATION (QTY REQUIRED: 4 SYSTEMS)

DESIGNED BY	CHECKED BY	APPROVED BY
E. H.		
DRAWN BY: C. CAMPION	CHECKED BY: [illegible]	
SCALE: N.T.S.	DATE: DEC 17/71	DRAWING NO. 372

PARTS LIST		
PART NO.	DESCRIPTION	QTY.



GENERAL ELECTRONIC BLOCK DIAGRAM OF THE FTP SYSTEM FIGURE 2

ELECTRONIC BLOCK DIAGRAM FOR C.C.I.W. FIXED-TEMPERATURE-PROFILING (FTP) SYSTEM

NO.	DATE	DESCRIPTION	DRWN. BY	APPD. BY
		REVISION		

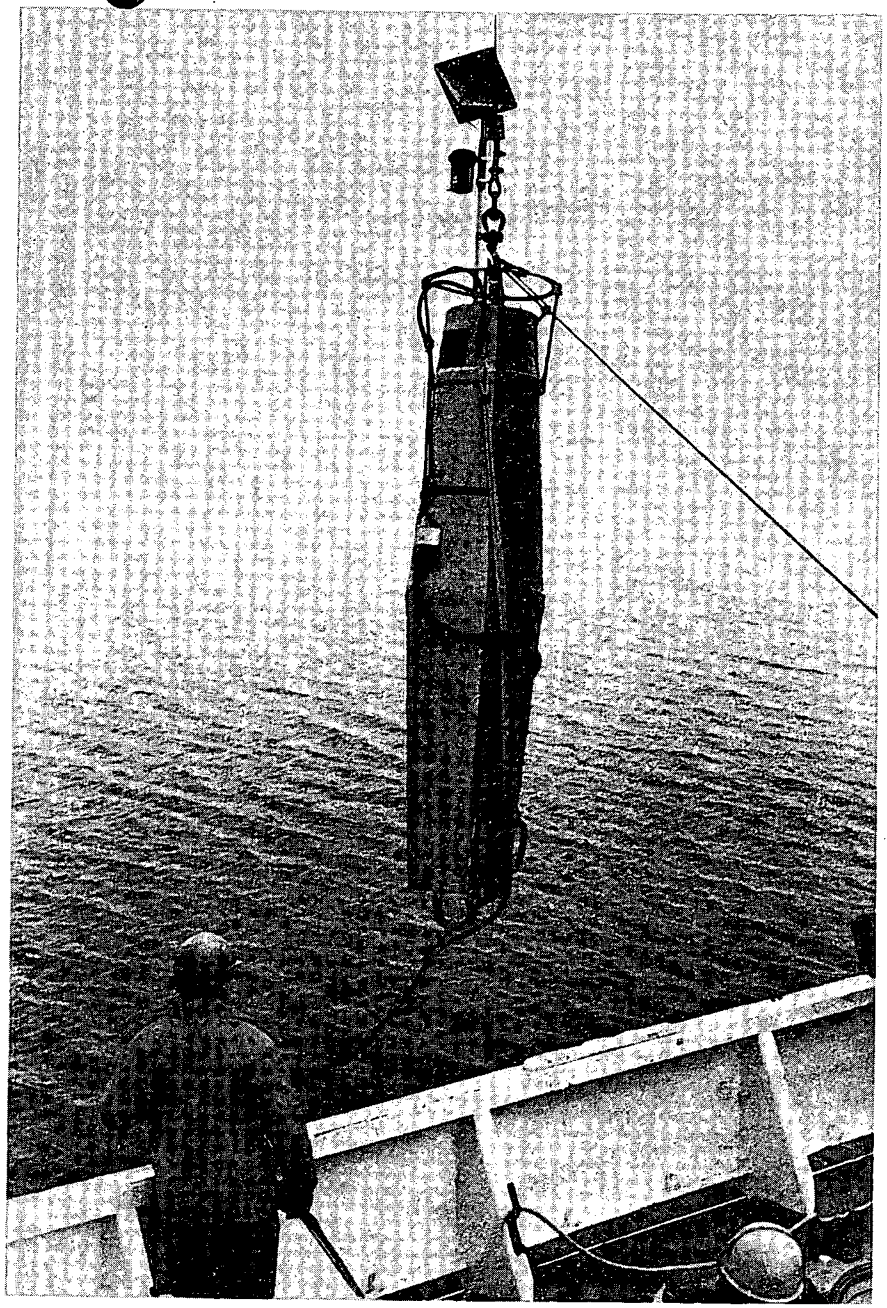
UNLESS OTHERWISE SPECIFIED
TOLERANCE ON THREE PLACE DIMENSIONS ±
TOLERANCE ON TWO PLACE DIMENSIONS ±
TOLERANCE ON ANGLES ±
EXTERNAL CORNER CHAMFER .015 - .025
INTERNAL CORNER RADIUS .010 - .020
SURFACE FINISH AA MICRO INS.
MATERIAL SPECIFICATIONS

CANADA CENTRE FOR INLAND WATERS
BURLINGTON • ONTARIO
ENGINEERING

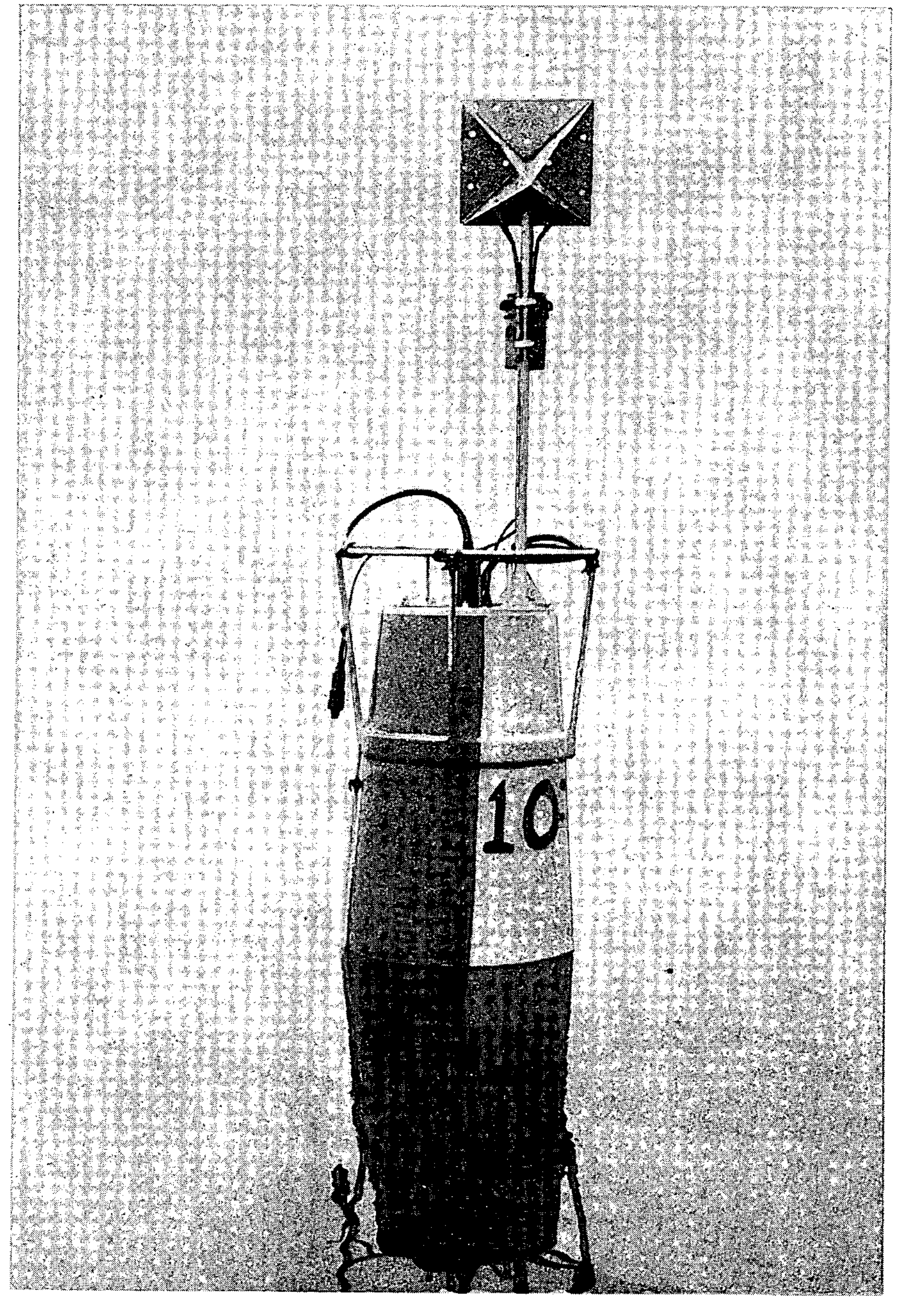
TITLE
Electronic Block Diagram
F.T.P. System

DESIGNED BY E.H.	CHECKED BY A.S.W	APPROVED BY A
DRAWN BY A.P.G.	CHECKED BY	DRAWING NO. 371
SCALE N.T.S.	DATE APR. 72	SHEET OF

R.B.P. 200 101M 10-71



SYSTEM JUST PRIOR TO MOORING



SYSTEM AS MOORED

FIGURE 3

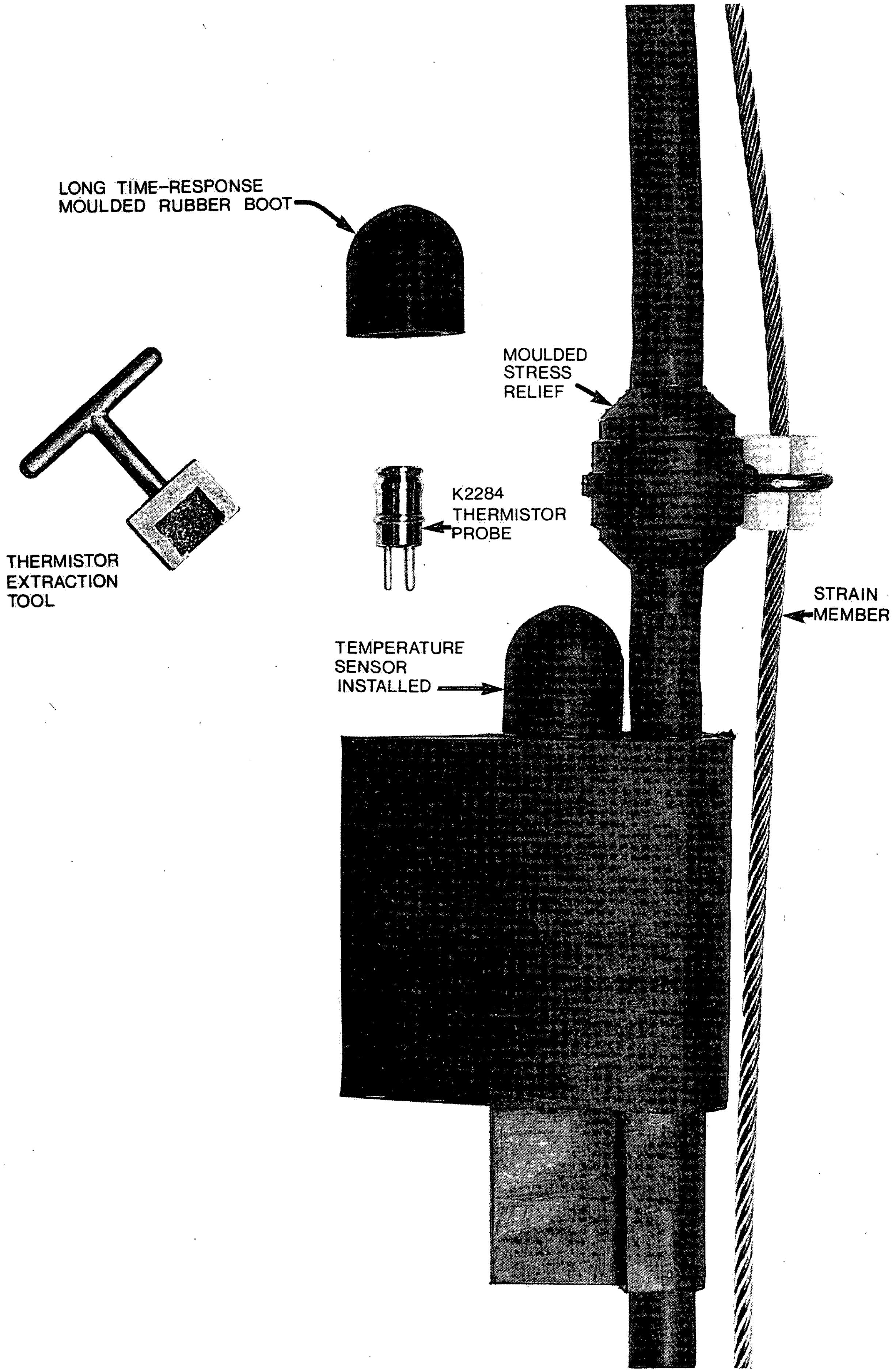
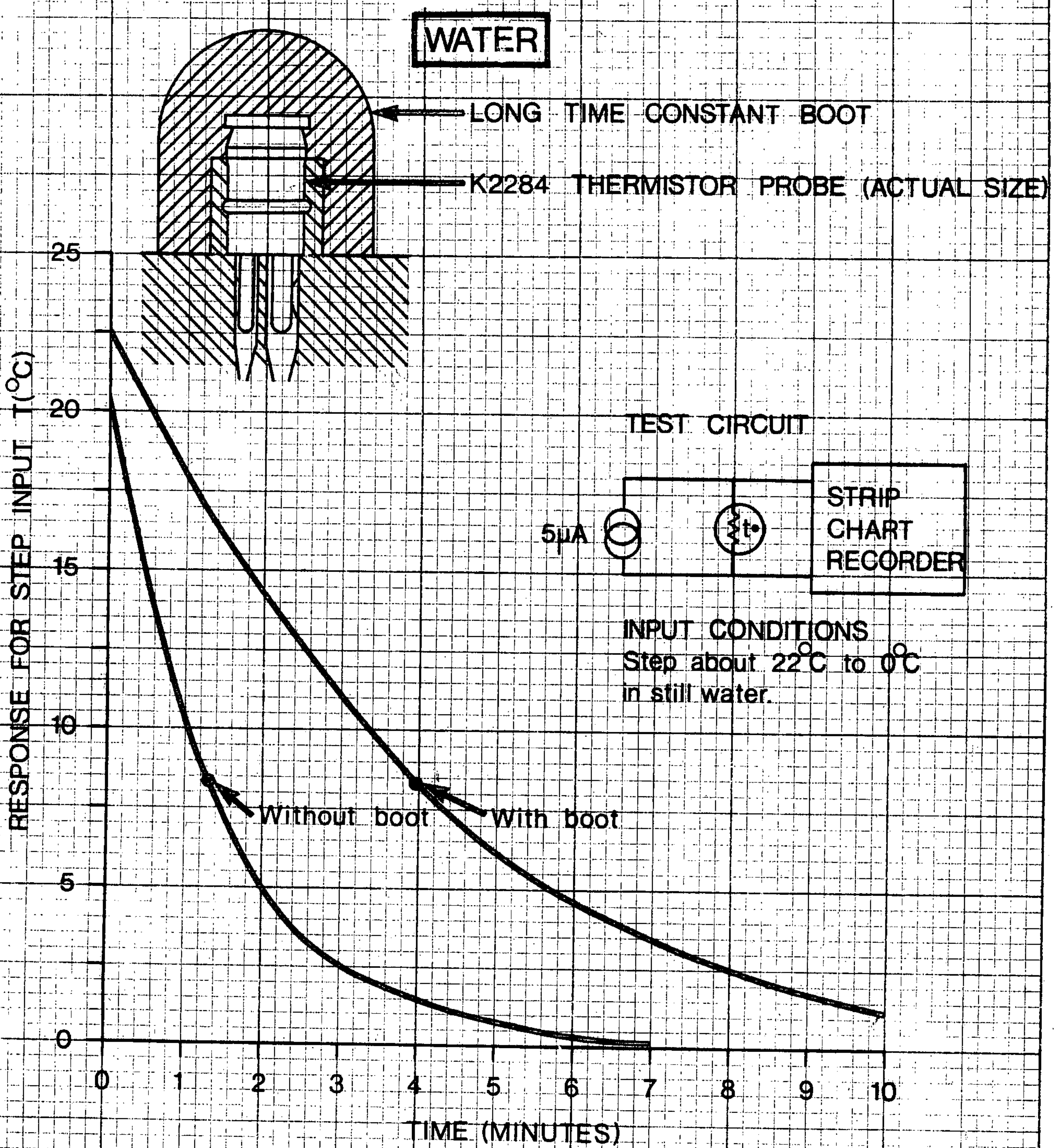
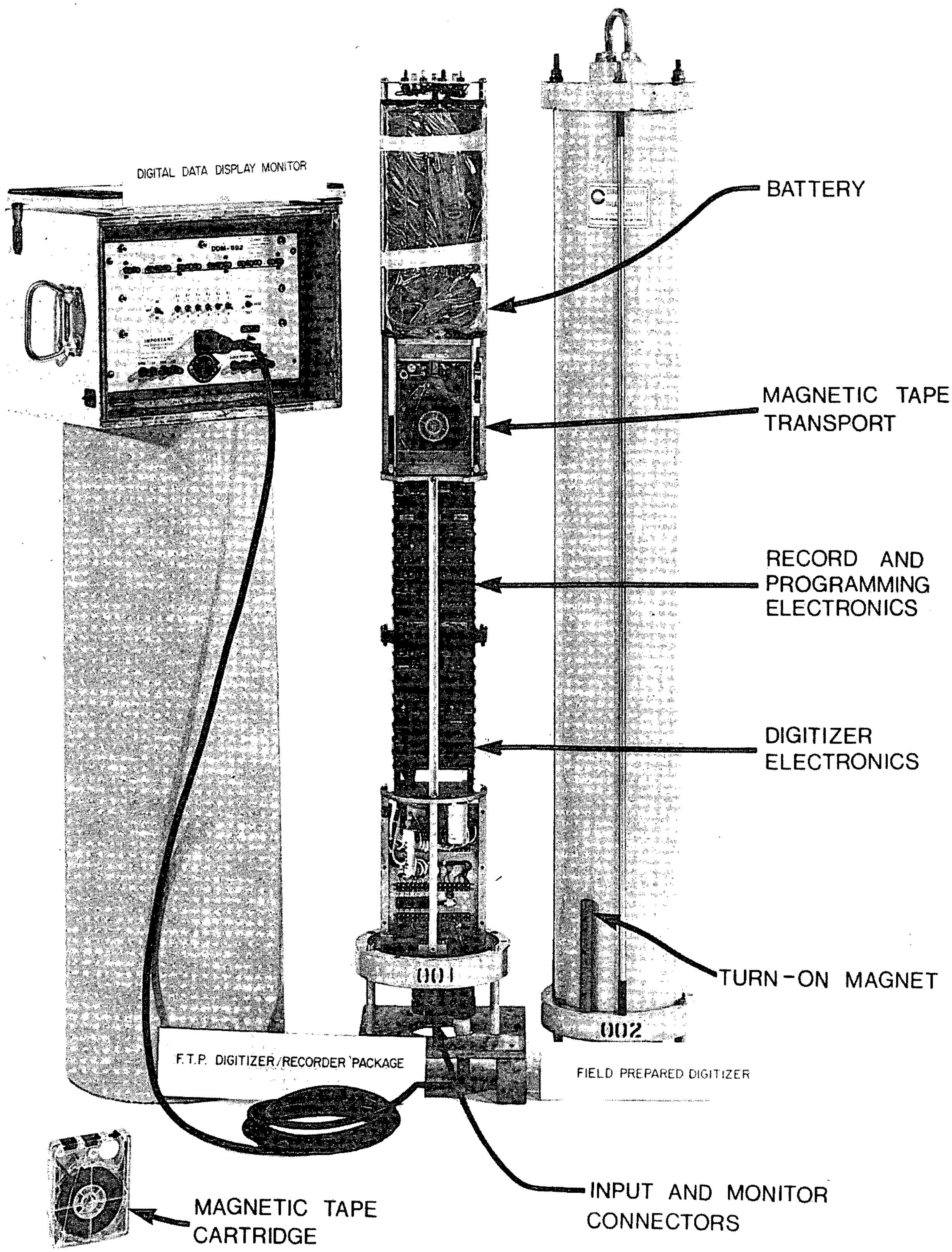


FIGURE 4. TEMPERATURE SENSOR ASSEMBLY



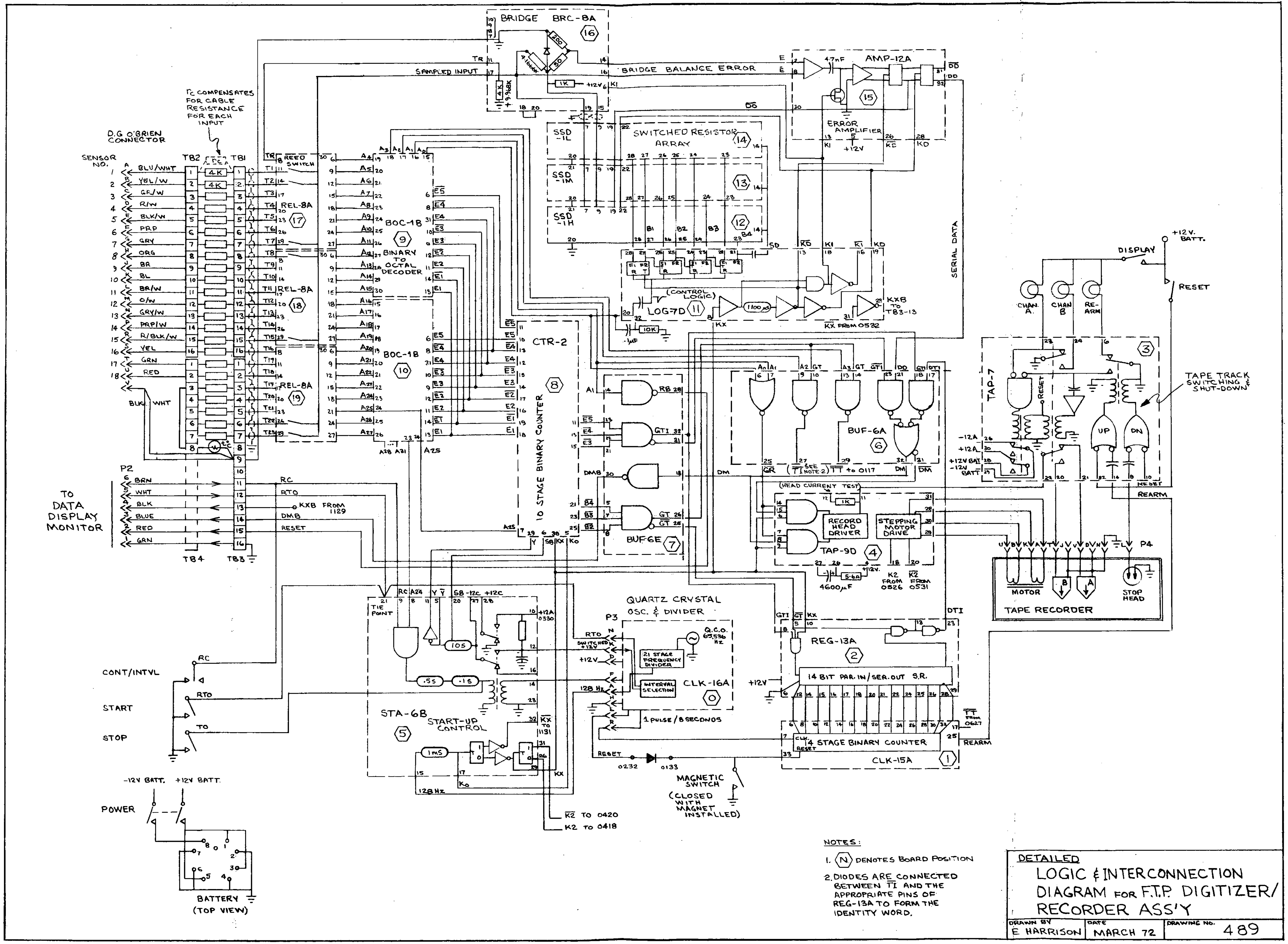
RESULTS Without boot τ = 84 sec.
With boot τ = 4.0 min.

FIGURE 5. TIME RESPONSE CURVES OF THERMISTOR PROBE ASSEMBLY



FTP DIGITIZER/RECORDER PACKAGE
WITH THE DIGITAL DISPLAY MONITOR

FIGURE 6



NOTES:

1. (N) DENOTES BOARD POSITION

2. DIODES ARE CONNECTED BETWEEN $\overline{TI}$ AND THE APPROPRIATE PINS OF REG-13A TO FORM THE IDENTITY WORD.

DETAILED LOGIC & INTERCONNECTION DIAGRAM FOR F.T.P. DIGITIZER/RECORDER ASS'Y		
DRAWN BY: E HARRISON	DATE: MARCH 72	DRAWING NO.: 489

FIGURE 7

E.T.P. RESISTANCE DIGITIZER TRANSFER FUNCTION

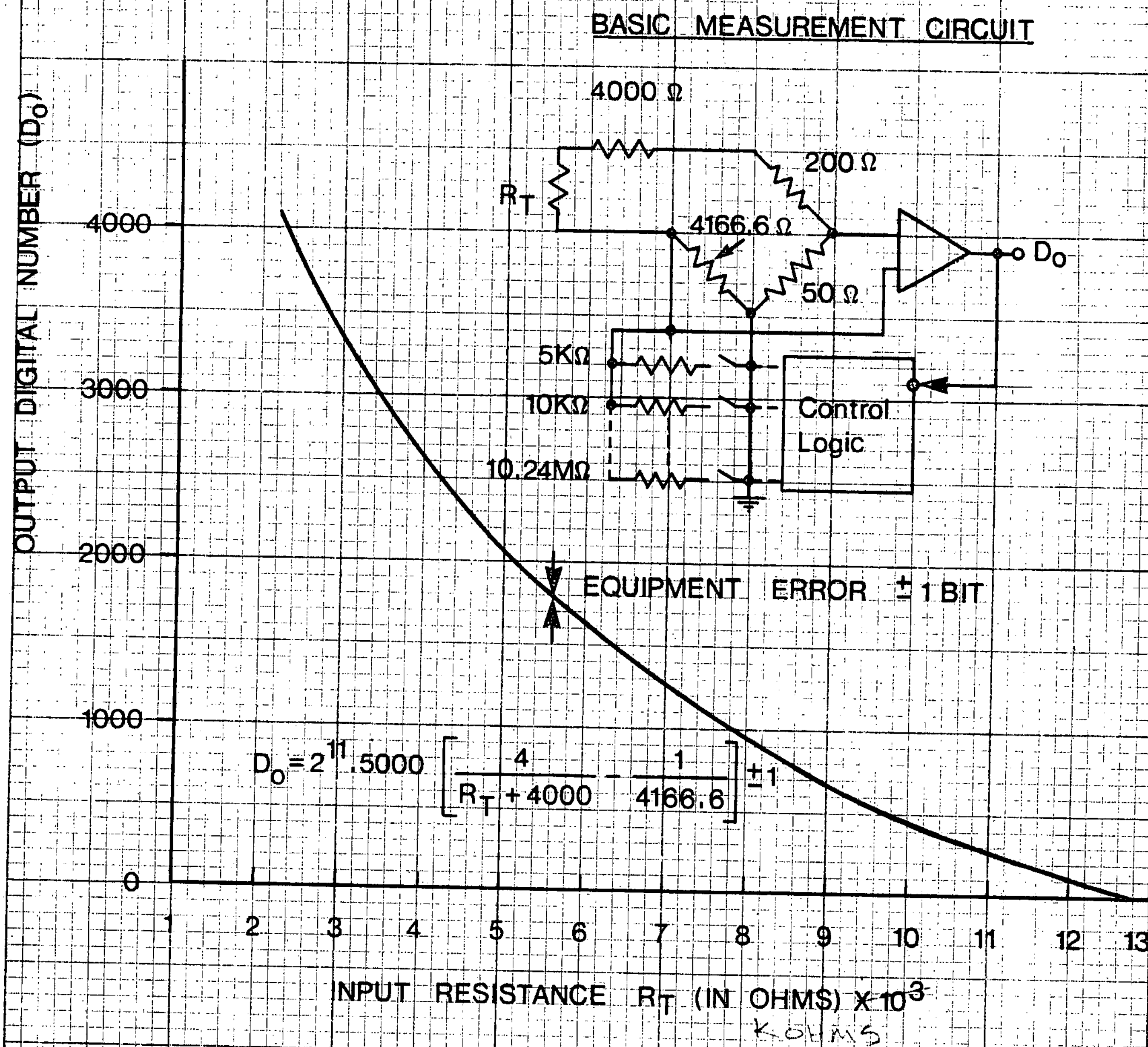


FIGURE 8

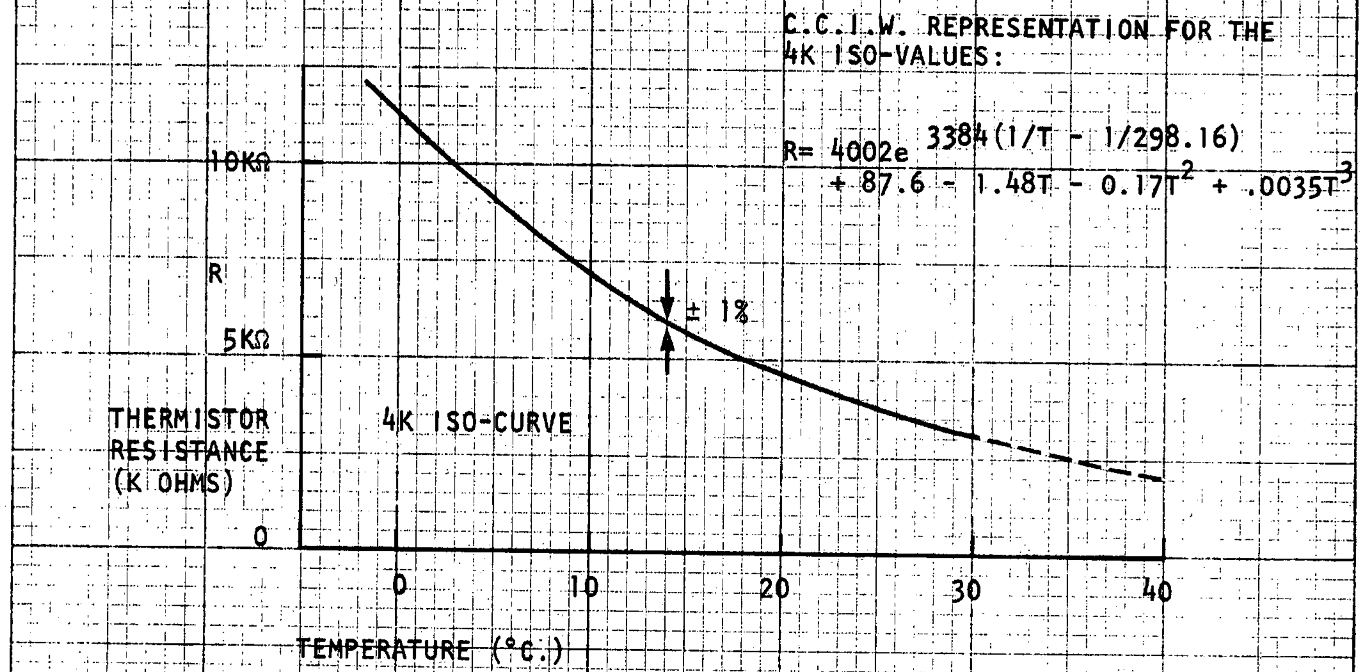


FIGURE 9. - DESIRED CHARACTERISTIC OF THE F.T.P. SYSTEM TEMPERATURE-SENSOR

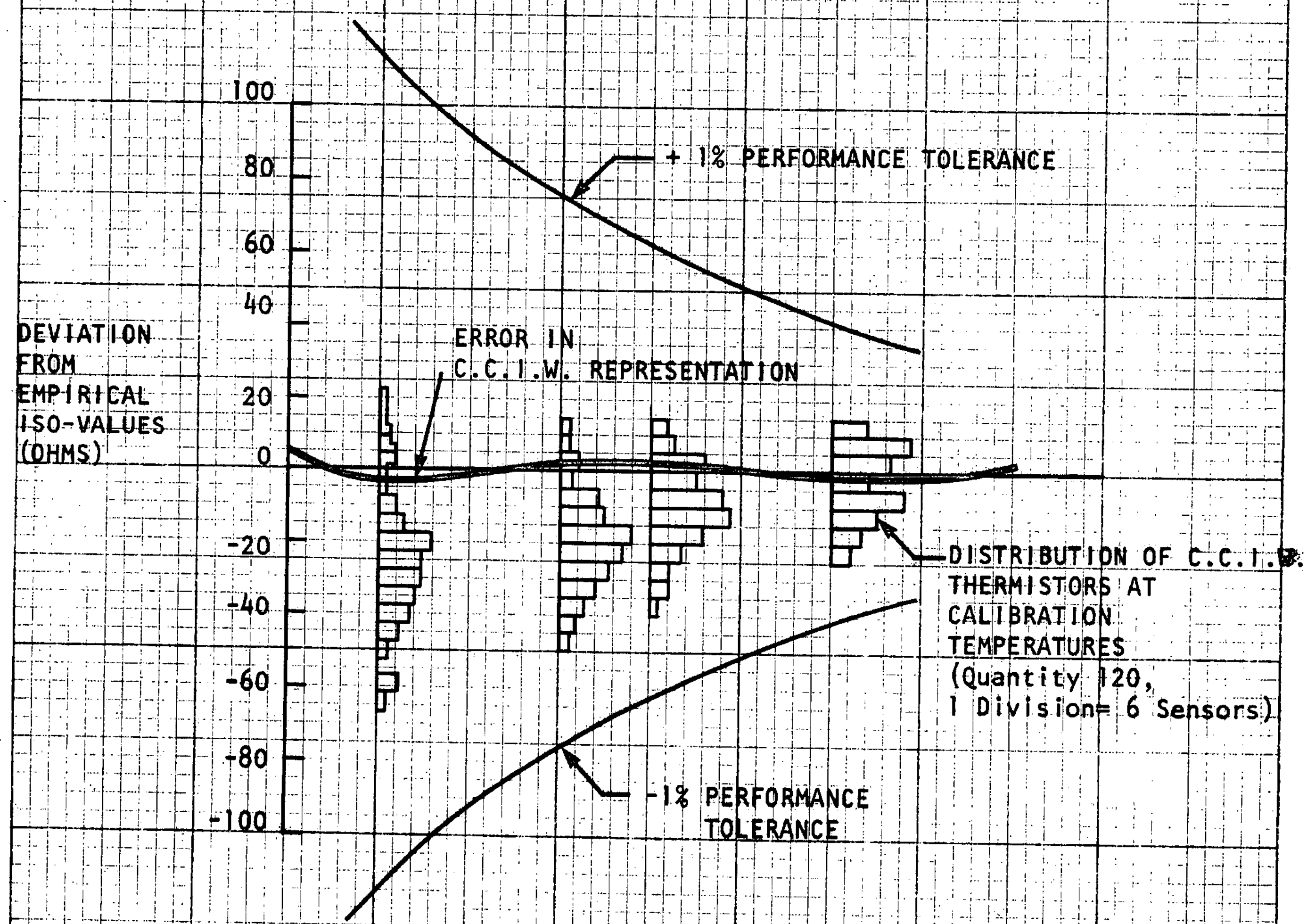


FIGURE 10. - VARIATIONS AND TOLERANCES FOR C.C.I.W.'S THERMISTOR POPULATION

DIGITAL TRANSFER FUNCTION FOR OVERALL F.T.P. TEMPERATURE SENSING SYSTEM

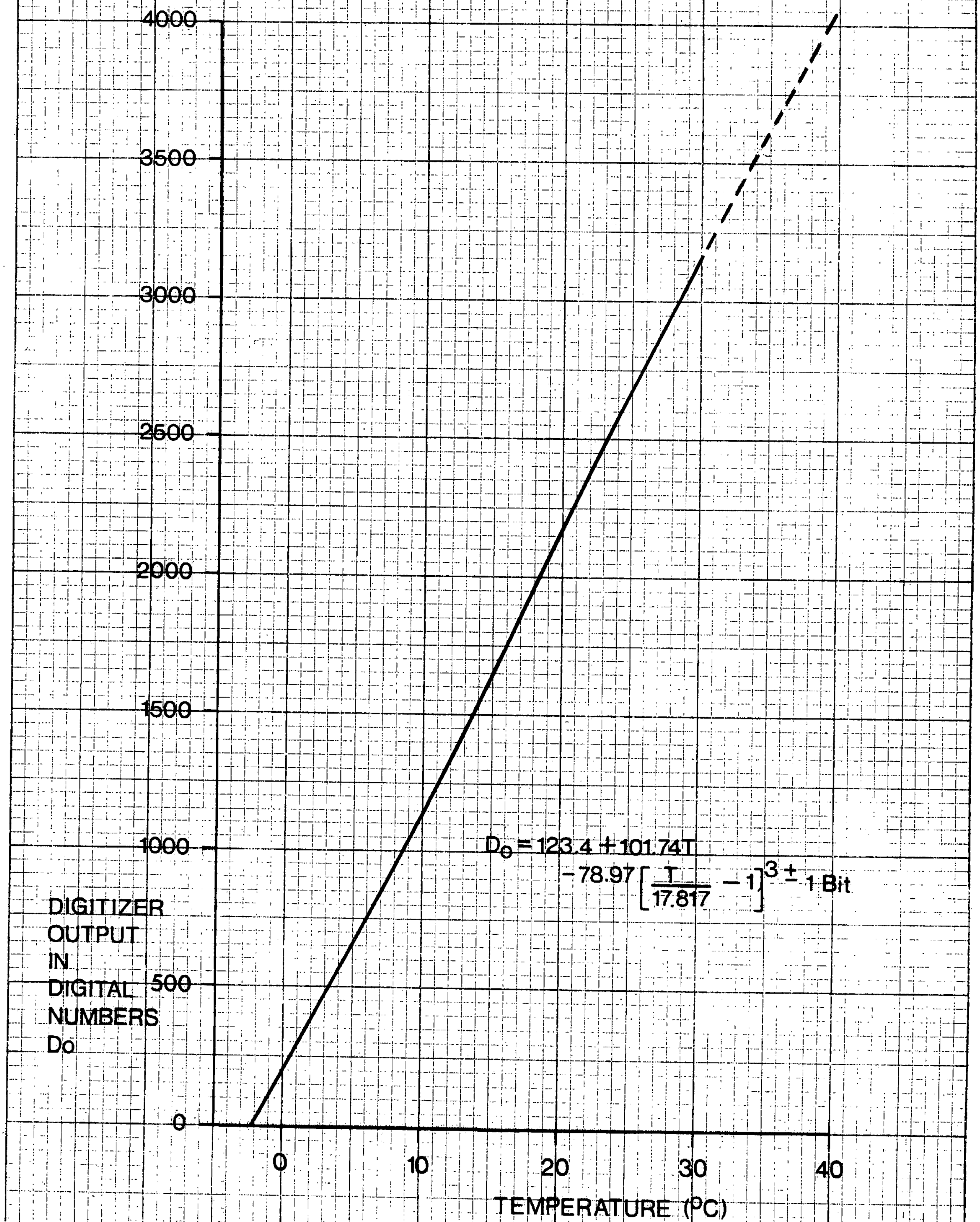


FIGURE 11

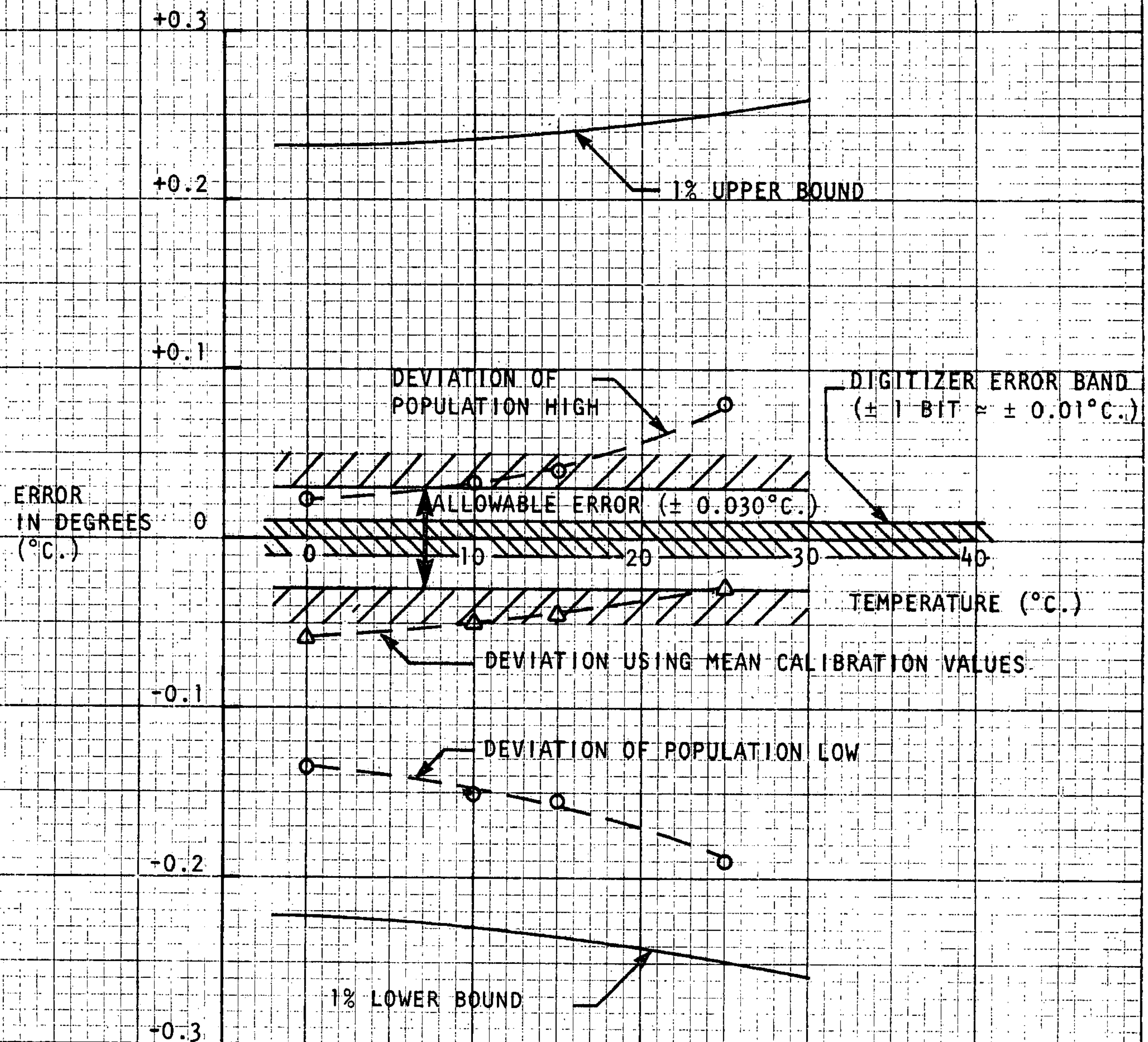
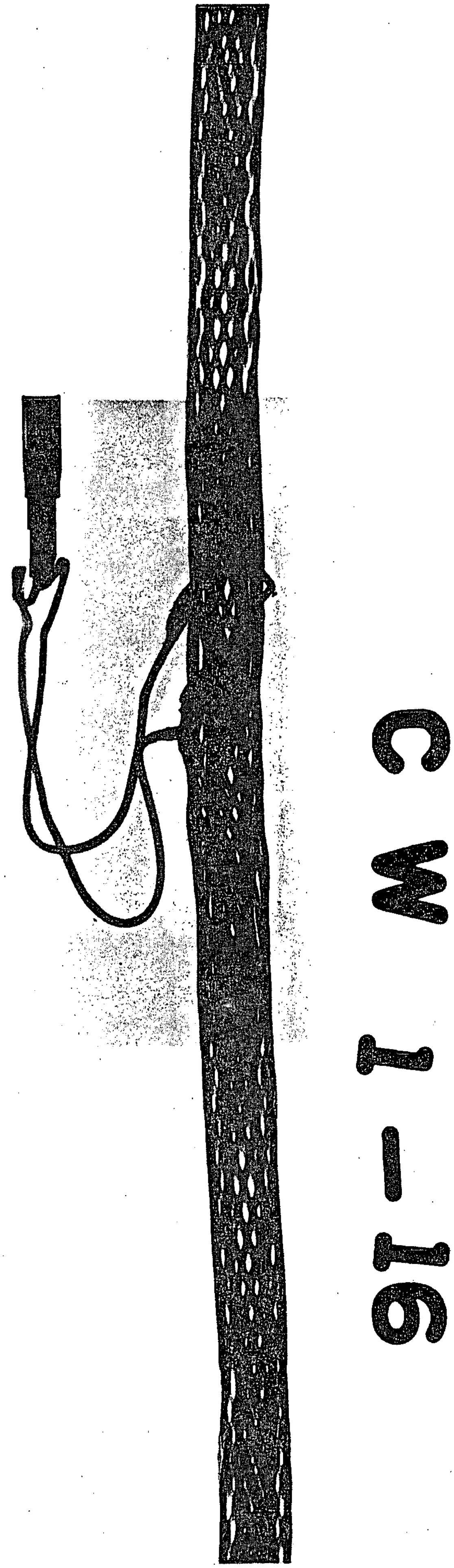
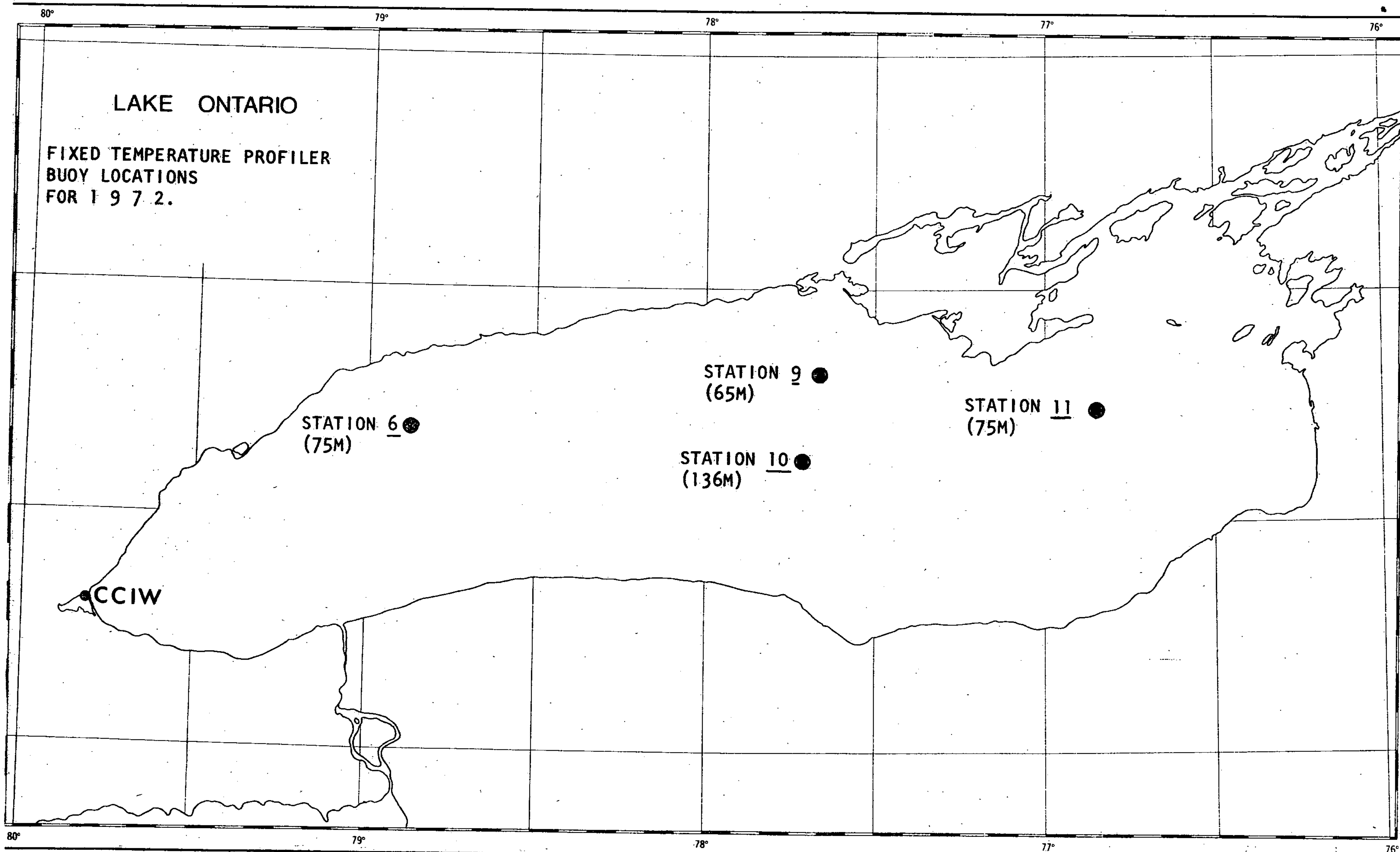


FIGURE 12. - SYSTEM PERFORMANCE ACCURACIES AND ERROR SUMMARY



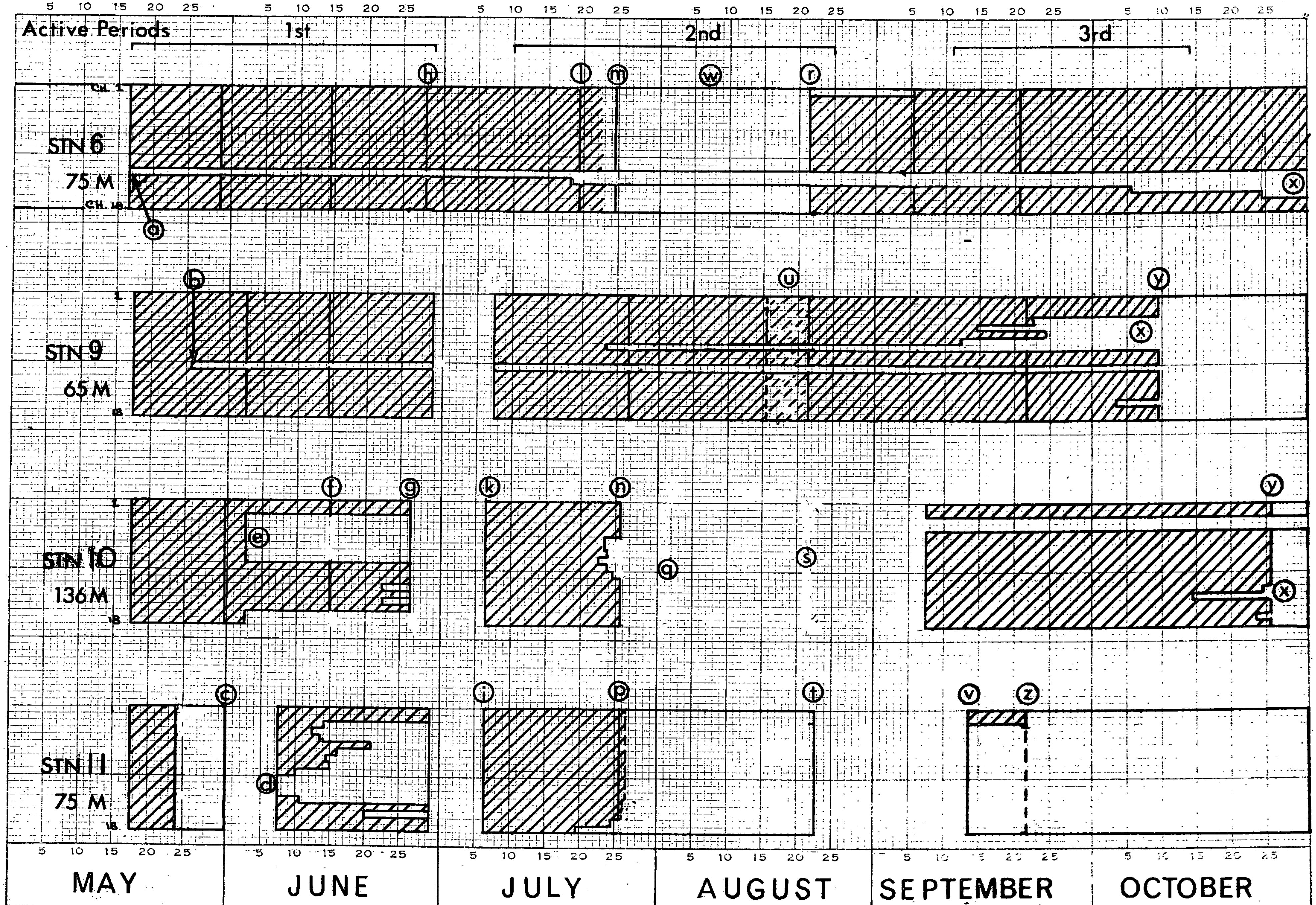
TYPICAL Q/C
X-RAY OF
TEMPERATURE
SENSOR ASSY

FIGURE 13



FTP BUOY LOCATIONS FIGURE 14

FTP BUOY SYSTEM PERFORMANCE RECORD 1972



NOTES

1. Vertical lines indicate field monitors of the buoy systems or cessation of the production of good data.
2. Cross-hatched areas indicate good data returned for the corresponding period.

FIGURE 15

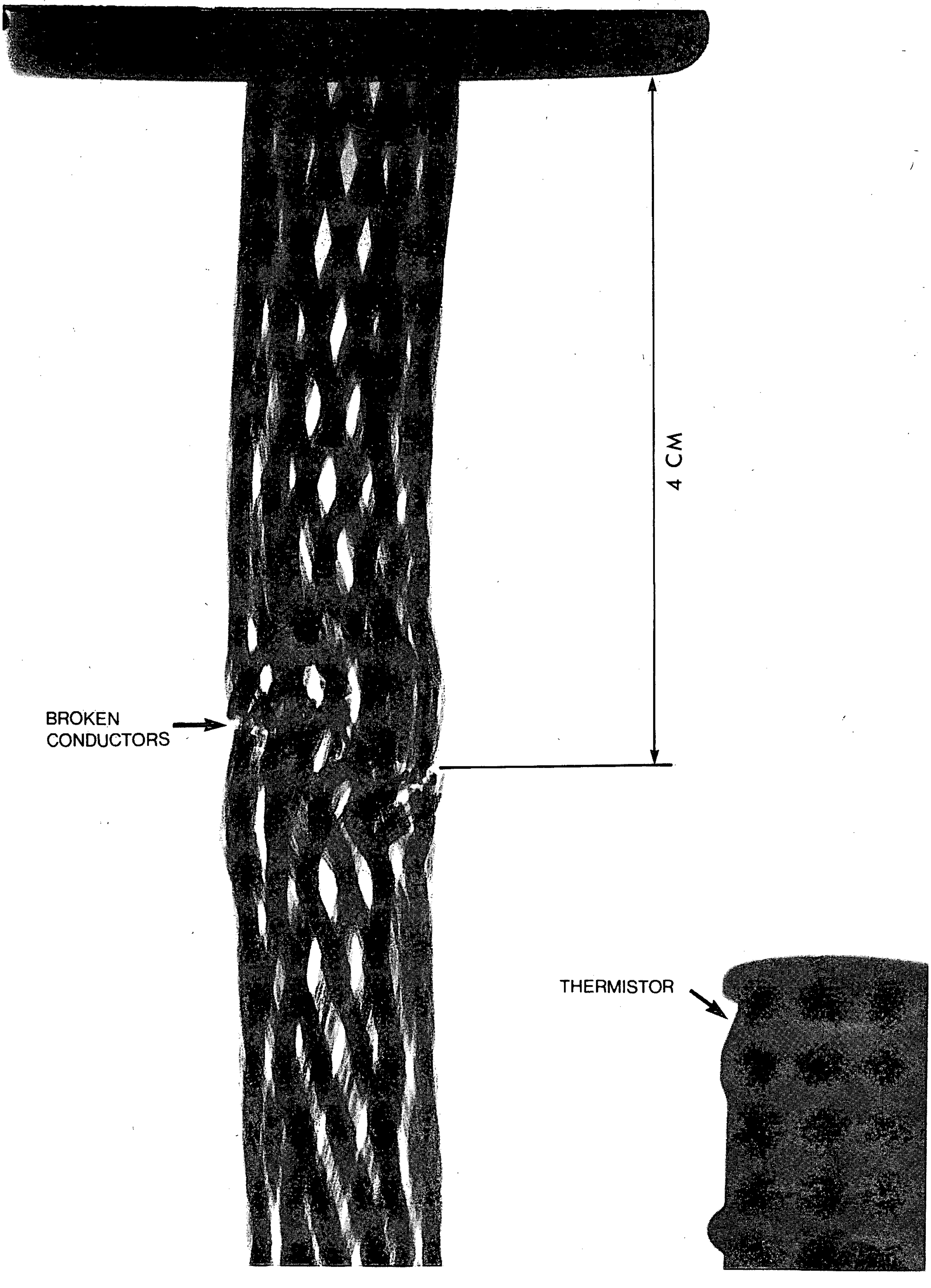


FIGURE 16 X-RAY OF CABLE FAILURE

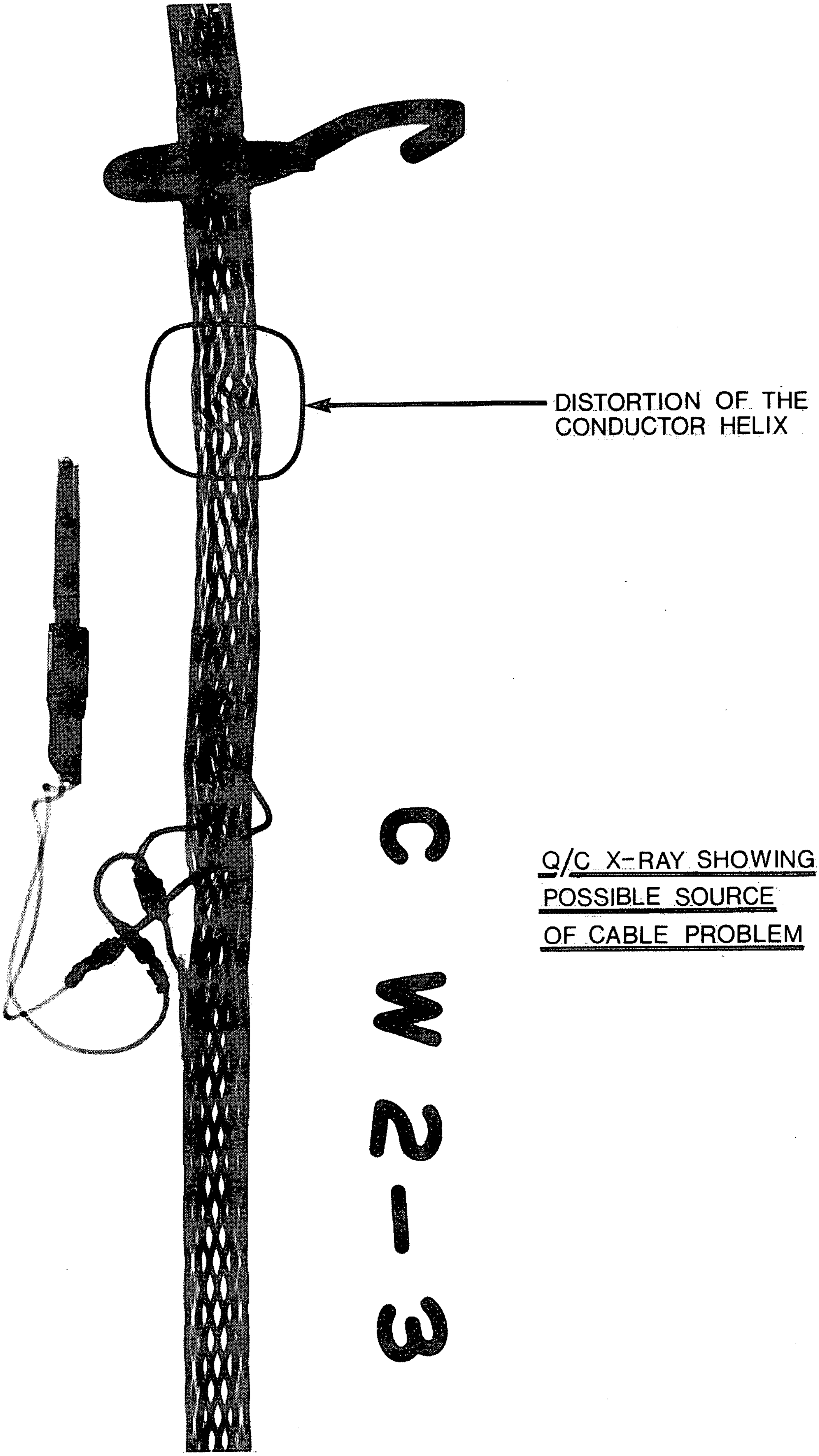

DISTORTION OF THE CONDUCTOR HELIX
C W 2-3
Q/C X-RAY SHOWING POSSIBLE SOURCE OF CABLE PROBLEM

FIGURE 17

HIGHLIGHTS AND UNSCHEDULED EVENTS

a) Channel 14 reads about 1°C. high, due to leakage at breakout. This was known from test mooring - unchanged.

b) Channel 11 reads about 0.6°C. high, due to leakage.

c) Digitizer S/N 005 failed on 22nd May, and was removed on 31st May. Battery pack failed.

d) Digitizer S/N 002 was installed on 7th June. Channels 11, 12 and 13 became open/circuit after 22nd May and the array deteriorated steadily (as shown by later data readout) until 13 channels became intermittant.

e) On June 1st, 6 channels at Station 10 became intermittantly open-circuit. Only about half the data for the uncross-hatched areas is recoverable.

f) Digitizer S/N 005 replaced S/N 004 as a result of apparent intermittant operation of digitizer, but it was cable array at fault.

g) On June 26th, the array was removed by Limnos so that the nature of the fault in the cable array could be determined.

h) On June 28th, the digitizer at Station 6 was replaced in order to keep a continuous record going at that station through the entire summer.

i) Cable array S/N 002 replaced with a complete new system (Digitizer S/N 003, cable S/N 003). The failure of the array was attributed to flexure beyond the capability of the cable.

k) A complete new system was installed using Digitizer S/N 001, and cable S/N 007

l, m) Monitor on the 20th showed channel 15 to be intermittently open circuit.

n) Cable assembly physically broken during a monitor attempt with the Lac Erie alongside. Most of the cable was returned to CCIW at the time, and the rest was later recovered by C.S.S. Limnos.

p) Monitor attempt unsuccessful due to bad weather. Water in monitor plug stalled digitizer. Cable was steadily deteriorating.

q) Attempt to moor new system was unsuccessful because the buoy was towed under, filled with water and sank. (Aug. 2nd) The System was recovered.

r) New digitizer was installed, but ch. 1 gives zero readings due to multiplexer fault.

s) Installed cable array and buoy, with digitizer installation due September 7th.

t) Array removed.

u) Quality of data poor for the remainder of the active period (Aug. 16th to 23rd), resulting from exhausted battery.

v) New system installed, however analysis of data printout showed failure of cable within one day. The cause was an improperly secured repair splice, just below the buoy.

w) Data not successfully recovered to date due to a digitizer fault which resulted in an improper format.

x) Gradual deterioration of all cables.

y) Digitizers shutdown automatically, after satisfactory operation for a full 50 day cycle.

z) Magnetic Tape tangled, but without loss of data due to cable problem.

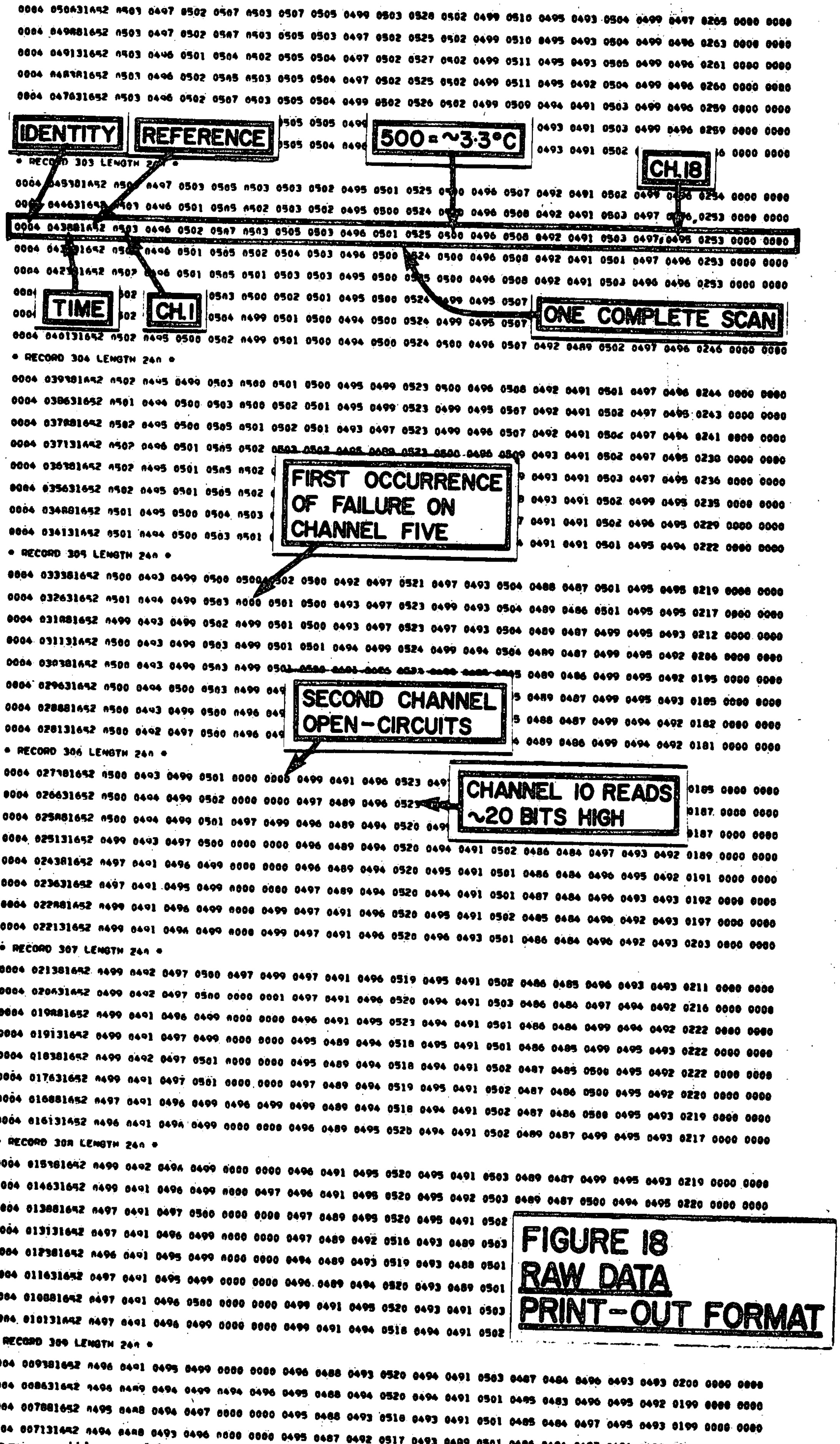
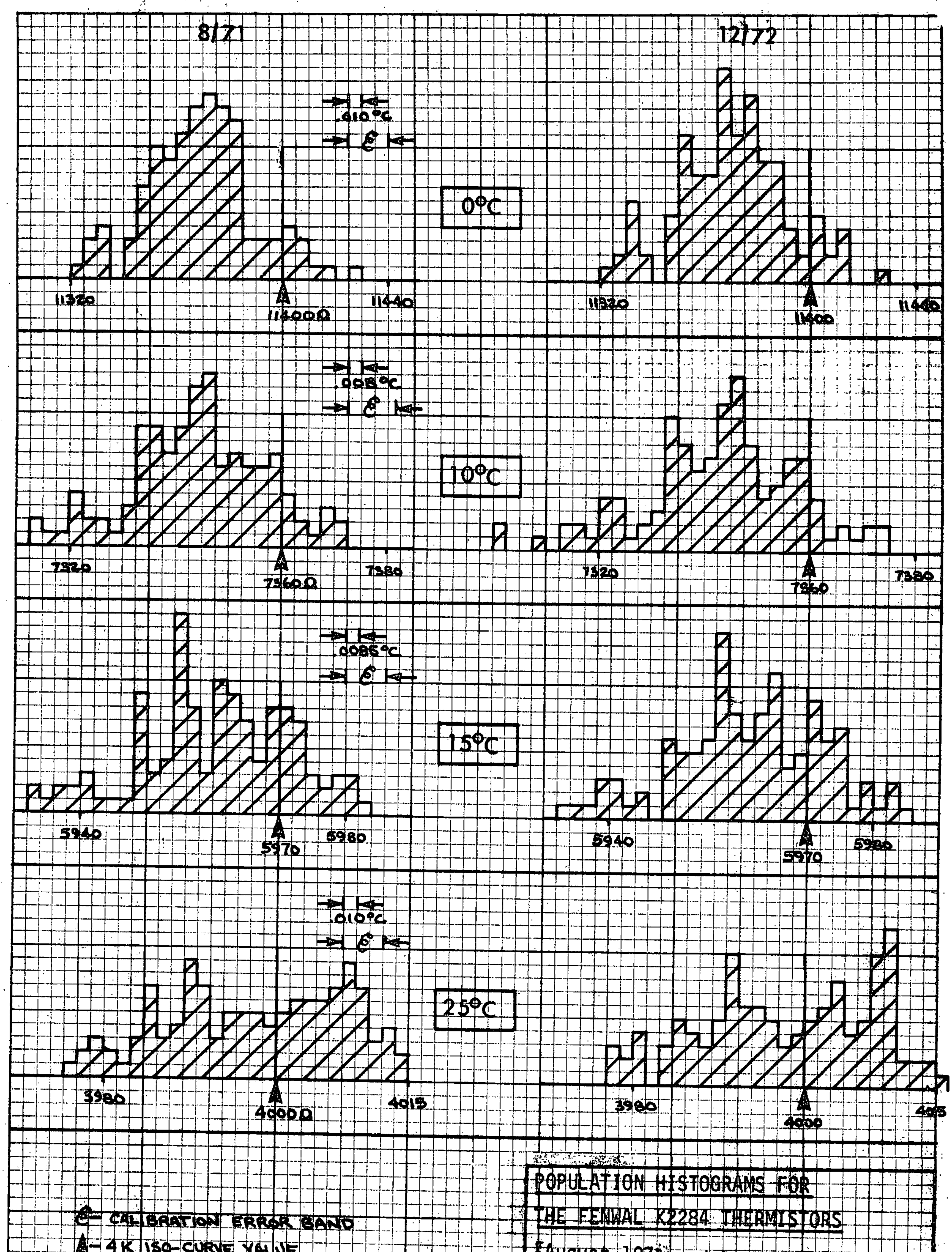


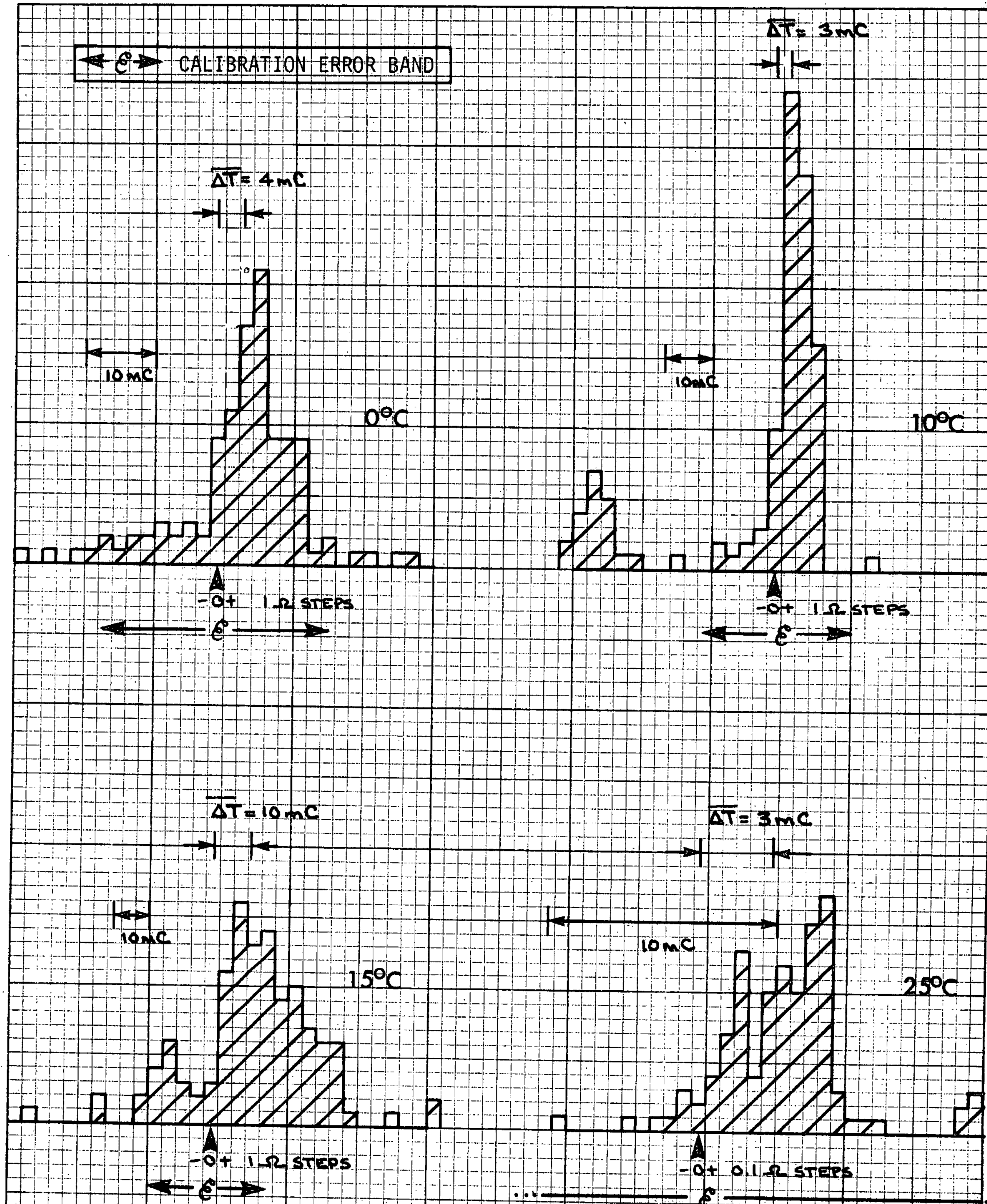
FIGURE 18
RAW DATA
PRINT-OUT FORMAT

NOTE: Virtually Isothermal Water from the Surface to Sensor #18 (100m.) STN. 10, May 2nd, 1972.



POPULATION HISTOGRAMS FOR THE FENWAL K2284 THERMISTORS [August 1971 and Dec. 1972]

FIGURE 19



CHARACTERISTIC DRIFT* HISTOGRAMS
FOR FENWAL K2284 THERMISTORS
[August 1971 to December 1972]

FIGURE 20

* due to a correctable manufacturing fault these histograms can be used only to indicate major trends, but not the drift of individual probes.

EH / Dec. '72