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A MINI-COMPUTER SYSTEM FOR ENVIRONMENTAL NOISE ANALYSIS

by

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CONTENTS

A MINI-COMPUTER SYSTEM FOR ENVIRONMENTAL NOISE ANALYSIS

ABSTRACT

A mini-computer system to analyse environmental noise has been developed by the Transport and Road Research Laboratory. Although initially expensive the system can analyse data much faster and with greater accuracy, than conventional methods allow. This report gives the salient features of the system hardware, and describes in detail the mode of execution of the assembly language noise analysis program.

1. INTRODUCTION

Development of the Transport and Road Research Laboratory's computer-controlled system for environmental noise measurement is now complete. This report, though intended primarily as a user's guide to the system, may also be of interest to those concerned with noise analysis or mini-computer applications.

The system, which is a development of the earlier system,(1) comprises 8 slightly modified Bruel and Kjaer (B & K) type 4920 outdoor microphone units, 8 B & K type 2607 measuring amplifiers, and a Texas Instruments 960A mini-computer. The outdoor microphone units convert sound pressures into electrical signals which may be transmitted over distances of several hundred metres by cable to the B & K 2607 measuring amplifiers. Here the signals are 'A'-weighted, rectified and 'logged', resulting in a d.c. output proportional to dB(A). Under control of specially written software the computer repeatedly scans the measuring amplifier outputs and, after a pre-determined interval, analyses the data, then prints out for each operative signal channel the values of the current indices of traffic noise.

The Bruel and Kjaer type 2607 amplifier is a flexible measuring instrument and the analysis of signals other than from the outdoor microphone unit is possible. Particularly useful is the capacity of the system to automatically analyse large quantities of tape recorded noise. Up to eight recordings may be analysed simultaneously, one through each measuring amplifier, with an overall precision better than that of the more conventional chart recorder/statistical analyser technique.

As the system hardware is adequately described in the manufacturers handbooks this report deals mainly with the specially written software. The software comprises two assembly language programs, both of which are required to run the system – a 'supervisor' program and a 'worker' program. As the supervisor program exists only to facilitate the running of the worker program, e.g. by handling input/output of data, providing time of day information, performing floating point arithmetic and so on, it is of little interest in the context of this report. It is sufficient to say that the building blocks of the supervisor program were supplied by Texas Instruments along with the 960A computer. The appropriate 'blocks' for the noise monitoring application were linked together by the author to form a unique program named PAM-MC.

The assembly language worker program was written by the author. It controls the way in which data is sampled, coded and stored, the display of information, and the analysis of data and output of results. Most of this report is given to describing the worker program and detailing the procedure necessary to load, modify and run it in the 960A computer.

Practical details on setting up the equipment to analyse noise from both the outdoor microphone unit and a tape recorder such as the Nagra IVS are given.

2. DESCRIPTION OF THE WORKER PROGRAM

A simplified flow chart of the program is shown in Fig. 1 and the real-time diagram in Fig. 2.

When the program is installed in the computer (see Appendix 3), 64 words of memory are automatically reserved for each of 16 possible signal channels. Each word is to represent one cell of a noise level histogram which covers the range 0–100 dB(A). Thus the cells have a width of 100/64, or 1.5625 dB(A).

When the program is executed, it first of all zeros the count in each histogram cell and initialises other areas of data storage. This takes about 10 ms. Next the digital display panel thumb-wheel switches and computer front panel switches are read, and the information stored in memory. The user's setting of the sixteen front panel switches indicates whether each signal channel is 'ON' or 'OFF', and the display panel switches indicate which channel reading to display and also whether or not the channel is being calibrated. All sixteen channels are then scanned. A 12-bit conversion of the analogue voltage representing the sound level is taken from each one. What next happens to the reading from a particular channel depends on the state of the channel at the time of reading. There are five possibilities and these are summarised in Table 1. Normally the channel will be 'ON' and then a bias is added to the reading. This is necessary since the B & K 2607 amplifier has an output of 0 – 4.5 volts which corresponds to a dynamic range of 50 dB(A), say from 40 to 90dB(A). To obtain a reading which is directly proportional to dB(A) it is necessary to add on a voltage bias equivalent, in this case, to 40dB(A). Next the 'biased' reading, held in binary notation, is shifted six places to the right (e.g. $110\ 010\ 011\ 110_2$ becomes $000\ 000\ 110\ 010_2$) leaving a 6-bit binary integer with a value between 0 and 63, and this integer is used as a pointer to locate the appropriate cell in the 64 cell histogram. The count in this cell is incremented by one.

TABLE 1

Summary of possible states for channel number X. ($0 \leq X \leq 15$)
Refer to Appendix 4, and Fig. 7 for display panel diagram

CHANNEL X STATUS	COMPUTER FRONT PANEL SWITCH, X	DISPLAY PANEL THUMBWHEEL SWITCHES	CALIBRATE SWITCH	PROGRAM ACTION TAKEN
On	Up	Not X	+ or –	Data put in histogram
Off	Down	Not X	+ or –	Data ignored
On/Display	Up	X	+	Data put in histogram, and also displayed at preset intervals
Off/Display	Down	X	+ or –	Data displayed at preset intervals, otherwise ignored
On/Display/ Calibrate	Up	X	–	

Executing a 16-channel scan, processing the data, and displaying in digital form the reading in one selected channel fully occupies the computer for approximately 15 ms. The computer then idles for what remains of 100 ms timed from the start of the scan, ie a wait of about 85 ms, before starting another scan.

On completing a pre-determined number of scans (usually 32 000, which takes just over 53 minutes) the program reduces the collected histogram data to the currently used indices of traffic noise. Appendix 1 shows the linear interpolation method used to estimate the basic indices L_{10}, L_{50}, L_{90} from a histogram of noise levels. In effect the program constructs the frequency polygon to fit the histogram data, then reads off the first, fifth and ninth deciles which are by definition L_{90}, L_{50} and L_{10}. NC and TNI are calculated directly from these basic indices:

$$NC = L_{10} - L_{90} \quad \text{..........} \quad (1)$$

$$TNI = 4.NC + L_{90} - 30 \quad \text{.....} \quad (2)$$

Having calculated the basic indices, all of which are either deciles, or are derived from deciles, of the distribution of sound levels, there remains the calculation of L_{eq} (the level of equivalent mean energy) and the related index L_{NP} (noise pollution level).

The expression used to evaluate L_{eq} is:

$$L_{eq} = 10 \log_{10} \left[\frac{-1}{100} \sum_{i=0}^{i=63} f_i . \ 10^{L_i/10} \right] \quad \text{............} (3)$$

where L_i = median sound level (dB(A)) of the i^{th} histogram cell.

$10^{L_i/10} \propto$ mean intensity of the i^{th} histogram cell.

f_i = per cent of the time that a fluctuating sound level is in the i^{th} cell.

Since the computer supervisor program does not have the facility of taking logarithms, a simple method is used to calculate the 'intensity' ($10^{L_i/10}$) at each of the cell mid-points. When the program is installed in the computer, the intensity I_o at the mid-point of cell zero is stored in memory. Then to calculate the intensity at the mid-point of cell 1, 2, etc.

$$I_0 = 10^{Lo/10} = 10^{\frac{1.5625/2}{10}}$$

and $$I_1 = 10^{\frac{1.5625 + 1.5625/2}{10}} = I_0^{\,2} \times I_0$$

and $$I_2 = I_0^{\,4} \times I_0$$

At the mid-point of cell i the 'intensity' is therefore:

$$I_i = I_0^{(2_i + 1)} \quad \text{..................} \quad (4)$$

and L_{eq} is calculated from the summation:

$$A \log \frac{L_{eq}}{10} = \frac{1}{T} \sum_{i=0}^{i=63} t_i . \ I_0^{(2_i + 1)} \quad \text{..................} \quad (5)$$

where T = total number of samples

t_i = number of samples in cell i.

To determine L_{NP} it is necessary to calculate the standard deviation, σ of the data since $L_{NP} = L_{eq} + 2.56.\sigma$. σ, in units of histogram cell widths (1.5625 dB(A)) is calculated using the formula:

$$\sigma^2 = \frac{\sum_{i=0}^{i=63} i^2 . t_i}{T} - \left[\frac{\sum_{i=0}^{i=63} i . t_i}{T} \right]^2 \quad \ldots\ldots\ldots\ldots\ (6)$$

The noise indices for each channel are output in the form shown in Fig. 3. L_{10}, L_{50}, L_{90}, NC and TNI are read directly from the printed output. To save programming effort the calculations of L_{eq} and L_{NP} are not carried through to the end within the computer, and it is necessary to carry out a simple separate calculation on the result labelled LEQ to obtain L_{eq} and L_{NP} (see Appendix 1).

After printing the results for each channel, the program requests the time of day from the supervisor program PAM-MC at 0.1s intervals until the minutes part of the information indicates the start of the next hour by changing from 59 to zero. Having completed a full cycle the program branches back to the start, re-initialises data storage areas, and starts scanning for another hour.

3. USING THE WORKER PROGRAM

The necessary hardware configuration required to run the program is listed in Appendix 2, and step by step instructions on how to load the program into the computer starting from a complete shutdown are given in Appendix 3.

In between loading the program and executing it, the user has the option of making several minor, but often useful, modifications to the program to suit a particular task. As loaded, the program will run as described in Section 2, and is most suitable for the usual type of field measurement in which traffic noise indices are calculated at hourly intervals for 24 hours, and noise levels generally stay within the range 40–90 dB(A). The salient features of the program are:

1. 0.1s interval between 16-channel scans
2. 32 000 scans (≃ 53 mins) before processing
3. 0.5s interval between change of digital display
4. accepts noise levels in the range 40 – 90 dB(A) from B & K 2607 measuring amplifier.
5. after printing out results, waits until the beginning of the next hour before restarting.

Each one of these features may be quite simply altered once the program is in the computer. Appendix 4 gives details of how the modifications are made, and also states the permissible extent of the modifications.

A typical application requiring some of the modifications is the analysis of tape recorded noise, for which the number of scans before processing will generally be about 6000 (i.e. 10 mins), the operating range of the measuring amplifier may need to be changed from tape to tape, and the idle time after print out is not required.

Appendix 5 shows how the whole system is set up for analysing signals from the B & K outdoor microphone unit type 4920, and also from the Nagra IVS tape recorder.

4. ACKNOWLEDGEMENTS

The work described in this report was carried out in the Environment Division (Division Leader: L.H. Watkins) of the Transport Systems Department of the Transport and Road Research Laboratory.

5. REFERENCE

1. CHEESEMAN, M. and P.M. NELSON. A data-logging system for the measurement of road traffic noise. Department of the Environment, TRRL Report LR 479. Crowthorne, 1972. (Transport and Road Research Laboratory).

6. APPENDIX 1

a) Linear interpolation method for estimating L_{10}, L_{50}, L_{90}

b) obtaining L_{eq} and L_{NP} from the output

a) See Figure 4

$$\text{"Tan } \phi\text{"} = \frac{\text{TALLY}}{1.5625} = \frac{R_1 - (\text{CUMUL} - \text{TALLY})}{X}$$

$$x = 1.5625 \left[\frac{R_1 - (\text{CUMUL} - \text{TALLY})}{\text{TALLY}}\right]$$

and $$L_{10}(L_{50}, L_{90}) = 1.5625 \left[X + \frac{R_1 - (\text{CUMUL} - \text{TALLY})}{\text{TALLY}}\right] \ldots\ldots\ldots\ldots (1)$$

For example, in order to calculate L_{10} for the output shown in Fig. 3 the cumulative frequency to the top of cell 35 is 85.78 per cent, and to the top of cell 36 92.22 per cent. Therefore L_{10} lies within the range covered by cell 36. Substituting in equation (1) above gives

$$L_{10} = 1.5625 \left[36 + \frac{90 - 85.78}{6.44}\right]$$

$$L_{10} = 57.27 \text{ dB(A)}$$

b) To save programming effort the calculations of L_{eq} and L_{NP} are not completed by the computer program. To calculate these indices for the example shown in Fig. 3 requires the following steps:

From the print out: LEQ = +.259600 E 06/0406
$= 2.596 \times 10^5/406$

$$L_{eq} = 10 \log_{10} (2.596 \times 10^5)$$
$$= 10 \times 5.4143 = 54.14 \text{ dB(A)}$$

$$L_{NP} = L_{eq} + \tfrac{1}{2} \sqrt{406}$$
$$= 54.14 + 10.08 = 64.22 \text{ dB(A)}$$

7. APPENDIX 2 — Hardware Configuration

1. T.I. 960A computer with 8K memory and arithmetic option board
2. Remex 300 cps paper tape reader
3. Silent 700 data terminal set at 30 characters per second
4. Digital display panel (see Figure 7)
5. CRU printed circuit modules:

Module	CRU slot	Purpose
16 channel ADC 15V power supply	EFB) EFF)	Analogue to digital converter
Input data, 32 in Output data, 32 out	EF8) EF7)	digital display panel
Data, 16 in/16 out	EF6	high speed punch
Data, 16 in/16 out	EF4	high speed Remex reader
Interval timer	EF3	system clock
Full duplex TTY/E1A	EF0	Silent 700 data terminal

8. APPENDIX 3 – Computer cold-start and program loading procedure

For detailed information refer to the following Texas Instrument manuals:

1. "Basic Programming guide for the series 960 computers"
2. "Process Automation Monitor (PAM) for the model 960A computer"
3. "Programmers reference manual for the model 960A computer"

For the locations of computer front panel switches see Fig. 5. Unless otherwise specified all numbers are in *hexadecimal* notation (i.e. to base 16).

1. Initialisation	**2. ROM + High speed tape bootstraps**	**3. PAM-MC (see Fig.6)**	**4. Worker program (see Fig.6)**
Key switch to UNLOCK		HALT, RESET	place worker program
battery power ON	MA to 0400	place PAM-MC tape	tape in reader.
mains power ON	ST to 01C0	in Remex reader.	enter JCON (job
HALT, RESET	Push RESET to LOAD	MPO ON	control)
enter 'clear' program:	display ST – 01C0?	set:	$$LDTS**0100**0090
MA MD	(restart at 2/if	7D 7C00	/*
80 4881	not) set:	7E 0C43	start reader, program
81 0090	PC 04C0	7F 0C40	will load
82 4C81	85 04C0	80 0C40	(modify program –
			optional)
83 0001	86 0000	ST 01C0	$$INST**0090**0090
84 7082	87 0F40	PC 0002	$$ABLE**0090
85 0080	ST 01C0	RUN, START	$$EXCT**0090
RESET	MPO ON	PAM will ask for	
PC to 0080	place HSPT boot in	time + date	program is started.
	reader.		
ST to 01C0	RUN, START	Define system	To delete the program:
		LUNOS: see Fig.6.	
MPO ON	04C6 displayed?	0002 0000	
RUN, START	(if not restart	0003 0002	$$DLTS**0090
	2/)		
HALT after 0.1 sec		0008 0004	
CHECK MA = MD	MPO OFF	0009 0000	
for a few locations.		000F 0000	

Note: After being loaded, PAM-MC immediately starts and requests time and date information. Only the hour and minute are relevant to the analysis of noise. Then, in order to load and run the worker program the system LUNOS are defined. Fig. 6 shows the necessary sequence of operations to load and execute the worker program.

9. APPENDIX 4 – Program Modification

It is assumed that the program is loaded at X'0100'. If it is loaded elsewhere then the locations given below must be changed by the difference between the new load address and X'0100'. For example if the program is loaded at X'00B0' then subtract X'0100' – X'00B0' (X'0050') from each location given below. Refer to Figure 6 for examples of program modification.

1. Scan rate

The interval between 16-channel scans is determined by the contents of memory location X'0122'. Normally the interval will be 0.1s but it may be changed to any multiple of 0.1s.

Interval(s) = (1 + contents of X'0122')/10

2. (a) Number of scans before processing

This may be set to any number in the range 1000 to 32767. Normally it is set to 32 000 which gives nearly one hour's scanning at 0.1s scan interval. The lower limit of 1000 is imposed by the accuracy of analysis – the program is not 'scaled' for lower numbers. The upper limit was taken for convenience as the capacity of a 16 bit word.

No. of scans = 1 + contents of X'0689'.

(b) Number of scans remaining

On executing the program the contents of X'0689' are transferred to X'011A' and the value in X'011A' decremented after each 16-channel scan. Analysis and printout commences when the value in X'011A' goes negative. The value in X'011A' may be altered when the program is running to either shorten or prolong the scanning stage of the program. Fig. 6 shows how this facility can be used.

3. Idle time after printout

After printing out the results the program will wait until the end of the current hour before restarting data collection. To eliminate this idle stage involves the following terminal entry before program execution: LMHA 0A26 7082 0680. This is shown in Fig. 6.

4. Display Panel

Figure 7 shows the functions of the digital display panel. Digits d_1–d_4 display the time of day in hours and minutes, and digits d_5, d_6 and d_7 display the latest reading from the channel indicated by the setting of thumb-wheel switches s_1 , s_2 . The program may be altered to display other relevant information. For example to display minutes/seconds instead of hours/minutes in d_1–d_4 the following entries are made:

LMHA 074B 0176

LMHA 0731 0177

Another useful display is a count down of the time remaining before analysis and printout of results. To obtain a count down display in d_3, d_4 the entries shown in Figure 6 are made.

As loaded, the program will update the display panel reading after every fifth scan, i.e. at half second intervals at the normal 0.1s scan interval. The program can be changed to update the display at intervals of any multiple of the scan interval.

display interval(s) = contents of X'06F7' x scan interval

The example shown in Figure 6 is correct to display minutes in d_1, d_2, countdown in d_3, d_4, and dB(A) in d_5, d_6, d_7. The display will be updated at 0.2s intervals.

5. Bias

The bias for a channel is the value added on to each reading from that channel; and corresponds to zero deflection on the B & K 2607 measuring amplifier. To calculate the correct input for a bias of x dBA:

$$\text{BIAS} = \frac{x}{100} \times 3686$$

e.g. for 34 dB(A)

$$\begin{aligned} \text{BIAS} &= 34 \times 36.86 \\ &= 1253.2 \\ &= \text{X'04E5'} \end{aligned}$$

BIAS for channel zero is stored at X'0240', for channel 1 at X'0241' and so on. In order to change the BIAS of, say, channel 14 to 34 dB(A) the correct entry is:

LMHA 024E 04E5. Fig. 6 shows the stage at which such an entry is made.

10. APPENDIX 5 – Analysing signals from B & K 4920, Nagra IVS

a) **B & K 4920**

Equipment – B & K outdoor unit, cable transmitted signal fed via Input Transformer (e.g. B & K type T10001) to Direct input socket of B & K 2607 measuring amplifier.

1. B & K 4920 = set range to '90'
2. B & K 2607 = Gain control – Cal., Input –1V
   Direct Input, 'A' – weighting, Output – x 0.3, Meter function – RMS,
   Averaging time – Fast, Log output, DC output.
3. Load and execute worker program (see Appendix 3)
4. Activate electrostatic calibrator on B & K 4920. Adjust Direct input sensitivity of B & K 2607 to give full scale deflection (i.e. 50 on 'log' scale), and check that digital display reads 90 dB(A).
5. To analyse the signal, set appropriate computer panel switch to the up position. (Switch 0 is for channel 0, 1 for channel 1, and so on).

b) **Nagra IVS**

Equipment – Nagra IVS tape recorder, line output to Direct input socket of B & K 2607 measuring amplifier.

1. Nagra IVS – Level, Flat, Mono, Line, Normal, Direct, External power, Line output to B & K 2607.
2. B & K 2607 = Gain control – Cal., Input 1V, Direct Input, Output – x 0.3, Meter function – RMS, Averaging time – Fast, Log output, DC output. If recording is 'A' weighted use only h.p. and l.p. filters; if recording is linear use 'A' – weighting filter.
3. Load and execute the Worker program (see Appendix 3).
4. Enter program options (see Appendix 4).
5. Set Nagra to 'Playback' – Adjust volume control so pistonphone signal reads –10dB on modulometer. Adjust Input sensitivity of B & K 2607 to give a reading of +40dB (log scale) and check that the digital output reads correctly. The digital readout should be 4dB above the recording level – e.g. if noise was recorded on '80A' then the digital readout should be 84.
6. To analyse the signal set the appropriate computer panel switch to the up position. Data may be censored by setting this switch to the down position. Whilst the switch is down, no data is stored. At the end of the recording set the switch down and enter:

   OP? LMHA 011A 0099 carriage return
   OP? carriage return

   and shortly afterwards the data is analysed and results printed out.

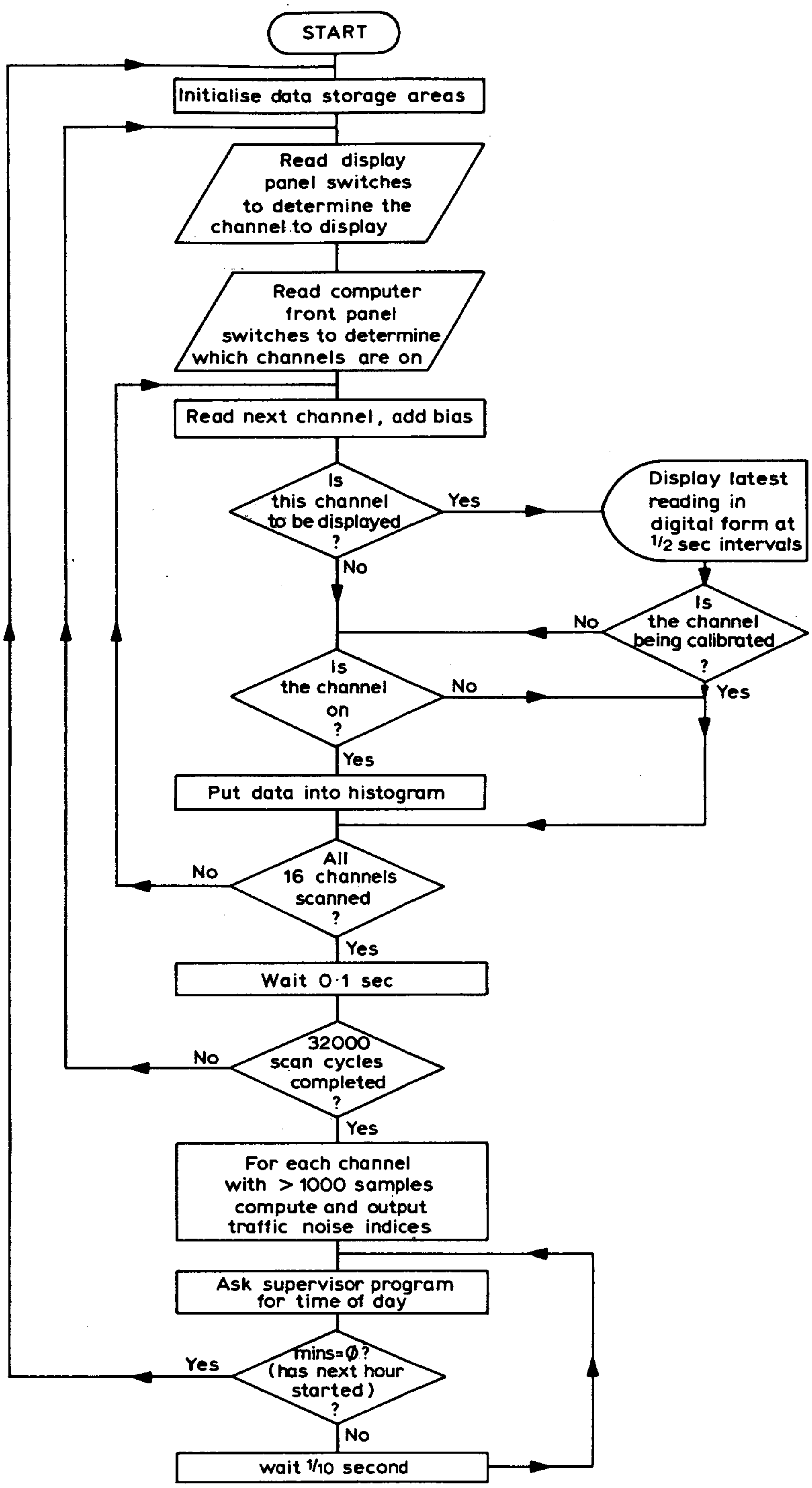

Fig. 1. FLOW CHART OF THE PROGRAM

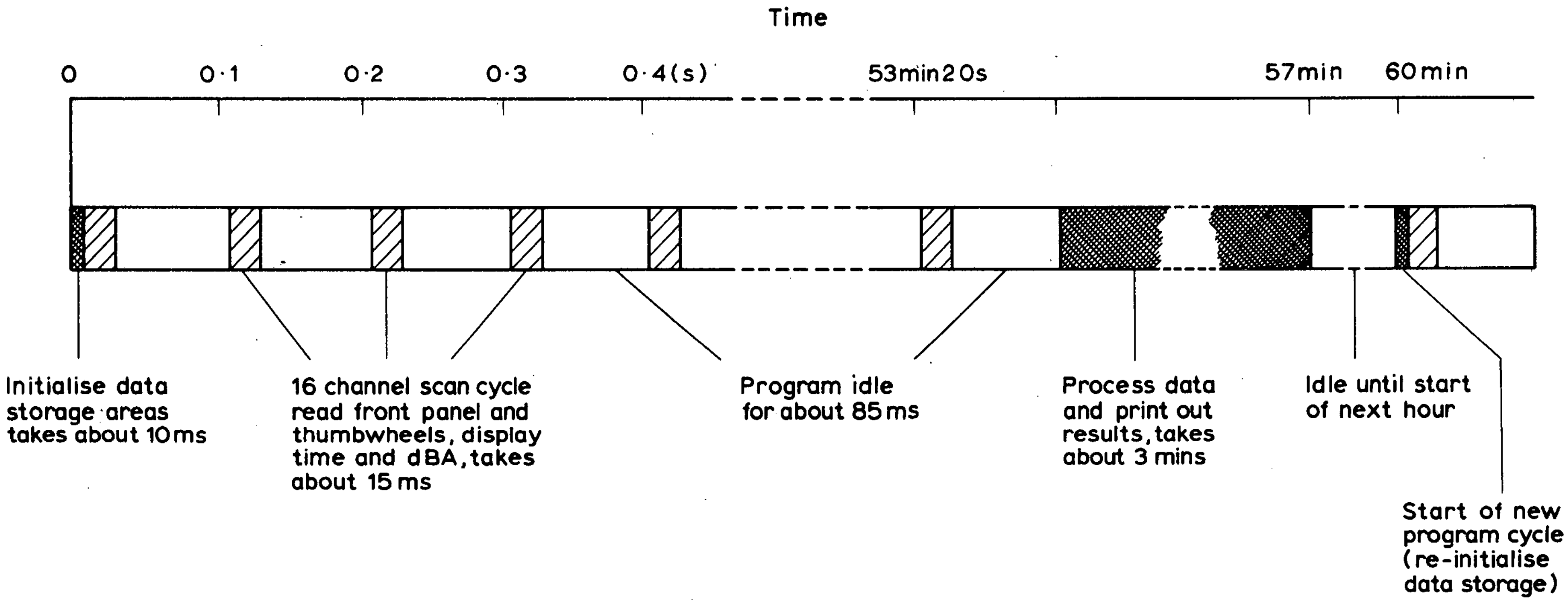

Fig. 2. READ - TIME DIAGRAM OF THE PROGRAM

```
CHANNEL 14        TIME RANGE  1200- 1300 HOURS



26   00.36
27   01.48   00
28   04.20   00000
29   08.25   00000000
30   15.31   00000000000000
31   25.31   00000000000000000000
32   40.56   000000000000000000000000000000
33   56.68   00000000000000000000000000000000
34   73.85   0000000000000000000000000000000000
35   85.78   000000000000000000000000
36   92.22   0000000000000
37   95.78   0000000
38   98.29   00000
39   99.35   00
40   99.66
41   99.83
42   99.90
43   99.92
44   99.96
45   99.96
46   99.98
47   00.00


              +         +         +         +         +
% APPROX  -   0         5        10        15        20


L10 = 57.26 DBA      L50 =  52.47 DBA      L90 =  47.26 DBA

 NC = 10.00 DBA      TNI =  57.29          LEQ =  +.259600E+06/ 0406
```

Fig. 3 EXAMPLE OF OUTPUT

TALLY = Contents of cell number X

CUMUL-TALLY = Cumulative frequency up to, but not including cell X

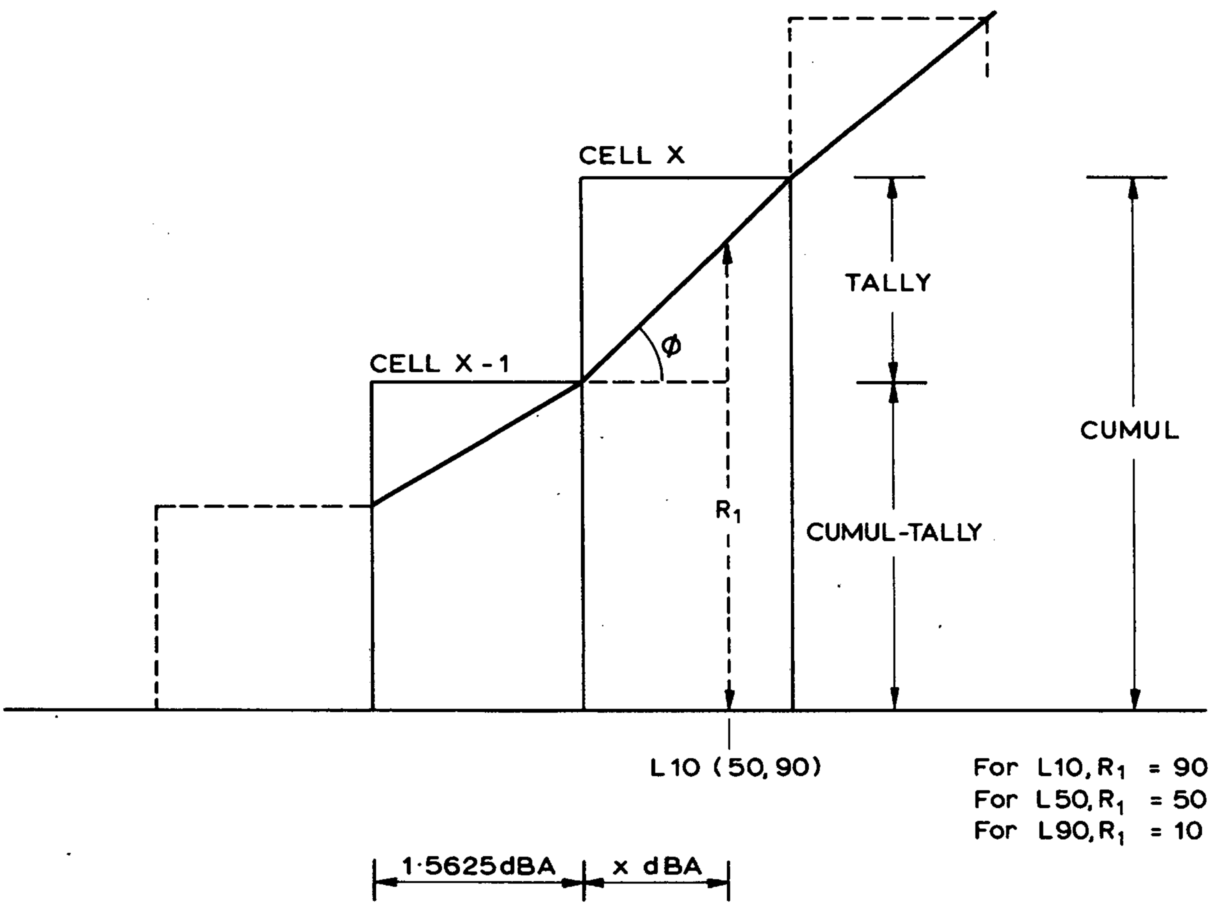

Fig. 4. CUMULATIVE FREQUENCY HISTOGRAM

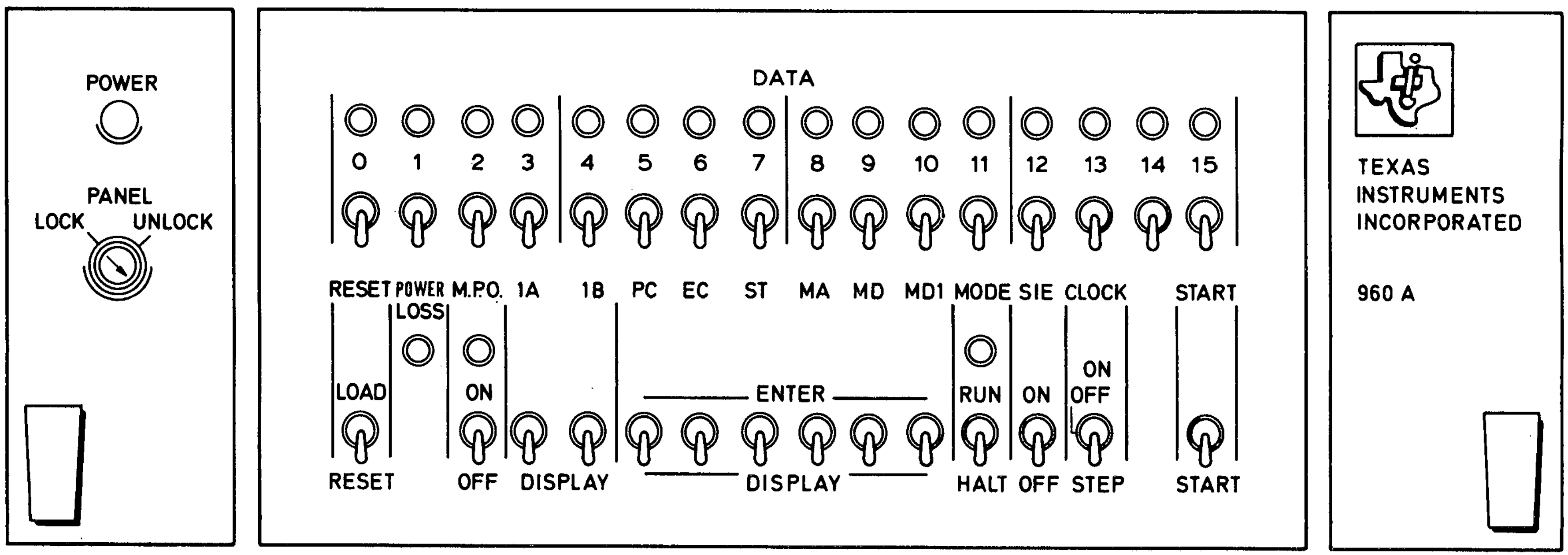

Fig. 5. THE 960 A COMPUTER CONTROL PANEL

```
ENTER YEAR   1973
ENTER DAY    0153
ENTER HOUR   0008
ENTER MIN    0040
```

Correct entry for 08.40 June 2 1973

```
!
OP? DFIO  0002  0000
OP? DFIO  0003  0002
OP? DFIO  0008  0004
OP? DFIO  0009  0000
OP? DFIO  000F  0000
```

Define system LUNOS 2,3 and 8 are for the job control (JCON) program, 9 is for on-line DEBUG and F is for the noise analysis worker program

```
OP? JCON
JC BID
££LDTS**0100**0090
/*
```

Load worker program at X`0100´ using high speed reader. Once loaded the program is labelled 0090

```
!
OP? LMHA  0122  0001  '
OP? LMHA  0689  270F  '
OP? LMHA  0A26  7082  0680  '
OP? LMHA  06F7  0001  '
OP? LMHA  024E  04E5  '
OP? LMHA  074B  0176  '
OP? LMHA  076E  141A  90A9  6407  01A9  '
OP? LMHA  0731  01A9  '
```

Optional program modification. This example gives:- 1) 0·2s scan interval 2) 10,000 scans 3) no wait after printout 4) 0·2s display interval 5) 34dB bias in ch.14 6) minutes and countdown displayed

```
OP? JCON
JC BID
££INST**0090**0090
££ABLE**0090
££EXCT**0090
```

Execute the worker program

The following entries are optional

```
!
OP? LMHA  011A  1500  '

OP? '

TERMINATE
```

1) Analyse data and printout results after a further X`1500´ scans (ie about 18 minutes at the 0·2s scan interval)

⟶

```
!
OP? JCON
JC BID
££DLTS**0090
```

2) Delete the program

```
!
OP? JCON
JC BID
££INST**0090**0090
££ABLE**0090
££EXCT**0090
```

3) Re-install and execute the program

```
!
OP? LMHA  011A  1100  '
OP? '
TERMINATE
```

4) Analyse data and printout results after a further X`1100´ scans (ie about 14 minutes at the 0·2s scan interval)

⟶

Note:- 1) A printout has been suppressed at the points marked ⟶

2) This listing is taken from an ASR 33 teletypewriter. When using the Silent 700 printer, replace £ by $

Fig.6 TELEPRINTER OUTPUT SHOWING THE OPERATIONS REQUIRED TO LOAD, EXECUTE AND MODIFY THE WORKER PROGRAM

d_1 - d_7 are decimal nixie tube displays
S_1 - S_4 are 10 way thumbwheel switches

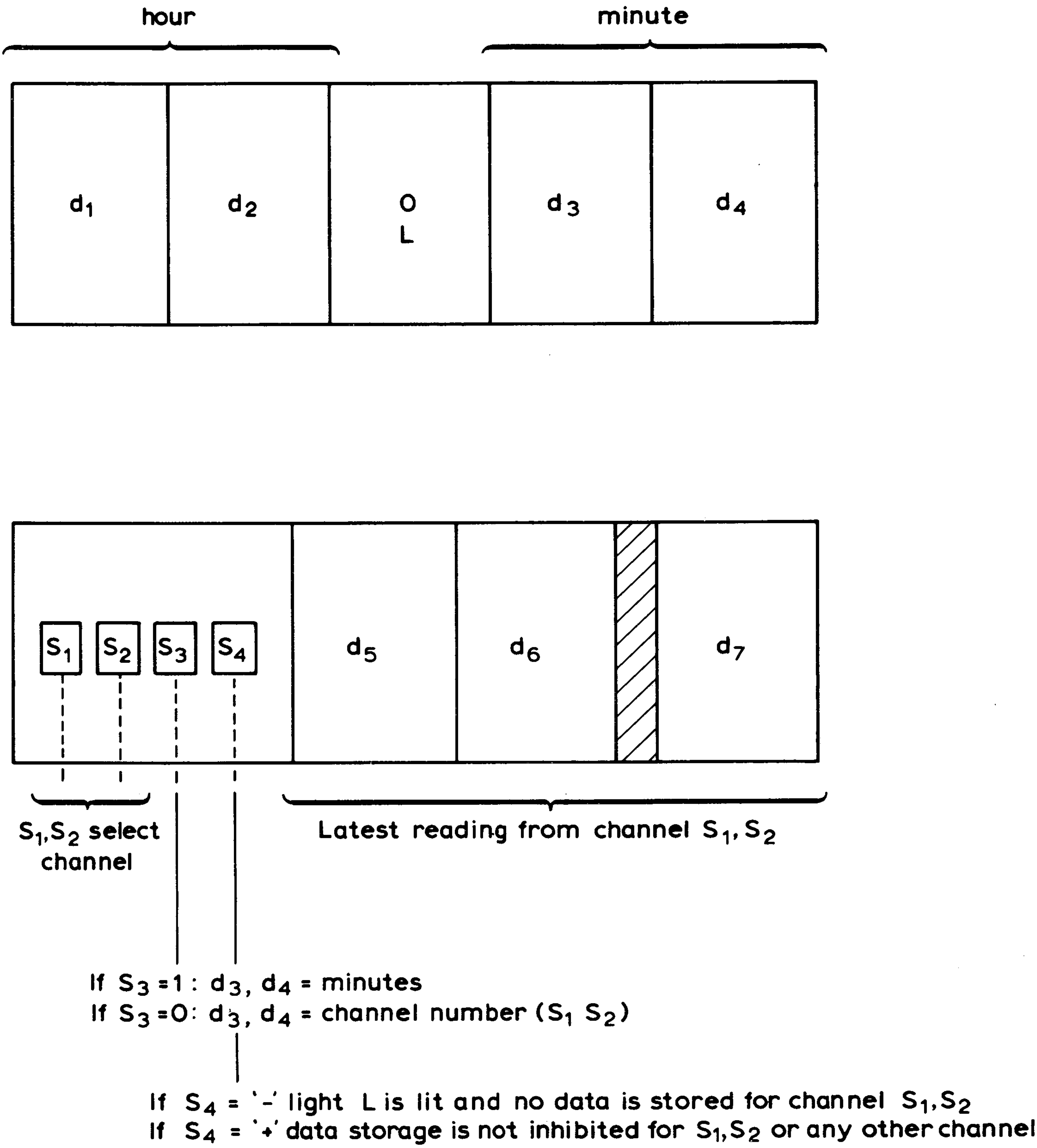

Fig. 7. DIGITAL DISPLAY PANEL

(938) Dd635247 600 6/74 HPLtd., So'ton G1915
PRINTED IN ENGLAND

ABSTRACT

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