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P. Allen, L. Barone, I. Laakso, F. Marcelja, G. Piredda, V. Rossi, G. Susinno, L. Votano and L. Zanello :

BASIC DATA ACQUISITIVE ROUTINES FOR PEPR.

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ABSTRACT.

A detailed account is given of the routines which directly command the PEPR hardware and receive back the results of the sweep.

1. - INTRODUCTION.

In this note we describe in some detail the data acquisitive (hardware contact) routines through which the user gives specific commands to the PEPR hardware and receives information on the results. A brief general description of the DEC PDP 11/45 Computer and PEPR is given in Ref. (1), where examples of the use of these routines in particular cases may be found. In general the function of the data acquisitive routines, is merely to obey limited commands given at a higher level. They are at the lowest level of the hierarchy. All decisions relating to the overall strategy of event handling and track following are made in the calling routines.

The computer "sees" PEPR as a Digital Controller of 32, 16 bit registers, each of which has an address in the computer's "external page". A summary of the usage of the individual registers is given in Appendix A. Further details of their construction and use may be found in Refs. (2) and (3). The registers are connected to the standard DEC UNIBUS by means of an M 1710 Unibus Interface Foundation Module. This enables input to the computer to be made via a Jam Command and output to be taken from the computer via a Strobe Command. In addition some of the registers (indicated with an asterisk in Column 3 of Appendix A) have access to a hardware processor or logic box (called the Spare). This allows operations (called J* operations), to be performed on contents of the registers. These operations include, incrementing, decrementing, comparing the contents of two registers and generation of the sine and cosine of an angle(4). The PEPR hardware also includes two auxiliary memories each of 128 8 bit words. It is possible to perform J* operations to read the contents of these memories into some of the registers.

In order to make measurements, the spot/line made by the Cathode Ray Tube must be deflected. The motion is produced in two stages : i) a main deflection to one of 2^{16}x2^{16} addressable

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(x) Istituto di Fisica dell'Università di Roma.

points on the face of the CRT. The Main Deflection Unit (MDU) is about 2.5 μ; ii) by setting up a scan cell to sweep about the addressed point in units of an Interpolation Count (IC). The maximum extent of the scan cell is $\pm$ 64 ICs but the user may limit its range by imposing lower and upper gates. When the spot/line crosses an object on the film the light received by a photomultiplier (PM) placed behind the film varies in intensity. The resulting signal is divided in an analog divider by the averaged signal of four reference PMs which monitor the light output of the CRT. This circuitry is regulated to give a signal proportional to the image density. Then a variable background (pedestal) is subtracted, using the technique of a dummy sweep with a defocussed spot. The digital sampling is performed at 128 points along the sweep, and is stored into one of the memories. During the following measuring sweep, which takes place in the opposite direction in the same cell the pedestal values are reconverted to analog form and subtracted from the signal. Finally the difference signal is converted to digital form for treatment by the digital Processor. To be acceptable, the signal must exceed a pre-set digital threshold, and its width at this point must be within a given limit, and be contained within the gates of the scan cell.

2. - COMMON FEATURES OF THE ROUTINES.

There are two data acquisitive routines, SCAN and MSCAN. The former is used to make a general search of a large area whose contents are unknown, and where one may expect to find several objects. It would be used for example to search for beam tracks at the entrance of the chamber. MSCAN is employed to search in a smaller area, when we already have a reasonable prediction of where to find the expected object. This is the case for example in looking for fiducial marks or following a track on the basis of say, a circular model. Both routines use the same set of registers, in a similar manner. For this reason, the routines have been written as entry points in the same subroutine, along with several other entry points, which initialize the registers for both.

2.1. - Initialization of the Registers.

There are four entry points which receive the values of parameters specified by the higher level user, and transfer them to the PEPR registers. Before any call to SCAN or MSCAN the user must call one or more of these entry points depending on which parameters he wants to change. Generally speaking he will nearly always call MSAB and MSIAFA, and often MSMODE as well. Calls to MSREG are less frequent.

2.1.1. - ENTRY MSAB.

The user gives the coordinates of the centre of the scan cell (see Fig. 1a) in units of MDU. They are written in REGS. XRD and YRD, whence they are converted to analog form, to drive

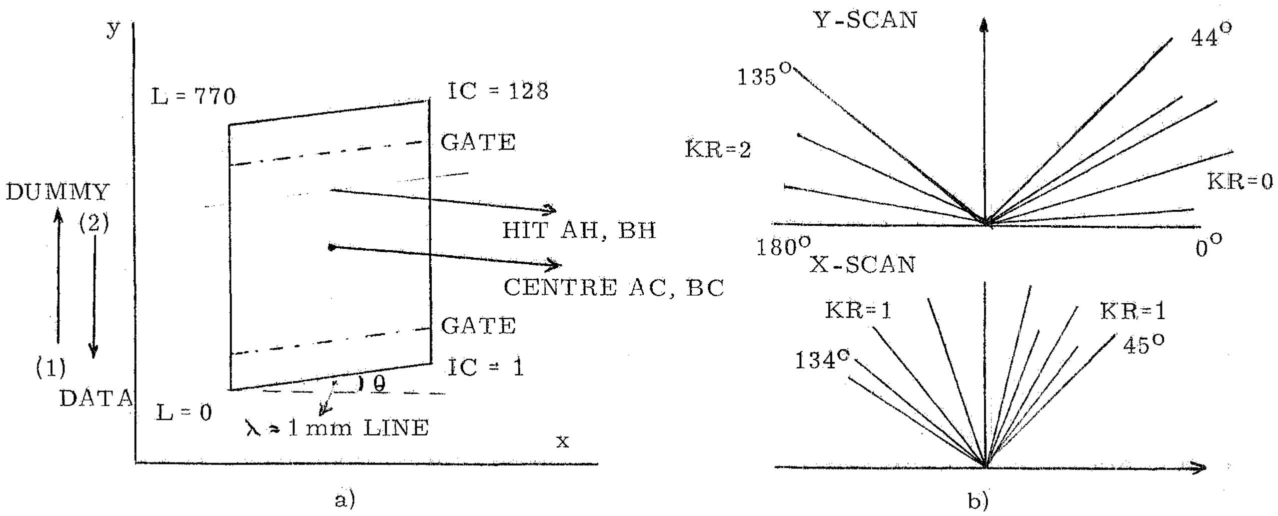

FIG. 1 - a) Geometry of a typical scan cell; b) Range of angles for x and y sweeps.

the deflection coils in the CRT. If the user has set a flag (Sect. 2.2) corrections are calculated for the dynamical focus (REG. FUS) and dynamical astigmatism (REGS. ASGX and ASGY) of the beam at the centre of the cell (x, y).

The correction current for the focus is of the form

$$dI_F = a_o(x^2 + y^2) + a_1 - a_2.f(\lambda).$$

The corrections for the astigmatisms are of the form

$$dI_A = b_o + b_1x + b_2y + b_3xy + b_4x^2 + b_5y^2 .$$

The coefficients have been obtained by displacing the beam, varying the currents in the focus and astigmatism correction coils and fitting the results to the forms given above. The last term in the expression for dI_F depends on the length of the line. The values of the currents loaded in these registers are converted to analog form and used to drive the focus and astigmatism correction coils.

2.1.2. - ENTRY MSREG.

In this entry the user supplies parameters which need not be changed very frequently.

a) Select a bit in REG. MKB which can launch a hardware interrupt.

b) The number of sweeps (including dummies), to be executed at each angle. This is loaded in REG. RET.

c) The maximum acceptable track width, and minimum acceptable pulse height (discriminating threshold). These are given in interpolation counts and fast ADC units respectively and written into REG. WAT.

d) The lower and upper gates on the scan cell are loaded in units of IC into REGS. OCO and OCC (see Fig. 1a).

e) The brightness of the spot/line, and the attenuation of the output pulse. The brightness is controlled by specifying the number of steps (of 2 Volts) by which a grid voltage in the CRT is to be increased. The attenuation of the output pulse (after subtraction of the background) is determined with a programmable resistor in the amplifier sum mode. These are given in REG. GAI.

f) We give the dead-time in clock ticks of 0.5 μsec between the closing of a scan cell and the opening of the next scan cell around the same centre. This dead time is needed to allow for refocussing the spot/line after a defocussed dummy sweep, and to change the orientation of the cell. If N is the number written in the bits of REG. DLY reserved for this parameter the actual dead time comes out to be

$$DT = (16 \times N) + 8 \qquad \text{(Min = 8, Max = 120)}$$

and the duration of the sweep is

$$S = 128 + DT \qquad \text{(Min = 136, Max = 248)} .$$

In this register we also make an allowance, directly in ticks, for the delay, DL, between the digital and analog ramps which displace the spot/line during the sweeps (See also the following description of ENTRY MSMODE). It is valued between 16 and 18.

g) We specify if the averaging facility is to be used; if the histogramming facility is to be used; if the alternating dummy procedure for background subtraction is to be employed (it usually is). We also give in arbitrary units, the threshold hysteresis. When a pulse has exceeded the threshold a J^* operation subtracts the hysteresis from the threshold. This helps to ensure that a pulse does not appear to split by signal noise. This information is loaded into REG. CTB.

2.1.3. - ENTRY MSIAFA.

Here the user supplies the angular information for the series of sweeps.

a) The base angle IANG1 in degrees ($0 < \theta < 180$). This is converted into units of 255/180 = 0.7°, and written into the 1 byte REG. IAI.

b) The number of angular increments NSTP. This is written into REG. NAS.

c) The size of the angular increment IDEL, in units of 0.7°. This is written in REG. AST.

d) The direction of sweep, IPKAI = 0 for y sweep, 1 for x sweep. This is written into REG. CTA (It is also possible to make an oblique sweep at the angle written in REG. IAI. This facility is not used in routines described here).

We determine in which regions (KR = 0, 1, 2) of Fig. 1b the initial and final angles (IANG2) lie. If these regions (KINI, KMAX) are the same, the direction of the sweep is as indicated in the figure. If KINI and KMAX are different, then the intervening boundary is stretched by 15°. If this is not sufficient to enclose the entire angular range we make an error return (see Fig. 2). The direction of the sweep KAI found in the routine, overwrites the input value IPKAI and is written into REG. CTA.

During the subsequent sweeps a J^* operation increments the contents of IAI by the contents of AST, while the contents of NAS are decremented by one, having made the number of sweeps given by REG. RET. Thus REG. IAI always contains the current angle and REG. NAS the number of remaining steps. Also, when we are using the line element for data gathering, we command a J^* operation before the sweep to write cos(2×IAI) into REG. MAN and sin(2×IAI) into REG. NAN.

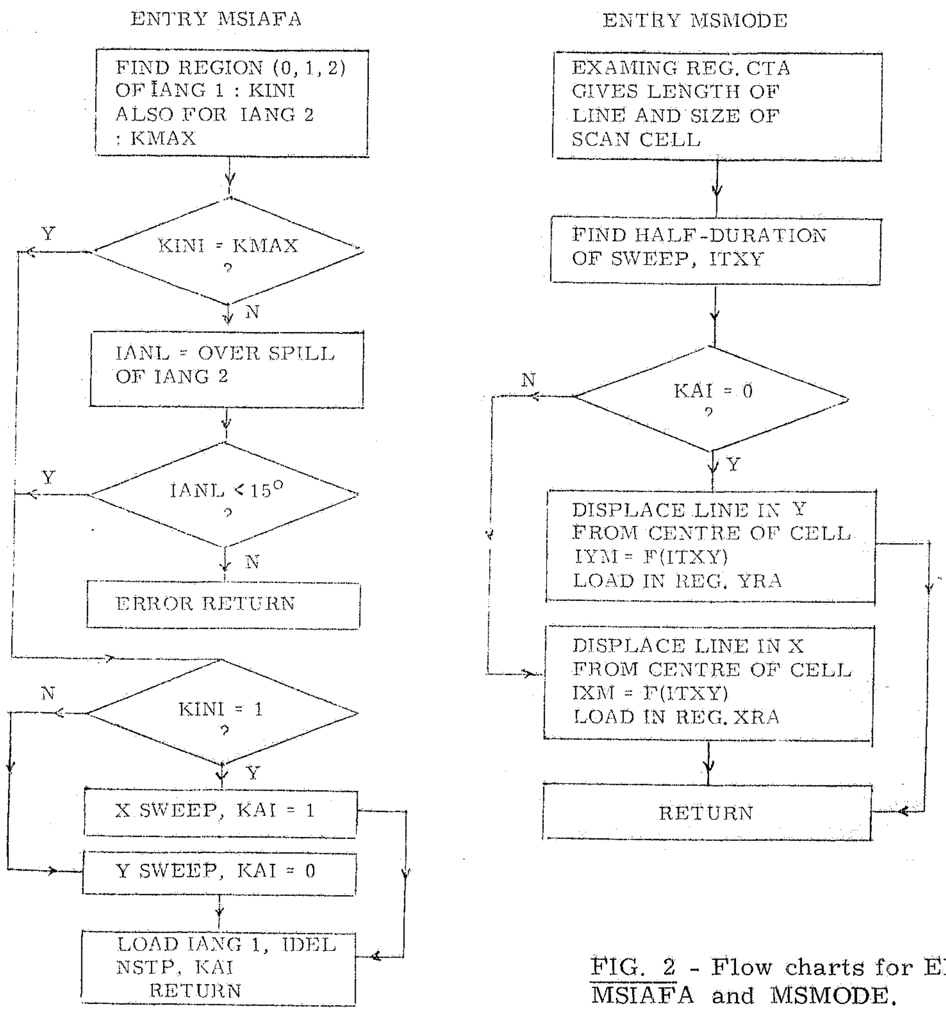

FIG. 2 - Flow charts for ENTRIES MSIAFA and MSMODE.

The user cares for the maximum setting time of .50 μs. These registers are used to govern the diquadrupoles which create and orient the line, and are updated at each change in REG. IAI, during the sweep.

2.1.4. - ENTRY MSMODE.

Here the user states whether to use the spot or the line to make the sweep. There are five line lengths available - 0.5 mm., 1.0 mm., 1.5 mm., 2.0 mm and 2.5 mm.

In practice the 1.0 mm line is normally used. The user also states which of the four sizes of scan-cell he desires. They are as follows

Name of scan cell	Length of scan cell (microns)	Interpolation count (microns)
Super track	192	1.5
Track	770	6.0
Find	3100	24.0
Super find	12300	96.0

The Track Mode is the more commonly used. These commands are loaded into REG. CTA (See Fig. 2).

The sweep is generated in either the XRA or YRA register by the PEPR digital processor. In order to displace the spot/line during the sweep a J* operation will increment or decrement an appropriate bit (depending on the length of the scan-cell), in one of these registers, at every tick of the clock. Thus, one of the registers is acting as a digital ramp, and is used (via a Digital to Analog Converter) to generate an analog ramp, which determines the true instantaneous displacement the spot/line from the start of the sweep. The analog ramp is delayed by DL tick with respect to the digital (REG. DLY). We note that the entire durattion of the sweep is always greater than that of the scan cell proper which is limited to 64 ticks (64 ICs) on either side of its centre. This is illustrated in Fig. 3 for a sweep of 248 ticks, an ungated scan cell (128 ICs), a delay DL=

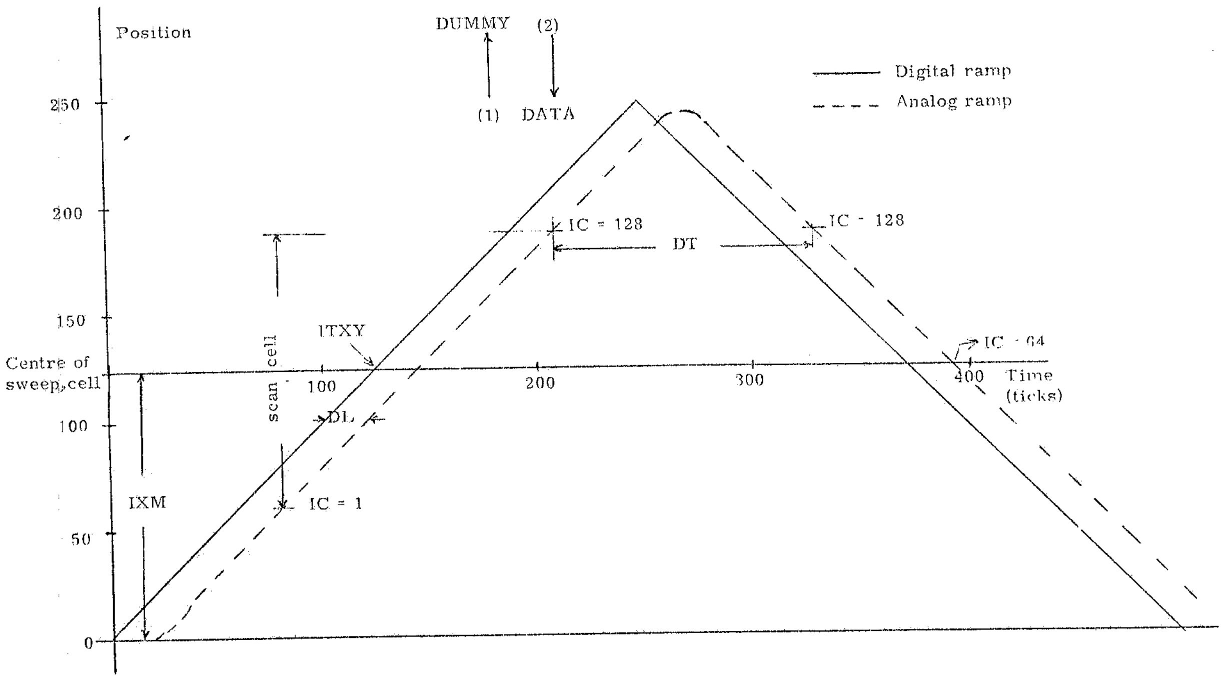

FIG. 3 - Displacement versus Time for a typical sweep (see text).

= 18 ticks, and a dead time DT = 120 ticks. The user should ensure that the interpolation count does not reach 128 before the end of the digital ramp. During the sweep REG. MEML contains the current interpolation count (analog ramp). Also, REG. WDT contains the interpolation count, until the track crosses the threshold and then remains fixed until the track again crosses the threshold. Thus at this unstant we have the centre and width of the track (in interpolation counts).

$$\text{CENTRE} = (\text{MEML} + \text{WDT})/2\ , \qquad \text{WIDTH} = |(\text{MEML} - \text{WDT}) \times 2|.$$

At this point a J^* operator sets WDT again equal to the current value of MEML, until another track crosses the threshold.

2.2. - Software Input.

In addition to initializing the registers the user must supply some software control parameters. These are

NHMIN : Minimum acceptable number of hits in one scan cell (MSCAN)

NHNS : Maximum acceptable number of hits in one scan cell (MSCAN)

ISS : controls point out

NFASG : if = 1, make correction for dynamic focus and astigmatism (MSAB)

IFAST : if = 0, Slow Mode ; if = 1 Fast Mode (MSCAN).

3.1. - Entry SCAN.

This is called from the higher level routines when the initialization described above has been made. It operates in the histogramming mode, and may use any of the four sizes of scan cell.

It commands the hardware, through REG. STA to commence sweeping at the position and through the range of angles already loaded.

The software waits for the completion of the sweep (as signalled by the arrival of an interrupt). SCAN then resumes control, and has at its disposal a summary of the results of the sweep again in REG. STA. We read how many multiplets, NPAK, have been found (see below). If this is zero, we make an error return (IERR = 1, No Data), and likewise if there are more than four multiplets (IERR = 2, Too Many Tracks). Otherwise we proceed to deal with the results of the sweep (Fig. 4).

In the histogramming mode, the hardware writes into one of the auxiliary memories (128 words, 8 bit), the "angle" (content of REG. NAS) at which the hit was obtained. The address in which this is written is numerically equal to the (IC-1) of the centre of the hit. In general, a track or other object, will be observed at several different values of the orientation of the line, up to a limit of a few degrees between the angles of the track and the line. In this case we overwrite the previous angle. If the IC of the hit also changes with angle, we have a multiplet of contiguous locations of the auxiliary memory corresponding to the same real object.

J^* operations extract information about each multiplet and write it into one of the four track buffers REGS. TBA, TBB, TBC, TBD. Each contains the multiplicity and the centre of a multiplet. In the case of even multiplicity we have the higher of the two central values. We extract the multiplicity, IMUL, of the first multiplet from REG. TBA. If this exceeds a limit we make an error return (IERR = 3, Hit Too Wide). This limit is 5 ICs (30 μ) in using the Track Scan Cell. We extract the address of the centre, IND, and find the address, IADR in the memory of the first member of the multiplet. This is loaded into REG. MEMH, and we command a J^* operation on this register. This reads the content of the given address, which is the "angle" of the hit, into REG. MEML. We proceed to read the "angles" of the remaining hits of the multiplet, and average them to obtain

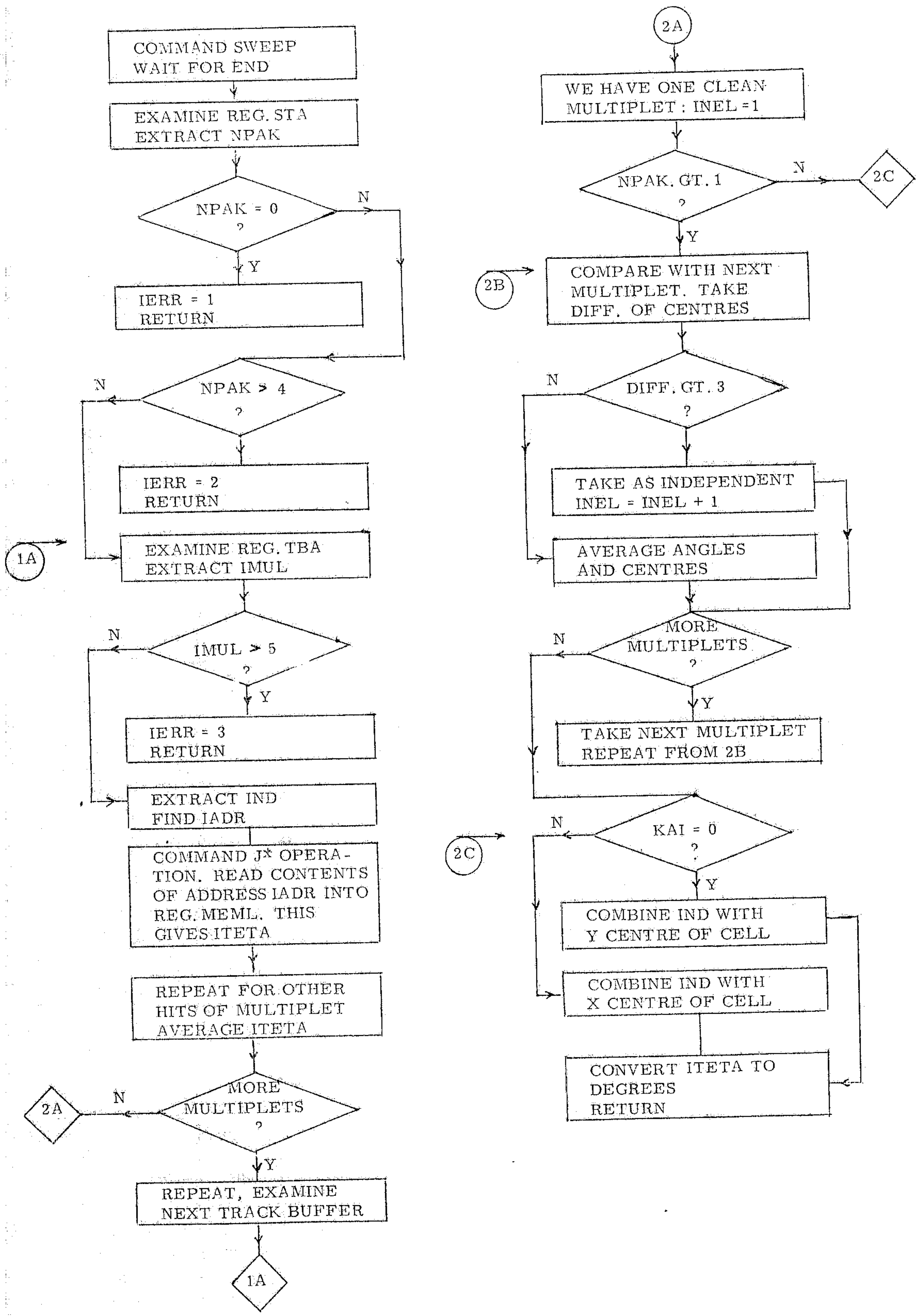

FIG. 4 - Flow chart for ENTRY SCAN.

ITETA. The process is repeated for the remainder of the NPAK multiplets. We compare the centre of the multiplet with the centre of the next one, and augment our counter of track elements, INEL, if they differ by less than 3ICs (Track Scan Cell, 18 μ). Otherwise, we combine the multiplets by averaging their centres and "angles". When sweeping in the y direction (KAI = 0) we combine the main deflection or centre of the scan sell with the coordinate of the hit (see Fig. 1a)

$$A_H = A_C \ , \qquad B_H = B_C + (IND - 63) \times F_{SY}$$

Sweeping in the x direction (KAI = 1) we have

$$A_H = A_C + (IND - 63) \times F_{SX} \ , \qquad B_H = B_C \ ,$$

where F is a scale factor (empirical) to convert the interpolation count to main deflection units. For a given type of scan cell the factors are almost equal, but vary by a factor of about four between the different types. The "angle" of the hit is transformed firstly to units of REG. IAI and thence to degrees. We return to the calling program.

3. 2. - Entry MSCAN.

This is called from the higher level routines when all necessary changes in the contents of the registers have been made. It is designed for use when the hardware is not operating in the histogramming mode. It may be used in conjuction with either the spot or line, and any of the four sizes of scan cell.

The sweep may be made in either of two ways. These are a) Stop Mode. Here we execute the initial dummy sweep, followed by data gathering sweeps at various angles. We stop the process at the end of the sweep in which we encounter the first acceptable hit, and return control to the software. b) Non Stop Mode. Here we go on making sweeps until we reach the end of the angular range. In both cases the centre and width of accepted hits up to a maximum of four are written into the track buffers (In the subsequent software analysis we only take account of the first hit). The averaging facility is not implemented in the present software.

In working with MSCAN it is intended that some initial sweeps be made in Stop Mode. The results of the sweep are summarized (as in the case of SCAN) in REG. STA, and we proceed to analyse the results of the first sweep. If there are no hits we make an error return (IERR = 1, No Data in Fast Mode), and likewise of the number of hits, NH, exceeds NHNS (IERR = 2, Too Many Hits). We note the angle at which we returned from the sweep (LA1), and whether this was the first angle in the sweeping range and augment the counter of hits, NHITS. If the number of hits is not equal to the required minimum, NHMIN, we begin sweeping through the remaininig angles to find more hits on the track. If the angular range is already exhausted, NAS = 0, we make an error return (IERR = 3, Not Enough Hits). After the resumed sweep we compare the angle of the new hit with the previous one. If these differ by more then two steps of angle (1. 4^{o}) we reject the identity of the hits and make an error return (IERR = 3). When we have obtained the required number of hits we note the angle at which we have returned LA3, and average it with LA1, to give the angle of the hit. Its position and width in units of IC are written in the first track buffer TBA. If the user does not want to refine the angular measurement by going to the Slow Mode, we combine the interpolation count with the main deflection as in the case of SCAN, and return.

If instead, the user sets the flag for slow mode, we command a series of sweeps in Non Stop Mode, using 15 steps of angle commencing from LA1. If there is no data during the sweep we make an error return (IERR = 4, No Data in Slow Mode) likewise if NH exceeds fifteen (IERR = 5, Too Many Hits in Slow Mode). The last angle LA3 is obtained from the first angle LA1 plus the number of hits. If the angle at which the track was first observed (LA1), did not coincide with the start of the angular range of the Stop Mode sweeps, we are now sure of having observed it over the range of its visibility, and we do not need to sweep again. If on the other hand we first observed the track at the initial angle of the Stop Mode sweep we set up another sweep in Non Stop Mode beginning at LA1, and going 15 steps of angle in the opposite sense. Finally, we combine the major and minor deflections and return to the calling program.

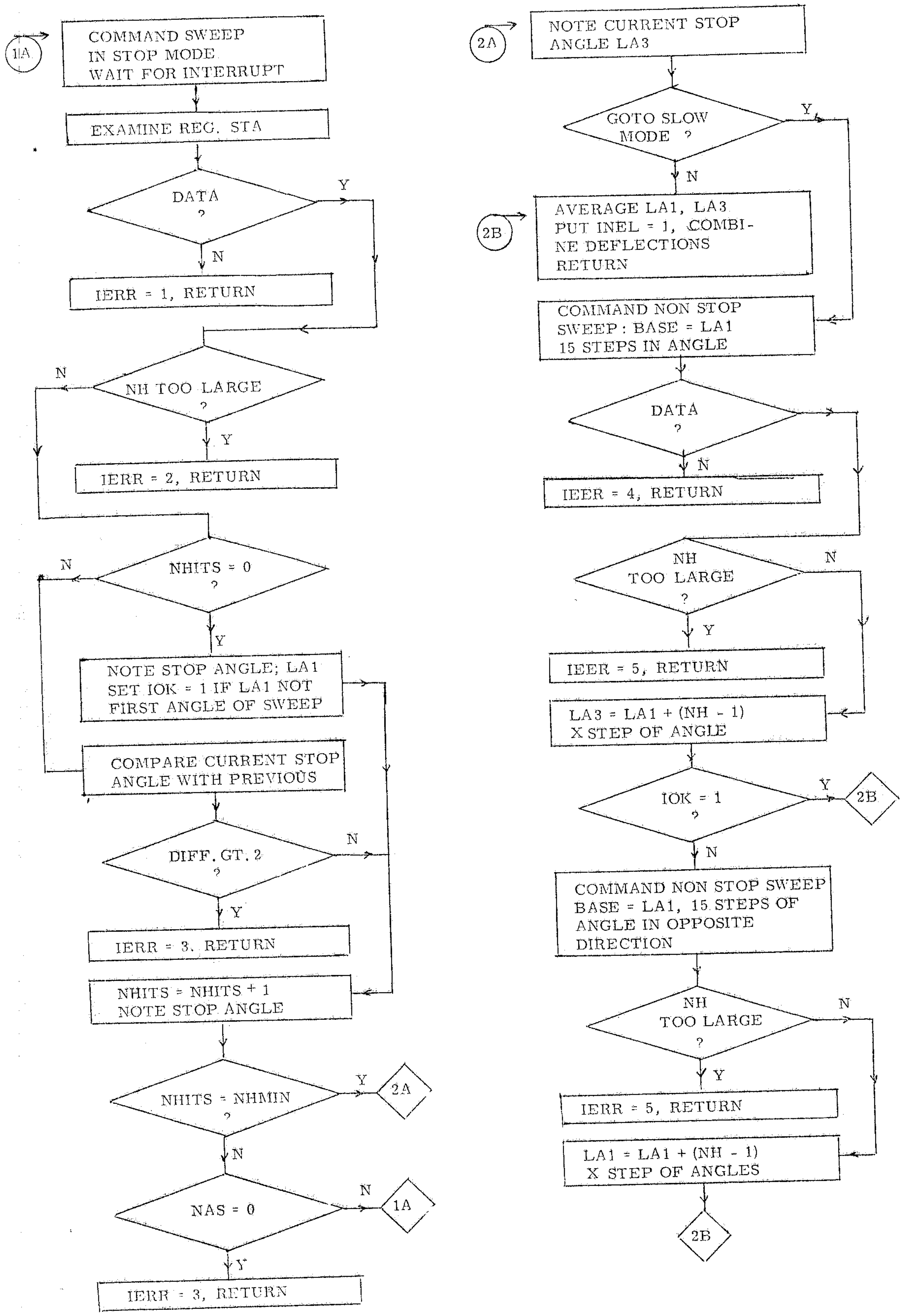

FIG. 5 - Flow chart for ENTRY MSCAN.

3. 3. - Output.

The items returned to the calling program from SCAN and MSCAN are

IERR	if 0 no error, if > 0, error	
INEL	number of track elements found	
ANG	angle of the track (degrees)	
XMSC	x-position of the track	MSCAN
YMSC	y-position of the track (MDU)	
ANGSC(4)	same for the four elements	
RSCX(4)	found in SCAN	
RSCY(4)	found in SCAN.	

REFERENCES.

(1) - P. Allen et al., Frascati report LNF-79/13 (1979).

(2) - P. Tollis, Tesi di Laurea, Università di Roma (1978) (in Italian).

(3) - Frascati-Roma PEPR Group, Proceedings of the Padova Conference on Computer Assisted Scanning (1976), pag. 187.

(4) - I. Laakso et al., Frascati report LNF-75/3 (1975) (in Italian).

APPENDIX A - PEPR Registers - Address = $(1640\ x\ x)_8$

N	xx	J*	REG	USE
1	00		MKA	Selects bits of REG STA which launch interrupts at addr. A .
2	02		MKB	Selects bits of REG STA which launch interrupts at addr. B .
3	04	*	STA	Commands film transport and start and end of sweep: status flags and number of tracks after sweep.
4	06		CTA	Select Stop Mode, size of scan cell, length of spot/line, direction of sweep.
5	10	*	TBA	First of four Track Buffers
6	12	*	TBB	All Track Buffers have centre and multiplicity (histogramming mode) of a hit
7	14	*	TBC	Or centre and width of a hit (not histogramming mode)
8	16	*	TBD	Last of four Track Buffers
9	20	*	WAT	Maximum acceptable width of pulse ; minimum acceptable height
10	22			Not in use
11L	24	*	WDT	The IC at which the track crosses threshold
11H	25		GAI	Intensity of line/spot ; attenuation factor for output pulse
12	26	,	CTB	Threshold Hysteresis ; select threshold search, histogramming mode, dummy or alternate dummy ; average mode
13L	30		OCO	Lower gate on scan cell (IC)
13H	31		OCC	Upper gate on scan cell (IC)
14L	32	*	MEML	During sweep contains true instantaneous position of spot/line ; out of sweep contents of the address in MEMH
14H	33	*	MEMH	Memory address whose contents are to be written into MEML
15L	34		AST	Angular increment for a series of sweeps at a given point (in units of 0.7 deg.)
15H	35			Not in use
16L	36	*	NAS	Number of angular increments
16H	37	*	IAI	Base angle for the series of sweeps (in units of 0.7 deg.)
17	40			Not in use

18L	42	*	RET	Total number of sweeps (including dummies) to be executed at each angle
18H	43			Not in use
19	44	*	MAN	(cos (2 *IAI)) x 256
20	46	*	NAN	(sin (2 *IAI)) x 256
21	50	*	XRA	Digital displacement in X of spot/line from start of sweep
22	52	*	YRA	Same in Y. Both are in least counts
23L	54			Not in use
23H	55	*	RAD	Contains displacement in time from start of sweep (in clock ticks)
24L	56		DLY	Delay between analog-digital displacement;dead time between successive sweeps (both in clock ticks)
24H	57			Not in use
25	60		FUS	Correction current for dynamic focus of spot/line
26	62		XRD	Centre in X of sweep (MDU)
27	64		YRD	Centre in Y of sweep (MDU)
28L	66		ASGY	Correction current for dynamic astigmatism (Y)
28H	67		ASGX	Correction current for dynamic astigmatism (X)
29	70	*	MDB	Contains the image of the operator buttons
30	72		FCT	Number of frames to be moved by the film transport
31	74		FCL	Number of steps of 100 μ to be moved within a frame
32	76			Not in use

L = Low Byte ; H = High Byte .

The above table refers to the state of the registers when the spot/line is used for measuring purposes. Some of the registers are used differently when making the TV pictures.