ROYAL OBSERVATORY, HONG KONG

TECHNICAL NOTE NO. 71

A MICROPROCESSOR-BASED RAINFALL RECORDER

by

B.Y. LEE and M.C. CHIU

FEBRUARY 1984

CONTENTS

		page
	FIGURES	iii
	TABLES	iv
1.	INTRODUCTION	1
2.	DESIGN OBJECTIVES	2
3.	THE DESIGN	
	(a) Data structure and storage	3
	(b) Hardware design	3
	(c) Power supply	4
	(d) Software design	5
4.	DISCUSSION	8
	REFERENCES	9
	APPENDIX 1 FLOWCHARTS	21
	APPENDIX 2 POSSIBLE MODIFICATIONS	34

FIGURES

		page
1.	Pin configuration of EPROM 2764	10
2.	System block diagram	11
3.	Programmable registers, ports and memory map in the MK 38P70 microprocessor	12
4(a)	The MK 38P70 microprocessor interfaced to EPROM 2764, quartz oscillator and other control switches	13
4(b)	The MK 38P70 microprocessor interfaced to the LED display unit	14
5.	The power supply	15
6.	Front view of the recorder	16
7.	Back view of the recorder	17
8.	Software system flowchart	18

TABLES

		page
1.	FORMATS OF RECORDS STORED IN THE EPROM	19
2.	PARTS LIST	20

1. INTRODUCTION

The tipping-bucket rain-gauge was first used by the Royal Observatory in 1962, when one such gauge was installed at the Airport Meteorological Office. Another tipping-bucket rain-gauge was installed at Waglan Island in 1975. The mechanisms by which this type of rain-gauge operates are described in the Guide to Hydrological Practices published by the World Meteorological Organization (1974). Essentially the two buckets in the rain-gauge rest on a pivot in such a way that when a given amount of rain (normally 0.5 mm) has been collected in one of the buckets, it tips and closes an electrical switch. The electrical pulse resulting from the contact closure is recorded by a nearby recorder, or a distant recorder via telemetry. The calibration procedure for the rain-gauge is described by Parsons (1941).

In 1978, the Royal Observatory, on a request by the Geotechnical Control Office in Hong Kong, designed a system (Lam and Li, 1979) in which the rainfall recorded by a network of about 20 tipping-bucket rain-gauges was telemetered back to a central control office. The amount of rainfall accumulated over every 15-minute interval was output to a calculator printer. In 1981, the Royal Observatory improved the design by the use of a central microprocessor system so that real-time rainfall data could be displayed on screen and at the same time stored onto magnetic cartridge tape.

The use of non-volatile solid state memory offers a relatively inexpensive way of mass data storage. Using EPROM (Erasable Programmable Read-Only Memory), Bracewell and Campbell (1981) designed an on-site recorder to record rainfall over a specified time interval.

This note describes the design of a recorder made up essentially of a microprocessor and an EPROM to meet the following requirements :

(1) store digital rainfall information with improved resolution in time ;

(2) estimate the intensity of rainfall ; and

(3) provide a display of accumulated rainfall over any specified time interval.

It can be operated either on site or, via telemetry, at a distance from the rain-gauge.

2. DESIGN OBJECTIVES

The recorder was designed to achieve the following objectives :-

(a) It should be capable of displaying accumulated rainfall over any specified duration of time.

(b) Rainfall data should be stored in digital form so as to facilitate subsequent archival by another computer system.

(c) Rainfall data should be stored in a format which enables an estimation of the rainfall intensity to be made.

(d) Data written onto the storage device should be verified to ensure that correct entries have been made.

(e) Data storage must be large enough to hold at least a month's data so that frequent visits to the rainfall station will not be necessary. However, the normal operation mentioned in (a) should not be disrupted even if the entire data storage capacity has been exhausted.

(f) The effects of bouncing in the electrical switch should be eliminated.

(g) Battery back-up should be provided to allow several hours of continuous operation after an A.C. power stoppage.

(h) Lightning and transient protection should be provided.

3. THE DESIGN

(a) Data structure and storage

The recorder is designed to store rainfall data from a tipping-bucket rain-gauge in the most primitive form. Instead of storing the rainfall amount over a specified time period, the recorder stores the times of occurrence of each tip of the bucket, in a manner similar to that adopted by Donnelly (1977). The recording of the time is done accurate to the second, but one further enhancement is to record the time to the nearest 0.1 s during intense rainfall situations. This is an improvement over taking 15-minute rainfall totals because of the better resolution in time, which enables the derivation of running rainfall totals over short durations. Also, the rainfall data thus recorded can easily be handled later on by a main computer system to give the rainfall amount over any specified time interval.

The storage devices used are Erasable Programmable Read-Only Memories (EPROM) 2716, 2732 or 2764 which contain 2K, 4K and 8K bytes of read-only memory respectively. The EPROM's are TTL-compatible. Referring to Fig. 1 which shows the pin assignment of 2764, data present in the data lines 01 to 08 can be programmed onto the byte addressed by the address lines A1 to A13 upon the introduction of (a) a programming pulse of 50 ms duration to the pin PGM and (b) a raise in the supply voltage from V_{CC} (normally at 5 V) to V_{pp} = 25 V. Once programmed, data stored in the device cannot be erased unless it is exposed under intense ultraviolet light for about 30 to 60 minutes.

To read data from the EPROM, a signal is input into pin $\overline{OE}$ so that the device becomes output-enabled. Then the contents of the byte addressed by A1-A13 will appear in the data lines 01-08.

Data are organized in units of 3 bytes, forming records which may be in one of the five mutually exclusive formats depicted in Table 1. For example, a 3-byte record with the most significant bit in the first byte equal to 1 is in Format 2, while an alphabet appearing in the second byte of a record indicates that the record is in the Format 5. The purpose of having these different formats will further be discussed in Section 3(d).

For a 0.5 mm-bucket rain-gauge, a 2764 EPROM is capable of holding rainfall data corresponding to a total depth exceeding 1 250 mm. This is more than half the normal annual rainfall at the Royal Observatory and also exceeds the historical record of monthly rainfall at the Royal Observatory -- 1 240.5 mm in May 1889.

(b) Hardware design

The many facilities specified in the design objectives, namely (a) - (d) and (f) in Section 2, warrant the use of a microprocessor. The basic functions of the microprocessor are to record signals from the rain-gauge, to keep the time, to interact with the EPROM during data transfer and to handle error in the case of a write-fault occurring in the process of data transfer to the EPROM. Fig. 2 shows a block diagram of the system.

The Mostek MK38P70 'piggy-back' microprocessor (Mostek Programming Manual, 1978) is a complete 8-bit microcomputer in a single MOS integrated circuit. This device features the F8 instruction set, 64 bytes of executable random-access memory (RAM), 64 scratchpad registers (RAM), a programmable binary timer, 32 pins (4 ports) of input/output, and a single 5V power supply requirement. On top of the microprocessor there are sockets for holding a 2K or 4K EPROM which contains the computer program developed for the operation of the rainfall recorder. The complete software architecture of the microprocessor is given in Fig. 3.

Fig. 4(a) shows the hardware design of the microprocessor system, interfaced with the EPROM used for data storage. Two 74LS244 line drivers put the 13 address lines through to 2764 EPROM. Data to and from the EPROM via the data lines 01 to 08 are buffered by two 74LS241 bidirectional drivers. The direction is normally from the EPROM to the microprocessor ('read' mode), but is reversed as soon as a programming pulse of 50 ms duration comes out from the microprocessor, indicating that some data are to be programmed onto the EPROM ('program' mode). At the same time, the pulse triggers off a de-activation signal to the output-enable ($\overline{OE}$) control in the EPROM and, via a transistor-based switching circuit, raises V_{pp} from 5 V to 25 V. These procedures are necessary during the 'program' mode.

The purpose of having a 74LS221 monostable multivibrator in the programming line is to delay the programming pulse by several microseconds to allow time for the signals on the data bus to stabilize.

Signal from the rain-gauge is passed via a relay to the microprocessor external interrupt (EXT INT) pin. As will be explained in Section 3(d), each signal is debounced for a duration characteristic of the rain-gauge and the electrical relay.

By the use of an active circuit consisting of a 74LS00 NAND gate, the system is timed by an external quartz oscillator of frequency about 4 MHz. Details of the timing process are described later in Section 3(d).

An eight-digit HP7650 LED (light-emitting diodes) display is scanned using 4 output pins for the BCD number and 3 output pins for the digit select (Fig. 4(b)). Such time-multiplexing is accomplished at the rate of 1 ms per digit (125 Hz for the eight digits), which is fast enough to prevent the display from flickering. Chip 7447 is a BCD-to-7 segment decoder/driver for each of the digit and 7442 is a BCD-to-decimal decoder for the digit select.

A switch on the front panel of the recorder allows either the rainfall amount or the time (month, day, hour and minute) to be displayed. Two other switches, also on the front panel, enable the time to be adjusted. There is another switch to control the start/stop of the system.

Photographs of the recorder are shown in Figs. 6 and 7. A parts list is given in Table 2.

(c) Power supply

A.C. power input is provided with lightning surge suppressing tranzorbs and varistors, and high-voltage bypass capacitors (Fig. 5) to eliminate power transients due to lightning or nearby switching of high power equipment. The output from a 24 V 2 A transformer is converted to approximately 32 Vdc which, apart from providing 28 Vdc to the EPROM and

13 Vdc to the voltage regulator, also charges up two 12 V 5.7 Ah lead acid rechargeable batteries. The LM323 regulator converts 13 Vdc to 5 Vdc required by the TTL components of the system.

The power consumed by the recorder is about 20 W.

(d) Software design

Some of the functions of the software, which resides in the 2716 EPROM riding on top of the microprocessor, are evident from Fig. 4(a). The software is designed to :-

(i) detect signals from the rain-gauge in form of an external interrupt ;

(ii) accumulate rainfall since the last scheduled observation time (i.e. 9 a.m./3 p.m. according to the practice of the Royal Observatory rainfall network) ;

(iii) receive signals from the 4 MHz quartz oscillator and then create a time interrupt every 1 ms to drive an internal clock ;

(iv) calculate the time between two successive tips in the rain-gauge in order to enable rainfall intensity to be estimated when there is heavy rain ;

(v) detect the status of a control switch (on the front panel) in order to display either the rainfall or the time :

(vi) detect time adjust signals from other control switches (on the front panel) and adjust the month, day, hour and minute accordingly ;

(vii) output the appropriate EPROM address on the address bus, and output the data to be written onto the EPROM on the data bus ; and

(viii) output a programming pulse of 50 ms duration whenever data are to be written onto the EPROM.

The software is composed of 3 main routines : time interrupt, external interrupt and normal routine (Fig. 8). The operation of these routines is described in the following paragraphs and in greater details in Appendix 1, in which software flowcharts are presented.

The 4 MHz signals from the quartz oscillator are pre-scaled to give time interrupts at 1 ms intervals——a pre-scalar value is chosen after some calibration because the oscillator does not produce signals at exactly 4 MHz. Every thousand of such time interrupts will increment the 'second' register (which is a RAM) by one. The 'minute' register will be updated every 60 seconds and so on for the 'hour', 'day' and 'month' registers. The time interrupt routine also monitors the status of the time-adjust control switches. When the switches are found to be 'on', the above 1-ms time interrupts will be ignored and, according to the different status of the control switches, the different time registers (for month, day, hour, minute and second) will be incremented automatically by 1 every second. This time-adjusting process ceases when the control switches are put back to the 'off' positions.

As a bucket in the rain-gauge tips, the electrical signal generated enters the microprocessor circuit as an external interrupt (Fig. 4(a)). Upon detection of the interrupt, the software activates a debounce timer of a duration characteristic of the rain-gauge and the electrical relay in use. The debounce timer is timed internally, so that any further external interrupts occurring within the debounce time will be ignored. For a bucket size of 0.5 mm, this amount of rainfall will be added to the total each time an external interrupt is detected. The time at which the tip occurs is taken from the time registers and stored in a 'Record Table' (REC TABLE) in the form of a 3-byte unit (HH, MM and SS respectively; see Format 3 in Table 1). If the time between the present and the last tip is less than or equal to 20 s, this time difference is also recorded to the nearest 0.1 s (Format 4 in Table 1).

Rainfall amount is accumulated starting from the last scheduled observation time, which is 9 a.m./3 p.m. each day for the Royal Observatory rainfall network. The rainfall total is retained on display for two hours after the observation time to allow time for the observer to take down the reading. (There is an alternative version which displays hourly rainfall and retains the rainfall amount over the past hour on display for 15 minutes).

The time interrupt routine also prepares a record of Format 2 (Table 1) as soon as the observation time is reached. This marks the beginning of the next observation period. The purpose of having such a record is to ease subsequent data analysis. The time over which the recorder is out of service can easily be determined to within several hours because in this case there will be no such record in the EPROM.

The normal routine is active all the time and looks for entry(ies) on the Record Table. When there is an entry on the Record Table, which has to be written onto the EPROM, control will be passed to a scheduler, which arranges the following subroutines to be executed.

(i) PGM subroutine - programs data onto the EPROM.

Procedure : 1) output EPROM address to EPROM,

2) output data stored in the Record Table to EPROM,

3) set a 50-ms timer,

4) output a programming pulse (50 ms duration),

5) pass control to VERF subroutine.

(ii) VERF subroutine - verifies data written onto the EPROM.

Procedure : 1) check the 50-ms timer and terminates the programming pulse after 50 ms have elapsed,

2) output EPROM address to EPROM,

3) read data from EPROM and verify them,

4) pass control to UDRT subroutine after a record (3 bytes) has been written and verified, otherwise to ERR subroutine.

(iii) UDRT subroutine - updates the Record Table.

Procedure : 1) delete from the Record Table the record (3 bytes) already written onto the EPROM,

2) advance EPROM address by 3 (3 bytes) to prepare for the next record entry,

3) pass control back to scheduler.

(iv) ERR subroutine - handles error in case of a write-fault

Procedure : 1) prepare a record of Format 4 (Table 1) to denote error condition,

2) enter this record into the Record Table,

3) advance EPROM address by 3 (3 bytes),

4) pass control to the PGM subroutine.

The purpose of having the scheduler in this manner is to avoid contention arising from the possible situation of having more than one record of different formats listed in Table 1 coming in at the same time.

The Record Table is made up of 60 of the 64 executable RAM's.

Technical details concerning the assignment of the 64 scratchpad registers and the use of the input/output ports are explained in the listing of the program. Copies of the program are kept in the Royal Observatory Library.

4. DISCUSSION

The use of microprocessor and non-volatile solid-state memory offers a way to inexpensive and fully-automatic recording of rainfall information in digital form. This saves considerable manual efforts involved in observation and in data compilation.

As long as the input from the rain-gauge to the recorder described in this report is of contact-closure type, the recorder can be applied on-site or at a distance, via telemetry.

Some features in the design are made completely flexible as they only need changes in the software. The recorder can be modified easily to read rainfall amount over an hour, 15 minutes or even shorter intervals. The time over which the display of rainfall total is retained can also be modified. The system clock can be calibrated by changing a time constant in the program. The length of time for debounce can also be altered when required. (As short as 0.1 s is possible in rain-gauges equipped with 'Mercoid' type of switches.) The necessary software modifications are explained in Appendix 2.

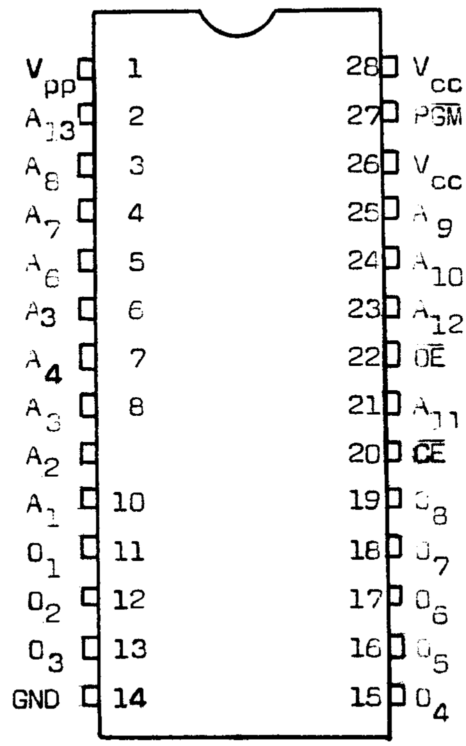
Compared to mechanical chart recorders, this recorder offers better resolution in time. Timed by quartz oscillator, the internal clock is accurate to within 30 seconds a day. The error arising from the time element used in intensity estimation is even less, because in this case only the differences in time are taken into account, i.e. the accuracy of the absolute time is not important. Measurements of rainfall intensity made with a tipping-bucket rain-gauge have been used to calibrate an electrical rainfall-intensity sensor (Battalino and Vonnegut, 1978).

For heavy rainfall, the rainfall intensity can be estimated from the stored data. Provided the intensity of rainfall persists over a period long enough to give a rainfall amount equal to two bucket sizes (i.e. 1 mm in the case of 0.5 mm buckets), so that at least two tips of the buckets occur, the recorded time difference between the two tips will give a reasonable indication of the rainfall intensity. However, it should be noted that the precise amount of rainwater delivered by the bucket is dependent on the rainfall intensity (Parsons 1941). For investigations requiring high accuracy, it is necessary to include a correction, which can be derived from a calibration curve for the model of tipping-bucket rain-gauge used.

The recorder has been put to test in the Central Forecasting Office of the Royal Observatory. At the time of writing this note, it has been running continuously for more than a year without any incidence of failure of any sort.

REFERENCES

1.	Battalino, T.E. and B. Vonnegut	1978	Electric Rainfall Intensity Sensor, J. of Appl. Met., 17, pp. 1225-1231.
2.	Bracewell, M.G. and L.A. Campbell	1981	A Rainfall Recording System Employing Solid State Memories, Second W.M.O. Technical Conference on Instruments and Methods of Observation, Mexico City, October.
3.	Donnelly, D.P.	1977	Digital Raingauge Recorder, J. of Appl. Met., 16, pp. 205-207.
4.	Lam, H.K. and P.C.S. Li	1979	A Remote Recording Digital Tilting-Bucket Raingauge, Royal Observatory Technical Note No. 47.
5.	Mostek Corporation	1978	Mostek F8 Microprocessor System Programming Manual.
6.	Parsons, D.A.	1941	Calibration of a Weather Bureau Tipping-Bucket Raingauge, Monthly Weather Review, July, P. 205.
7.	World Meteorological Organization	1974	Guide to Hydrological Practices, W.M.O. Report No. 168.



CE	-	chip enable
GND	-	ground
OE	-	output enable
PGM	-	programming
V_{cc}	-	5V TTL supply
V_{pp}	-	power supply for programming

Fig. 1 Pin configuration of EPROM 2764.

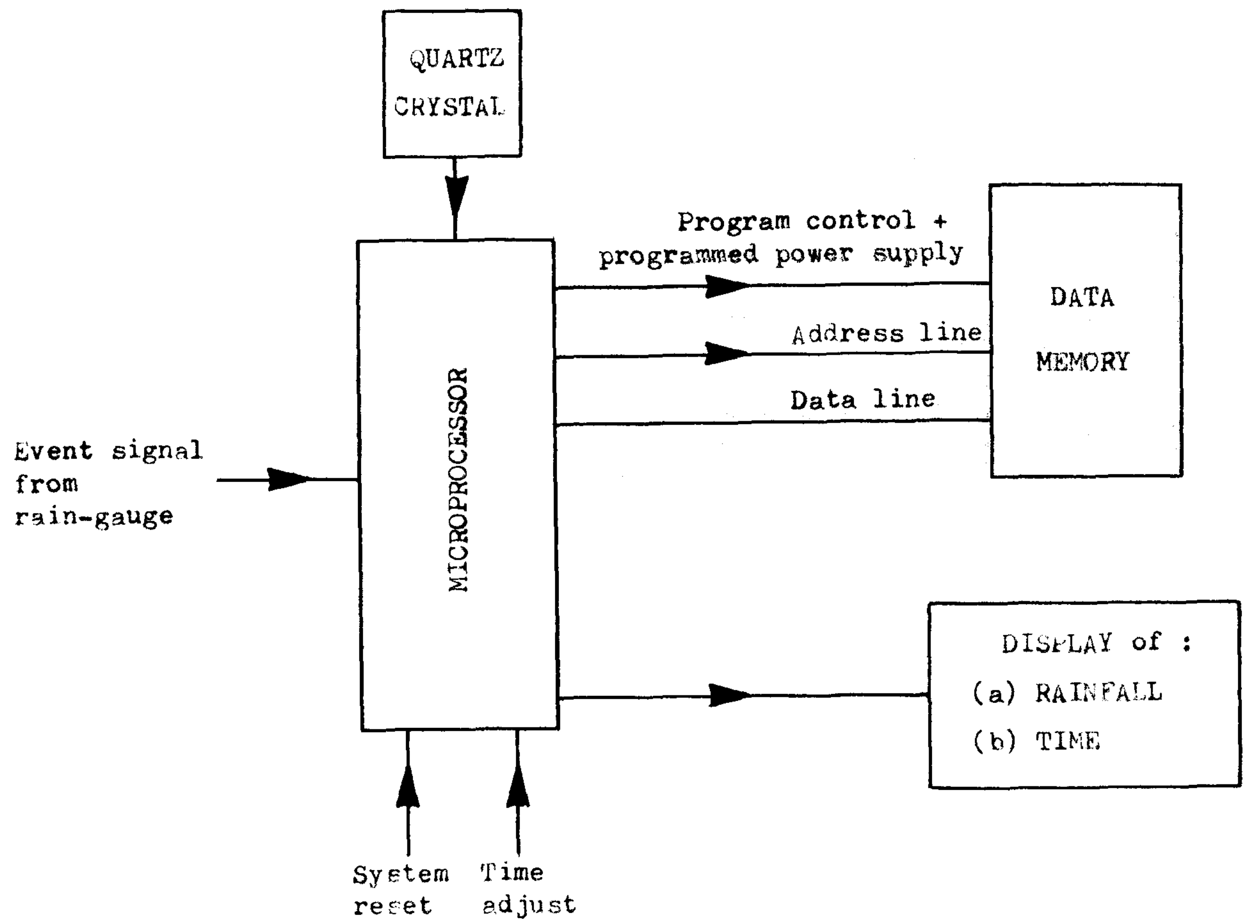


Fig. 2 System block diagram

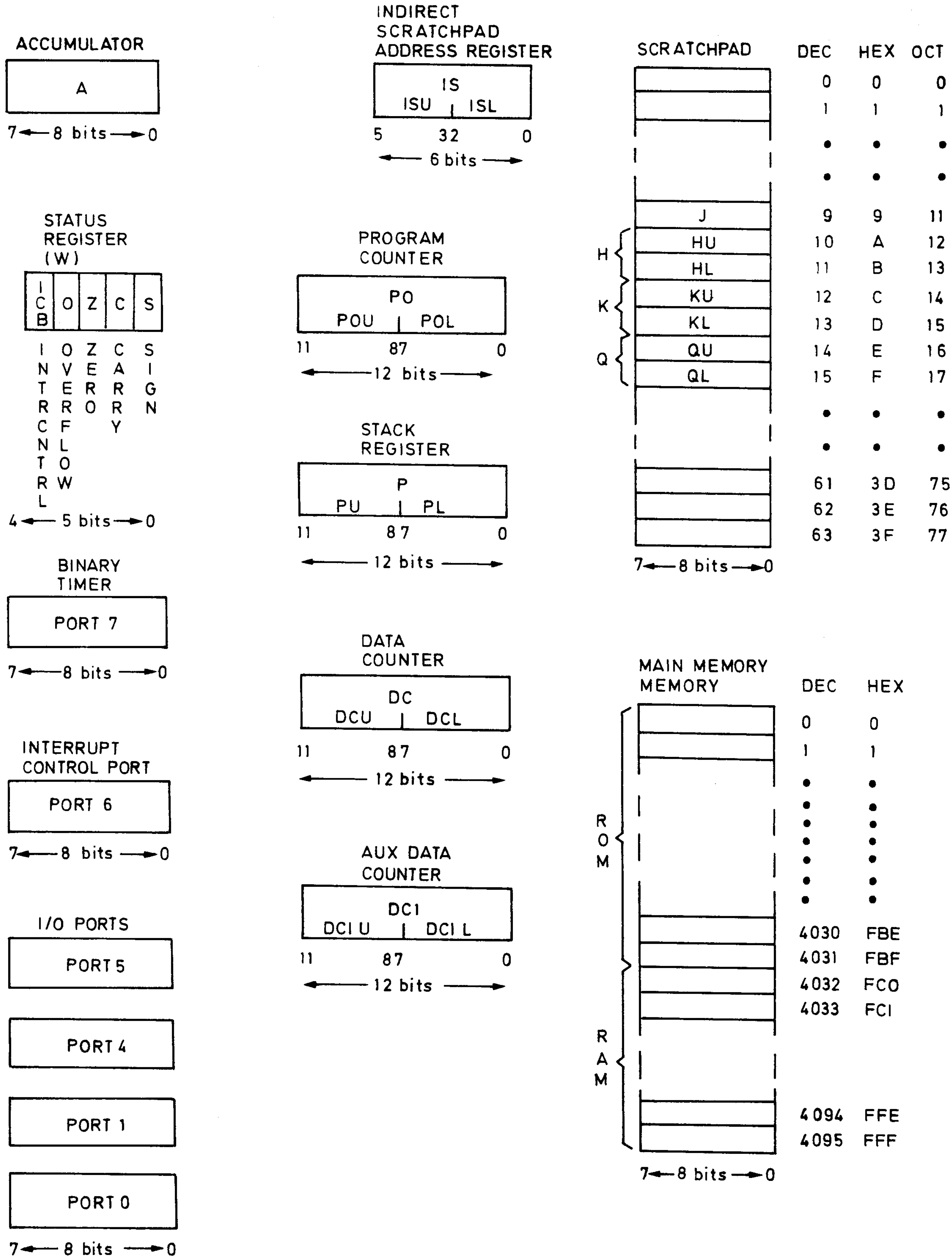


Fig. 3 Programmable registers, ports and memory map in the MK 38P70 microprocessor.

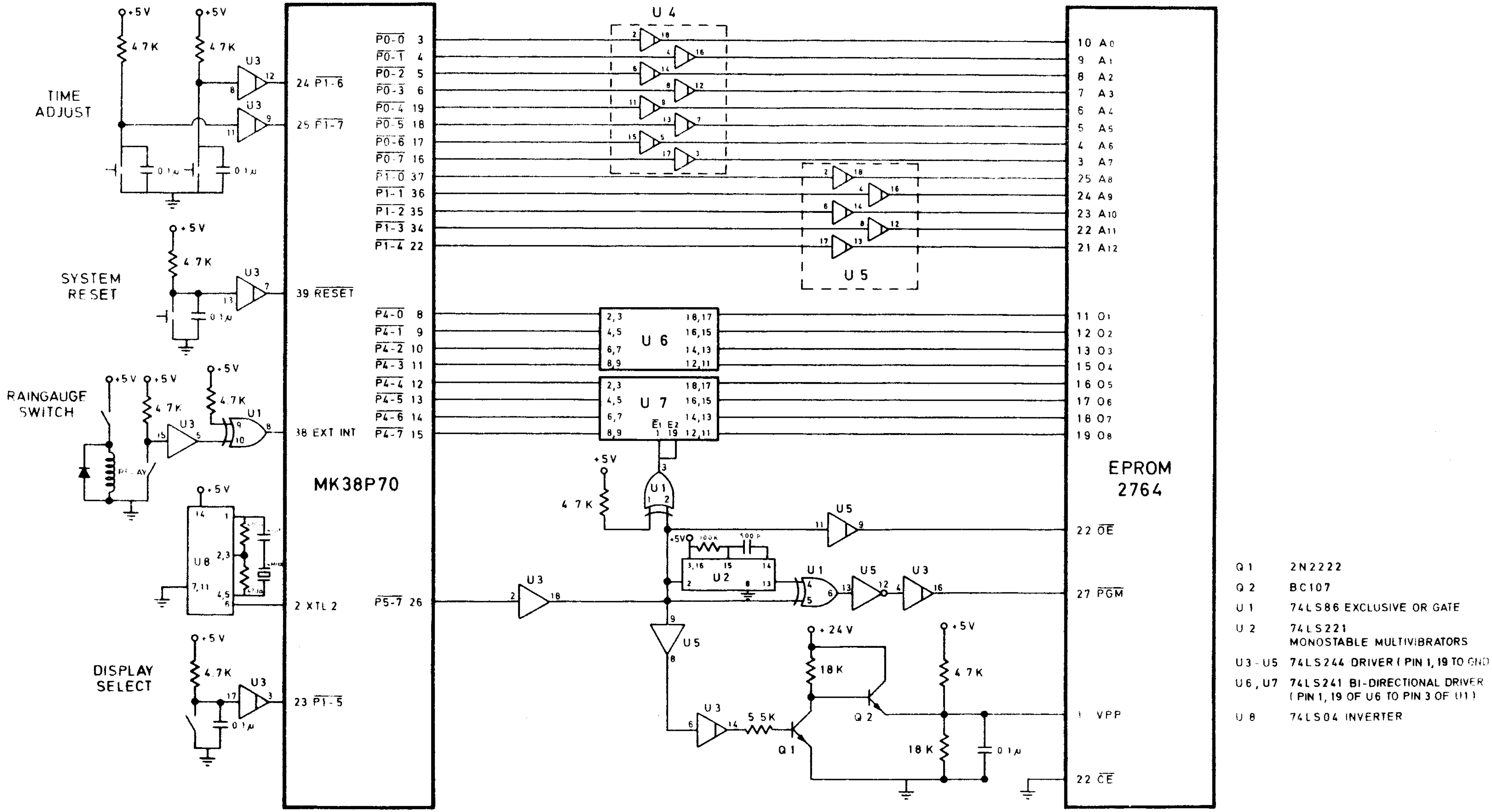


Fig. 4(a) The MK 38P70 microprocessor interfaced to EPROM 2764, quartz oscillator and other control switches.

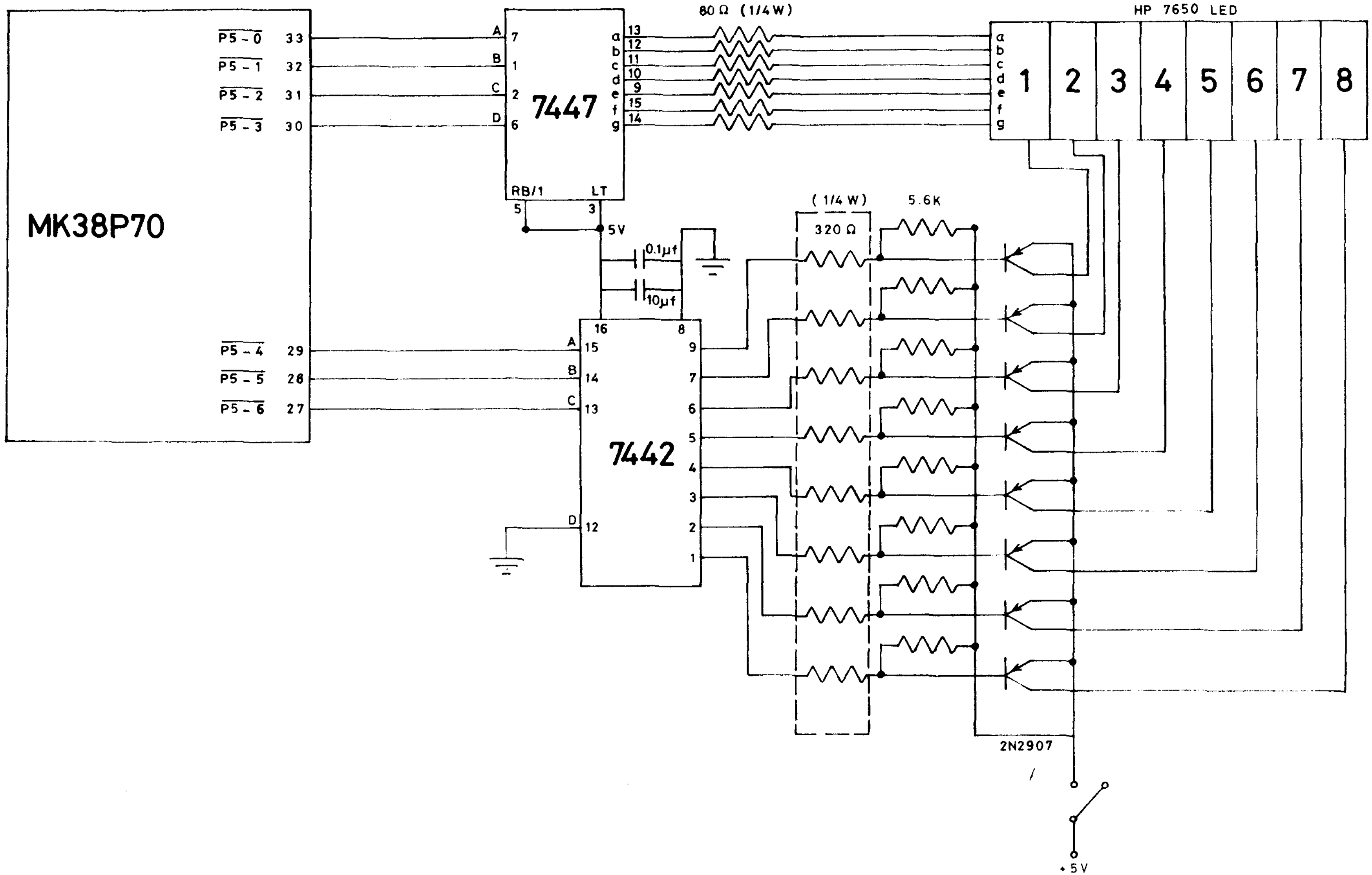


Fig. 4(b) The MK 38P70 microprocessor interfaced to the LED display unit.

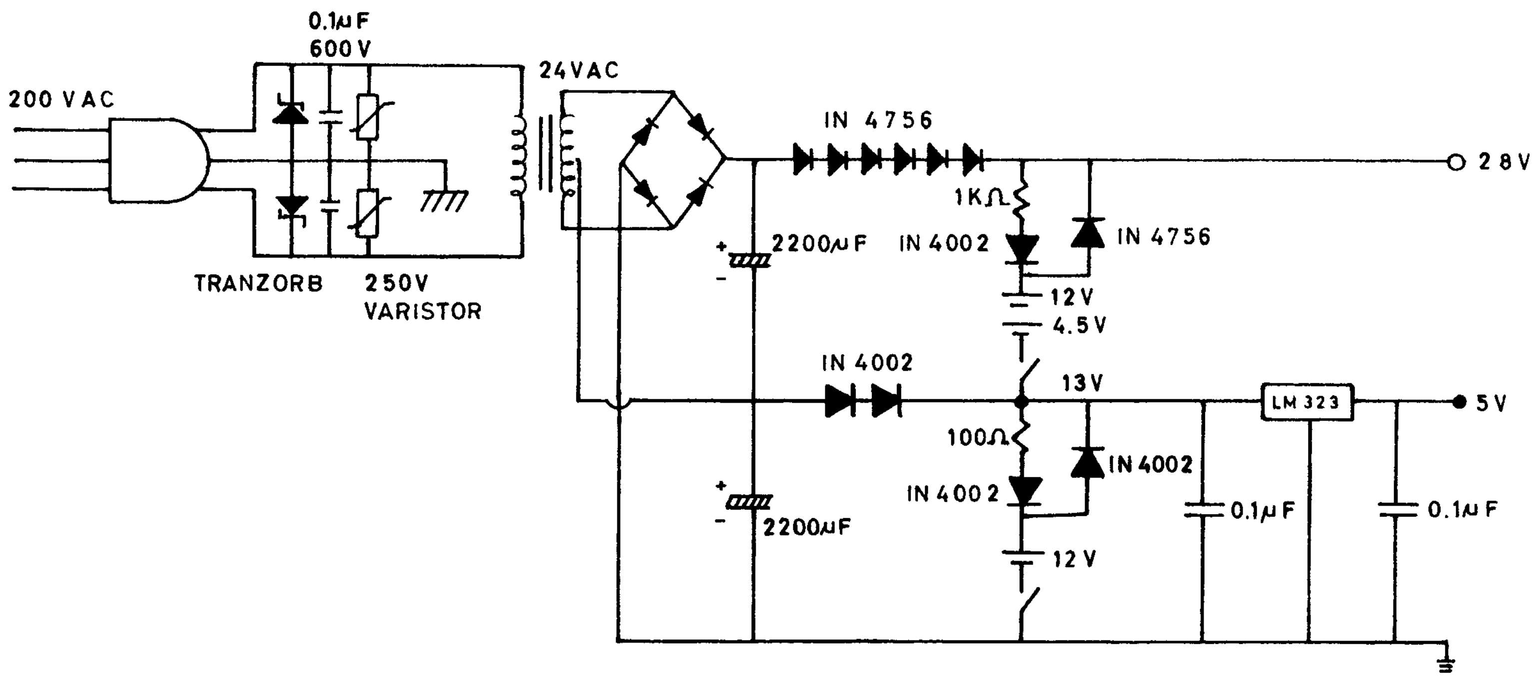


Fig. 5 The power supply

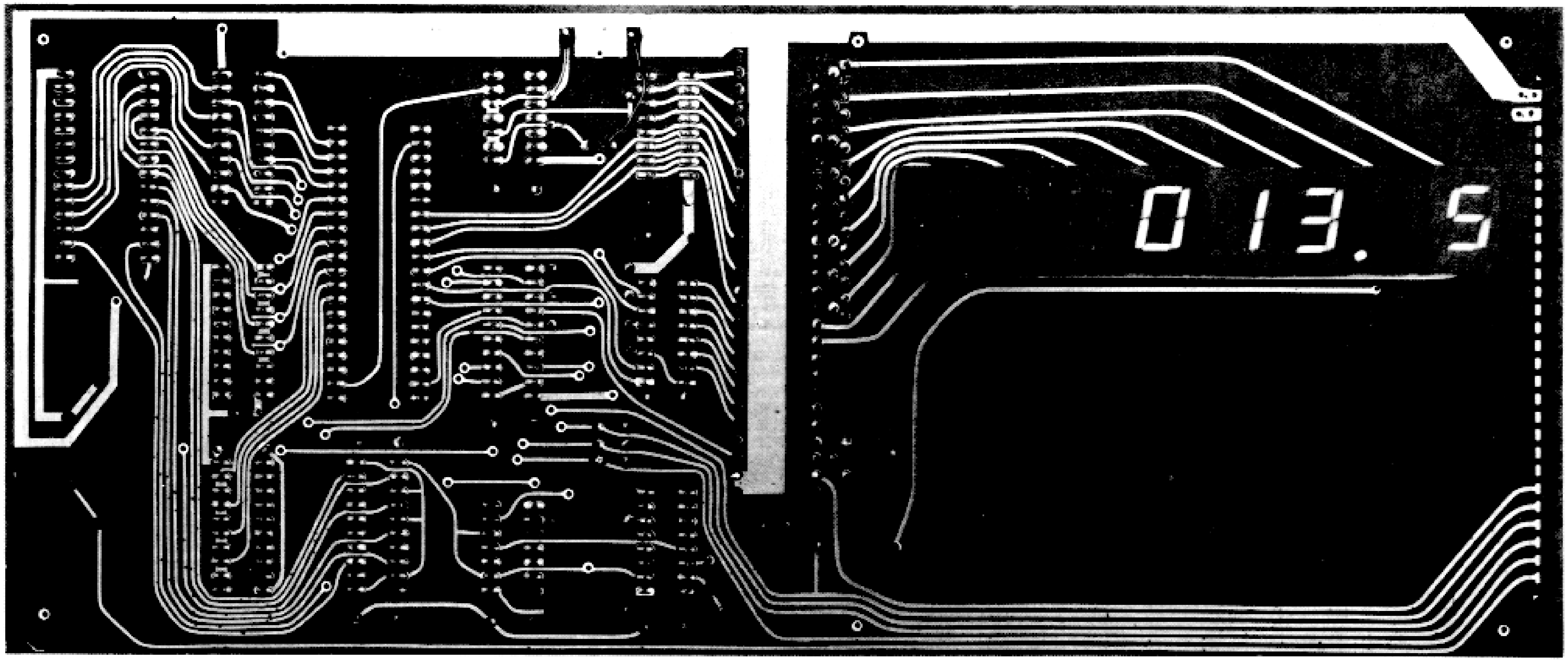


Fig. 6 Front view of the recorder

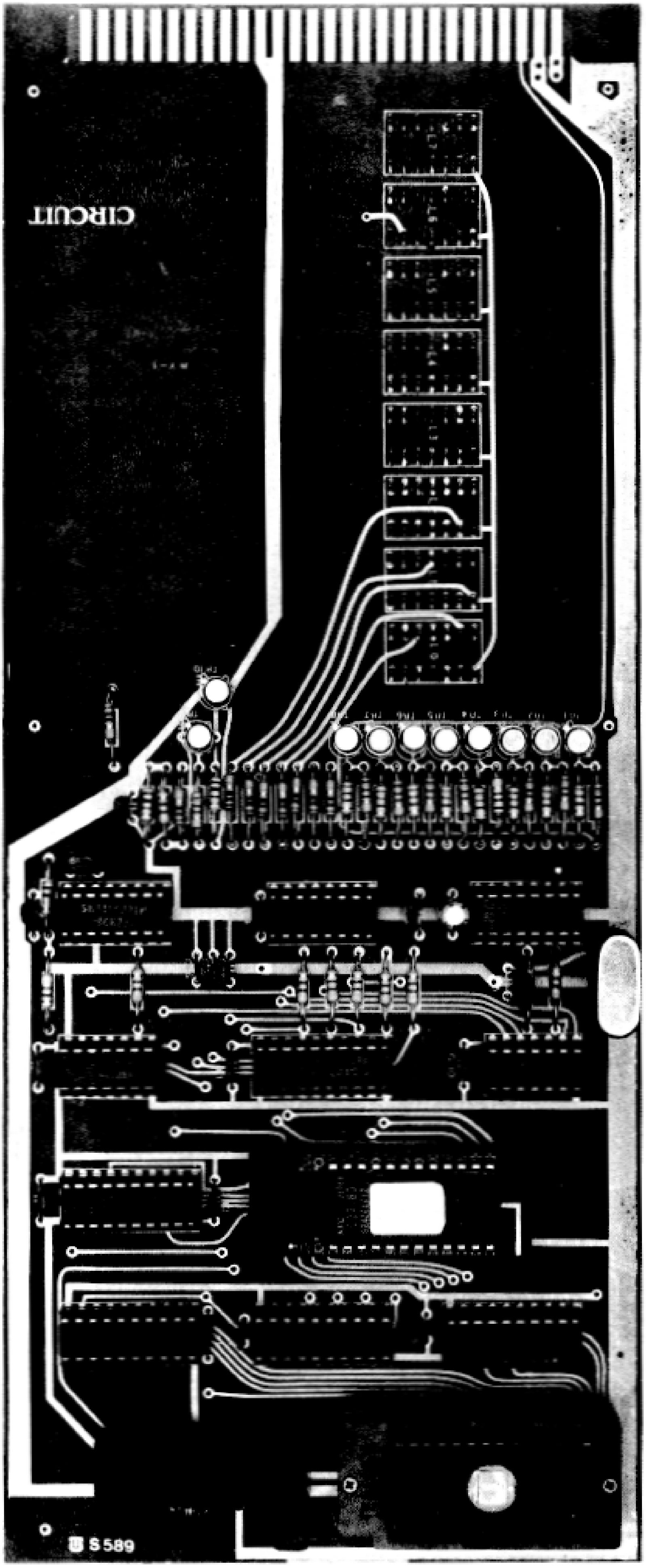
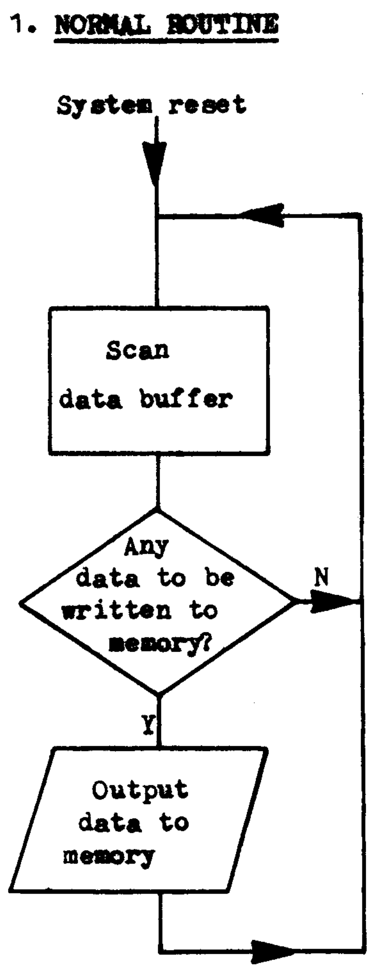
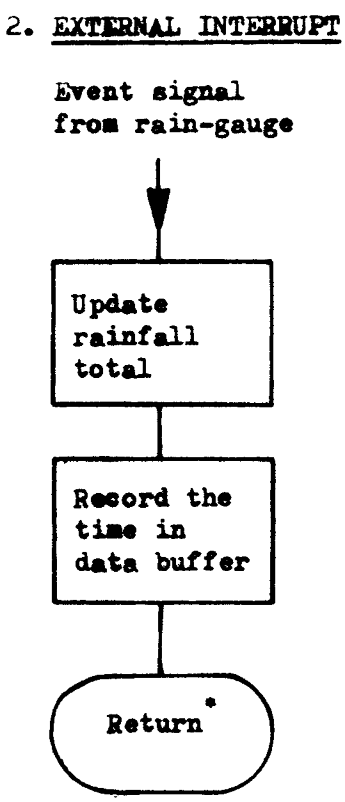
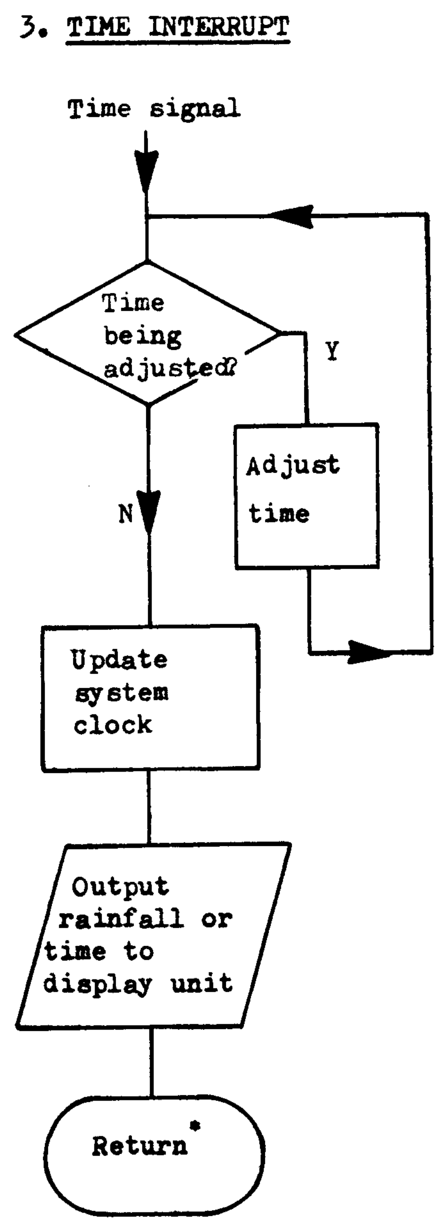


Fig. 7 Back view of the recorder







* means return to the point at which the Normal Routine was interrupted.

Fig. 8 Software system flowchart

TABLE 1. FORMATS OF RECORDS STORED IN THE EPROM

Format	Contents of the 3-Bytes	Explanation
1	0 0 'EE' (hexadecimal)	System start up.
2	'1XYYYYYY' (binary) MONTH DAY	X=0 for period 0900-1500 local time. =1 for period 1500-0900 local time. YYYYYY is the station identification. (Note. This format appears twice per day).
3	HH MM SS	Time of tip of bucket.
4	0 SS 'DX' (hexadecimal)	SS= time in seconds (≤ 20) between two previous tips recorded under intense rainfall situation. X= tenths of a second.
5	0 XX XX	XX (hexadecimal)= AA, AB, AC ... AF, BA, ..., FF. Write fault. 'AA' indicates write fault on the preceding 3-byte record. 'AB' indicates write fault on the 2 preceding 3-byte records; and so on.

Note : MONTH, DAY, HH (hour), MM (minute) and SS (second) are all expressed in binary-coded-decimal (BCD).

TABLE 2. PARTS LIST

Components

C1, C3, C4, C6–C10	Capacitor	0.1 uf
C2	Capacitor	10 uf
C5	Capacitor	47 pf
C19	Capacitor	500 pf
D1	Diode	1N4007
Q1–Q8	Transistor	2N2907
Q9	Transistor	2N2222
Q10	Transistor	BC107
L0–L7	LED	HP7650
R1–R8, R13	Resistor	5.6K
R9–R12, R23–R25, R27, R40	Resistor	80 ohms
R14, R32–R38	Resistor	4.7K
R15–R22	Resistor	320 ohms
R26, R28	Resistor	18K
R29	Resistor	100K
R30, R31	Resistor	470 ohms
U1	IC	7442
U2	IC	7447
U3	IC	74LS221
U4	IC	74LS04
U5, U8–U9	IC	74LS244
U6	IC	74LS86
U7	Microprocessor	MK38P70
U10–U11	IC	74LS241
U12	EPROM	2764

Edge connector

1	Rain-gauge input
3	Toggle switch (Time adjust)
5	Toggle switch (Time adjust)
7	Switch (Start/stop)
9	Switch (Display of time/rainfall)
22, 24	+24 V
52	Switch (LED)
54	0 V
55	+5 V

APPENDIX 1. FLOWCHARTS

1. External interrupt routine.
2. Time interrupt routine.
3. System start-up routine.
4. Normal routine.

Explanation of some terms referred to in the flowcharts

DD - day
HH - hour
MM - minute
SS - second

PAD - scratchpad register, referred to by octal numbers.

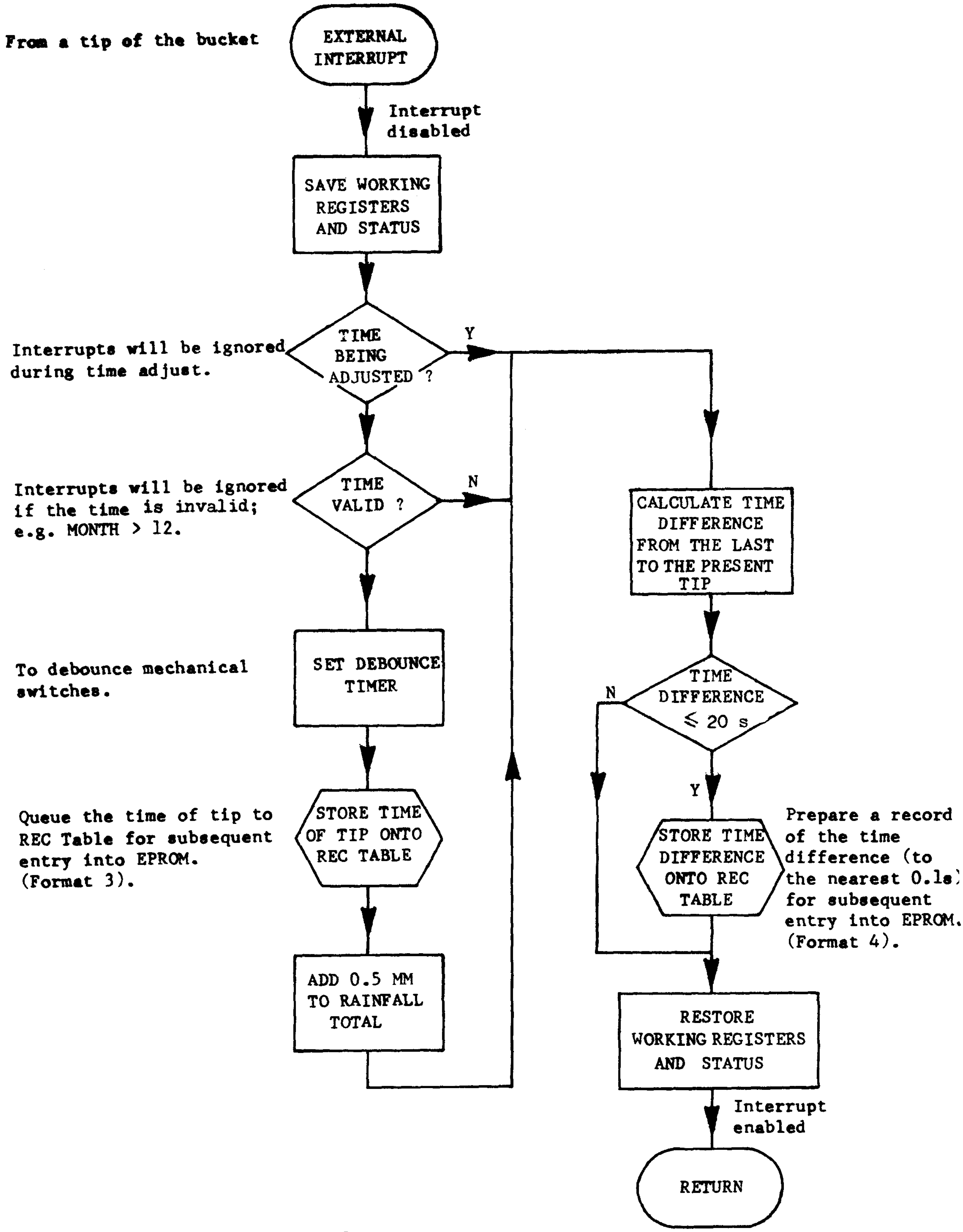
PGM MODE - programming mode, i.e. the microprocessor is transferring data to the EPROM.

RECORD - consists of 3 bytes in the REC Table (Record Table) which are to be output to the EPROM.

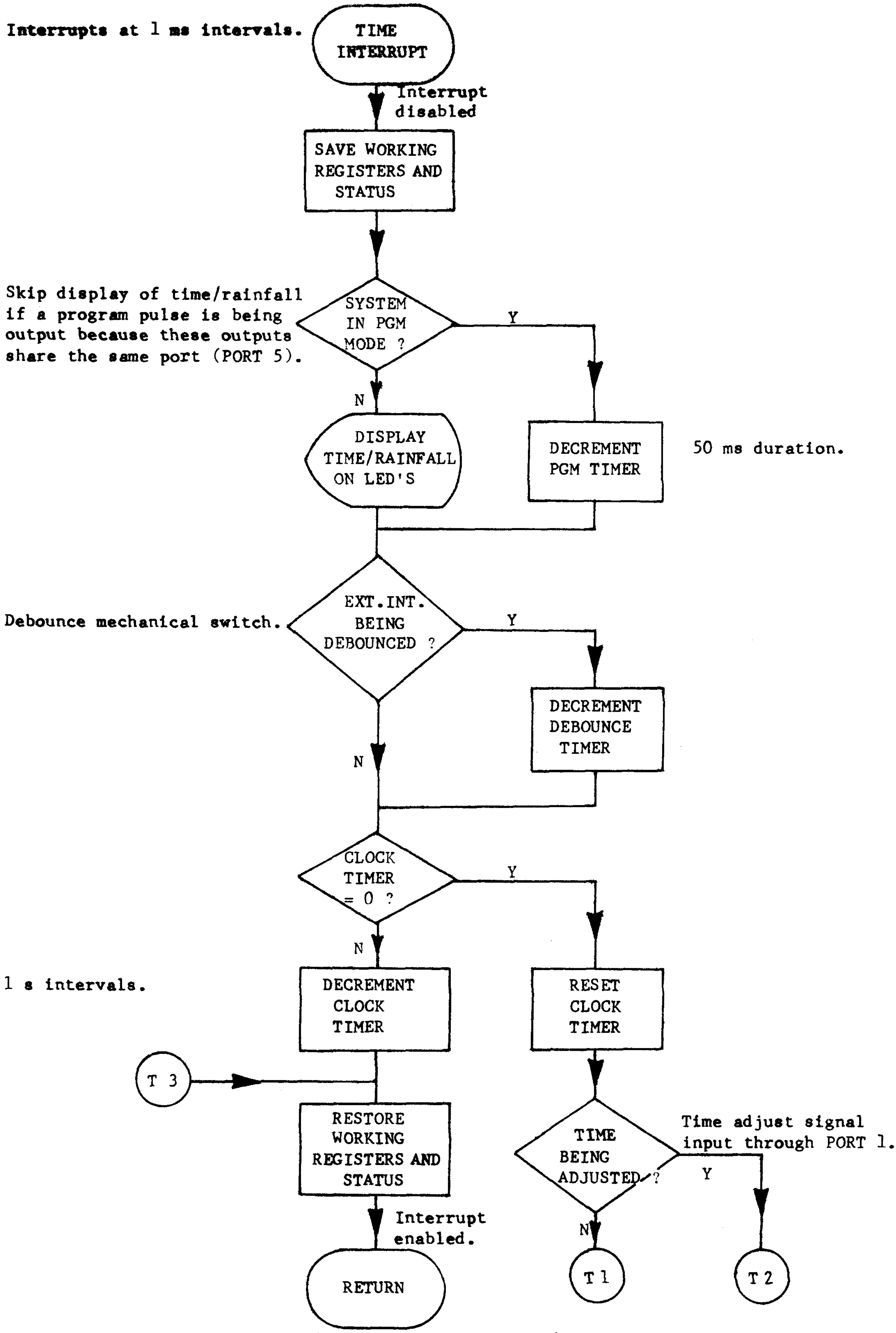
REC Table - consists of 60 bytes in the Executable RAM area (Fig. 3) and holds data to be output to the EPROM.

XEC - scheduler

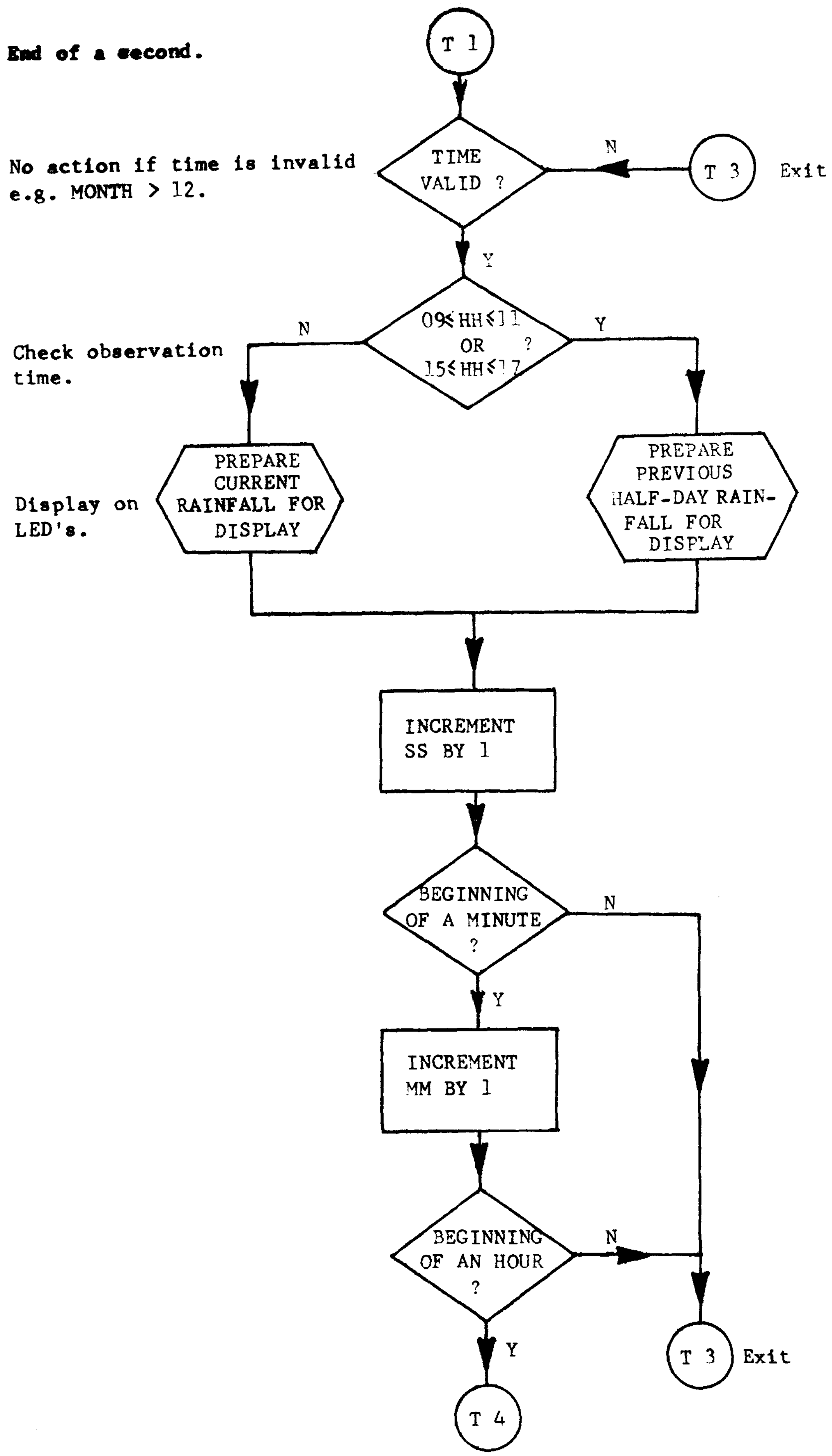
XEC No. - a number by which the scheduler calls up individual routines.



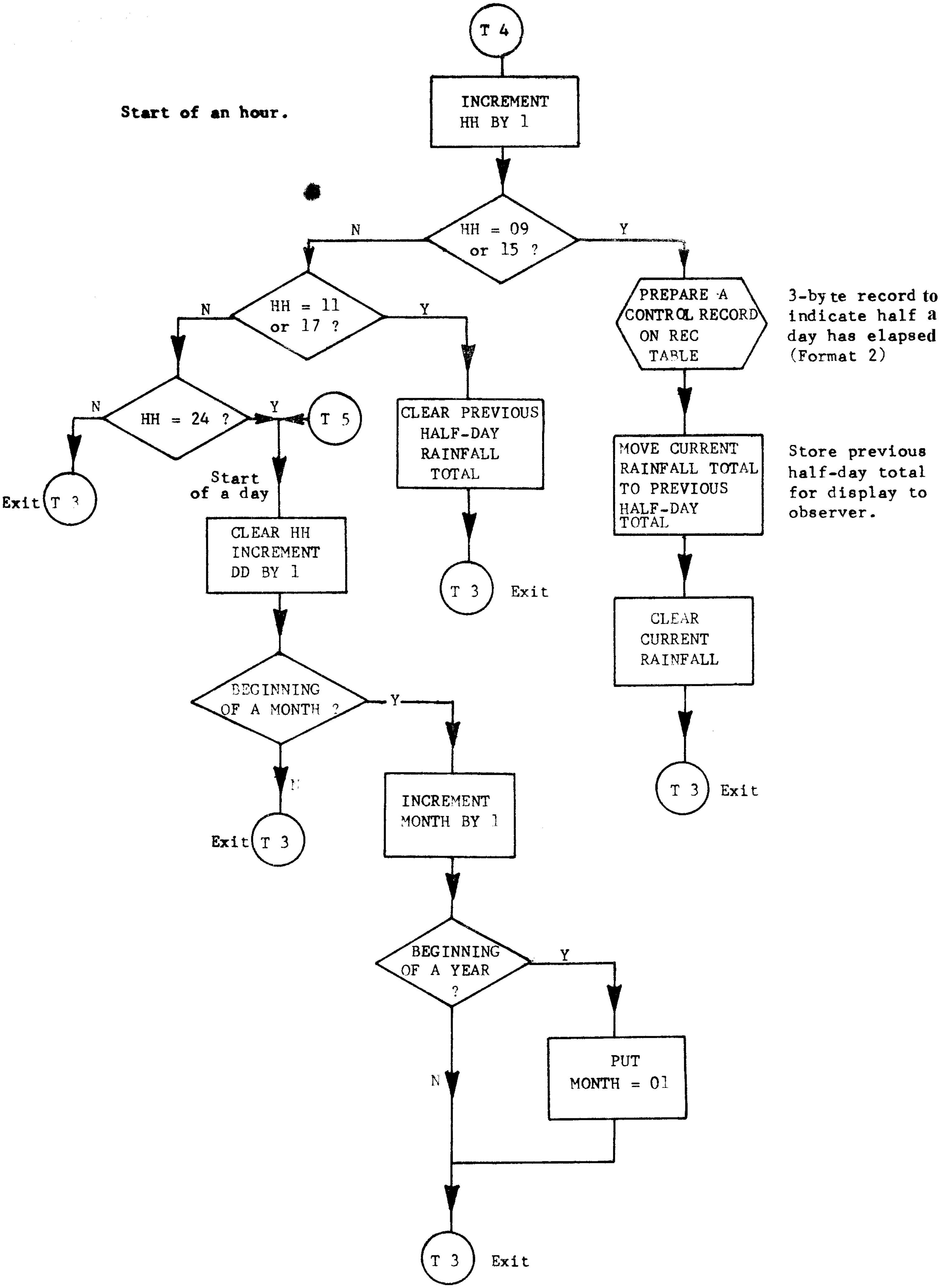
Flowchart 1. External interrupt routine.



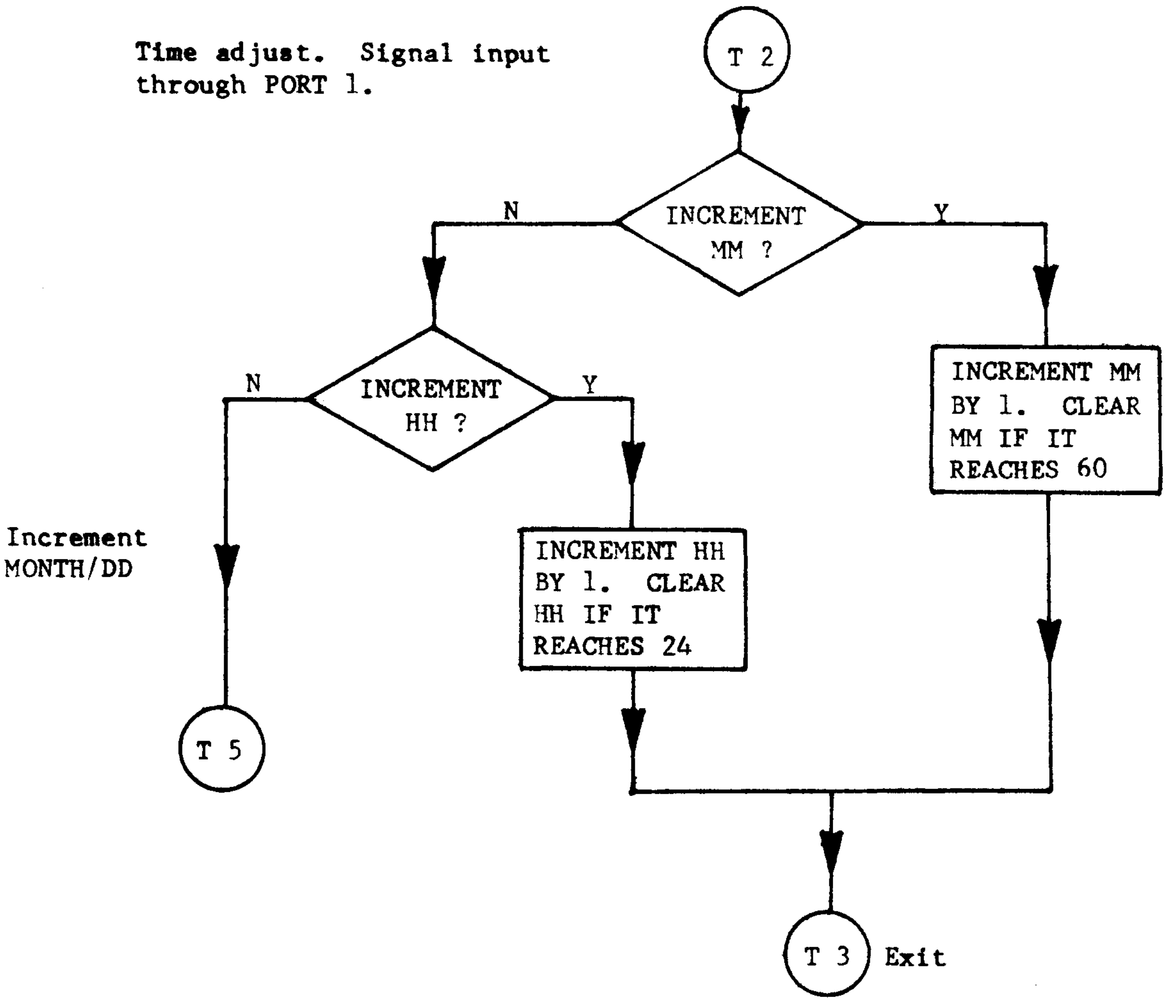
Flowchart 2. Time interrupt routine.



Flowchart 2 (Cont'd):Time interrupt routine.



Flowchart 2 (cont'd): Time interrupt routine.



Flowchart 2 (cont'd) : Time interrupt routine.

System reset.

Distinguish between power-up start and reset start. For reset start, scratchpad 73-77 already contain 1 to 5 respectively.

FF - hexadecimal

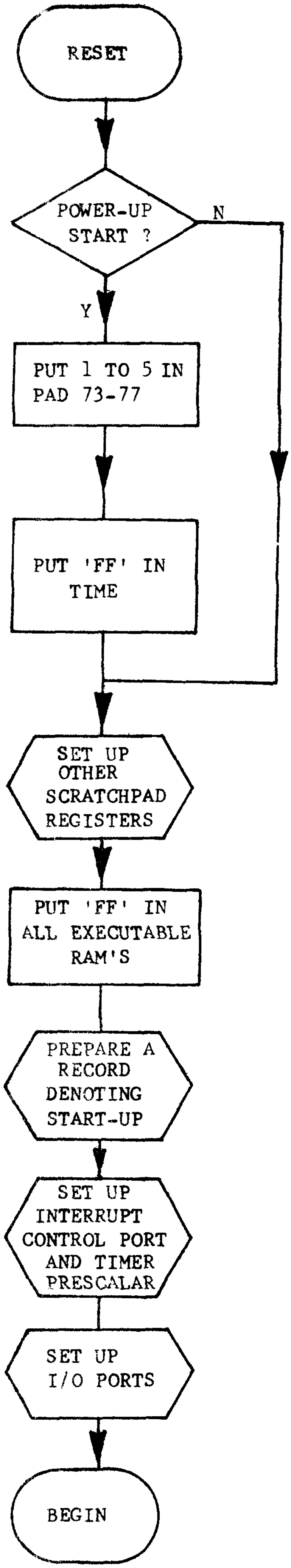
Clear rainfall figures, external interrupt and debounce timers etc. Set up clock timer, error codes etc.

3-byte record to denote reset of System. Queued to REC Table for subsequent entry into EPROM. (Format 1).

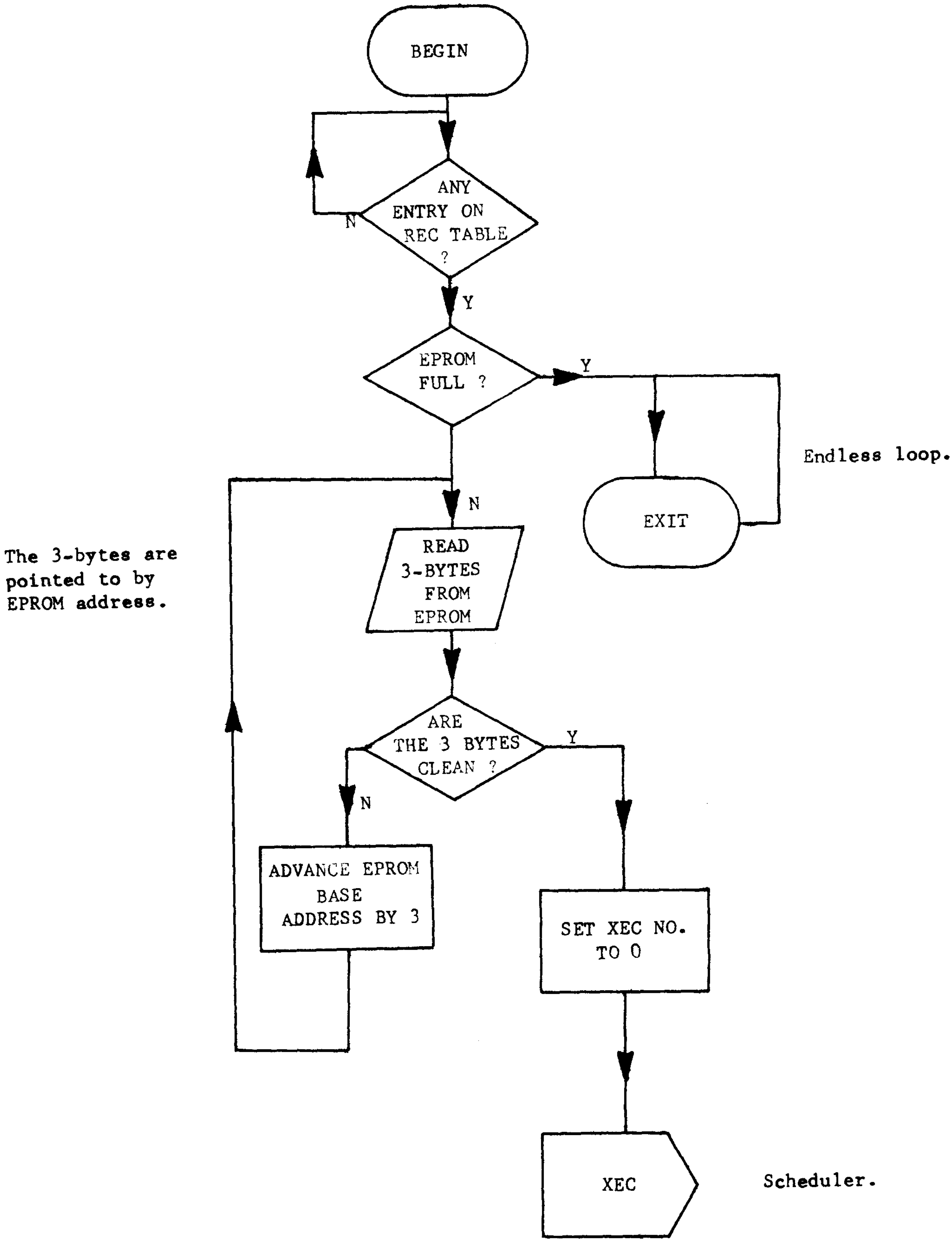
Ports 6 and 7.

Ports 0, 1, 4 and 5.

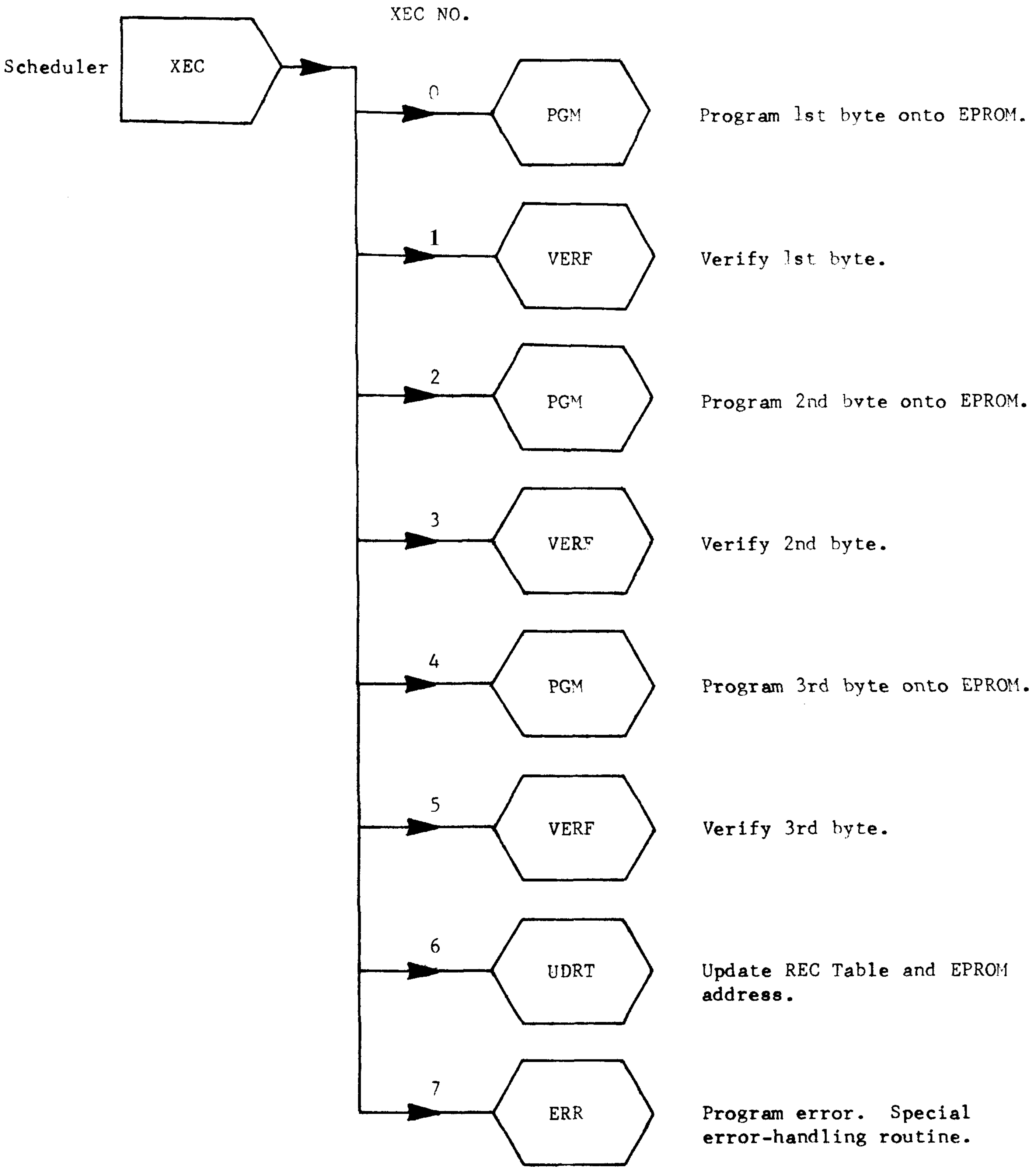
To normal routine.



Flowchart 3. System start-up routine.



Flowchart 4. Normal routine.



Flowchart 4 (cont'd) : Normal routine.

PGM routine :

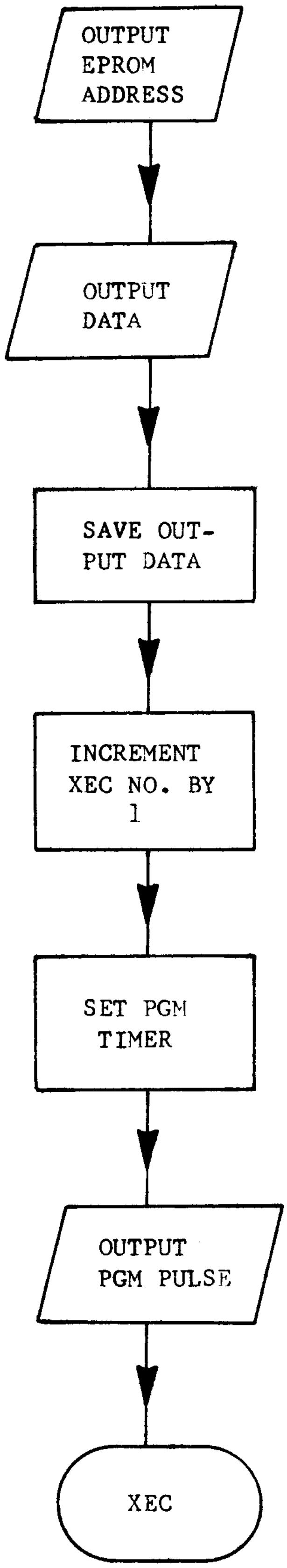
Address EPROM.
Output at PORTS 0 and 1.

Output at PORT 4.

Save data for
subsequent verification.

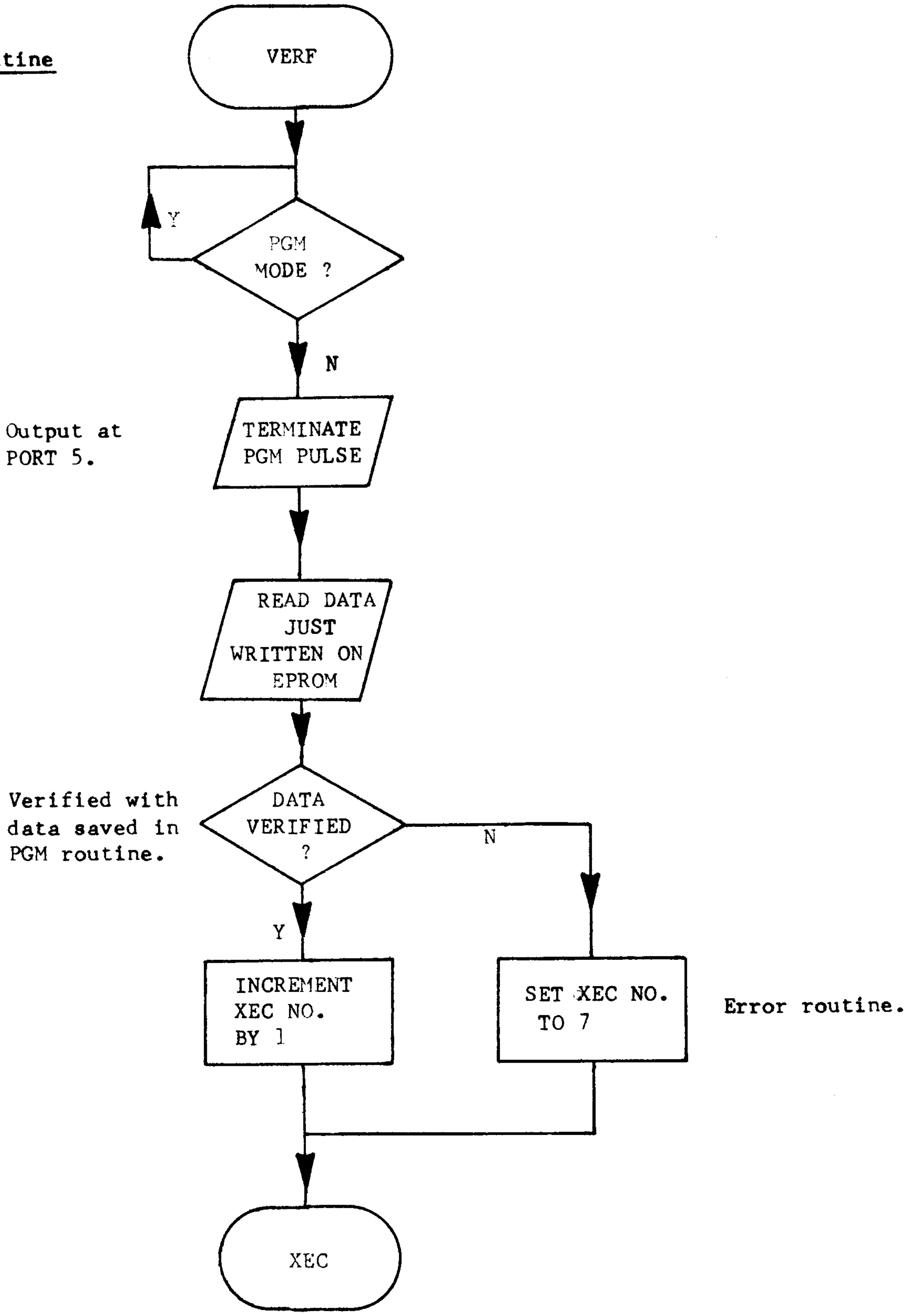
50 ms duration for
programming pulse.

Output at PORT 5.



Flowchart 4(cont'd) : Normal routine.

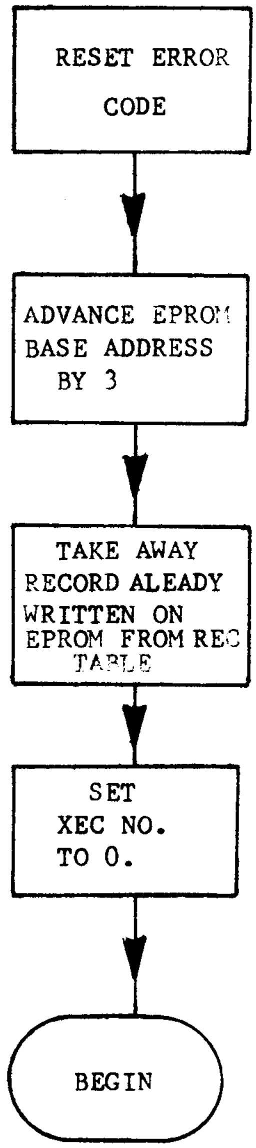
VERF routine



Flowchart 4 (cont'd) : Normal routine.

UDRT routine

Dequeue REC Table.

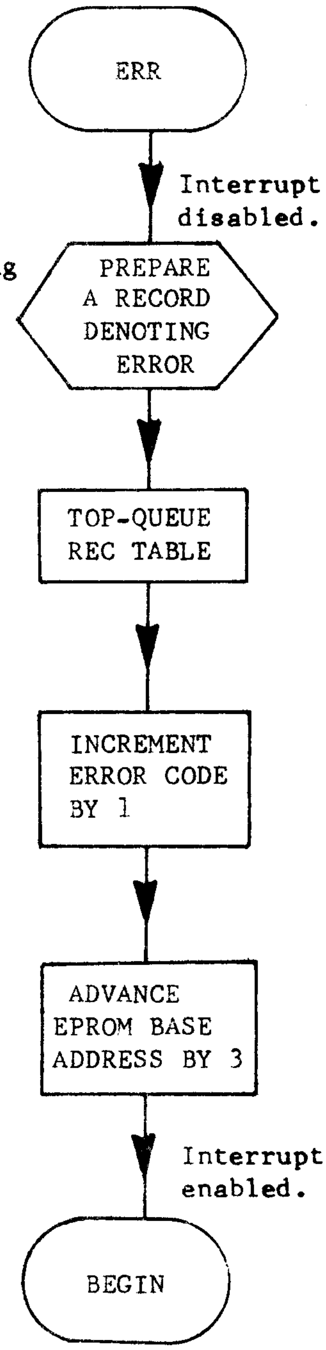


Flowchart 4 (cont'd) : Normal routine.

ERR routine

Prepare a record denoting error to REC Table for subsequent entry into EPROM. (Format 4).

See Table 1.



Flowchart 4 (cont'd) : Normal routine.

APPENDIX 2. POSSIBLE MODIFICATIONS

(a) If a rain-gauge with a different bucket size is used, the size can be specified in the constant 'BUCKET' (line 115 of the listing), which is expressed in tenths of a millimetre.

(b) The size of data memory can be specified as H'07', H'OE' or H'1E' for the value of the constant 'EPEM' (line 116 of the listing), according to different EPROM types - 2716, 2732 or 2764 respectively. It is necessary to make slight changes in the circuitry when either 2716 or 2732 is used. For 2716, just connect Pin 1 of the 28-pin EPROM socket to Pin 23. For 2732, interchange the bias resistors R14 and R26; disconnect Pin 22 of the 28-pin EPROM socket from Pin 9 of U5 and connect it to Pin 1 of the same socket.

(c) The system clock can be calibrated by changing the value of the pre-scalar constant 'PSLR' (line 119 of the listing). Suppose the clock is found to lag (lead) by y minutes a day, then the existing value of 'PSLR' should be decreased (increased) by an amount : PSLR.y/1440.

(d) The debounce timer is presently set at 2 seconds. If necessary, the existing value of the constant 'DBT' (line 121 of the listing) can be changed to correspond to the required time of debounce by direct proportion.

(e) The existing version of the recorder displays hourly rainfall with the total rainfall over the past hour retained on display for the first 15 minutes of the hour. To convert it to display accumulated rainfall twice daily at 9 a.m. and 3 p.m., it is necessary to make the following changes :

(i) Replace lines 400-406 by the following :

```
LISL 3   ;
LISU 4   ;  PREVIOUS R/F TOTAL WILL BE
            RETAINED ON DISPLAY BETWEEN
LR A, S  ;  9 AND 11 A.M. AND BETWEEN
LISL 2   ;  3 AND 5 P.M.
LISU 2
CI H'09'
BZ TIO3
CI H'10'
BZ TIO3
CI H'15'
BZ TIO3
CI H'16'
BZ TIO3
```

(ii) Delete lines 441-452. Insert the following after line 475 :

```
LISL 0   ;  MOVE PAD 20-21 TO 22-23
LISU 2
LR A, S
LISL 2
LR D, A
LR A, S
LISL 3
LR S, A
CLR
LISL 0   ;  CLEAR PAD 20-21
LR I, A
LR I, A
```

The rainfall total between 3 p.m. the previous day and 9 a.m. and that between 9 a.m. and 3 p.m. will be retained on display during the periods 9 to 11 a.m. and 3 to 5 p.m. respectively.