

PROGRAMS FOR THE INTERFEROMETER

DDP-116 COMPUTER

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## DDP-116 COMPUTER

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ERRATA

- p. 1-3        The resolution component  $\underline{u}$  is not a vector. Read  
$$\underline{u} = \vec{R} \cdot (\vec{w} \times \vec{u})$$
- p. 1-8        Word 19 of the data record contains the offset; word  
              20 contains the rms.
- p. 3-5        The vector  $(A_C, A_S, A_D)$  should be removed from the matrix  
              shown. It is properly printed on the second line of the  
              equation.
- p. 3-8        Read  
$$\Delta\alpha \cos \delta = A_0 \cos \delta + A_1 \sin H \cos \delta + A_2 \cos H \cos \delta$$
$$+ (A_3 + A_4 \sin H + A_5 \cos H) \sin \delta$$
$$+ A_6 + (A_7/\cos z + A_8) \sin P \sin z$$
- p. 5-2        Format of flux (columns 40-46) is SSSS.SS.

## PROGRAMS FOR THE INTERFEROMETER

## DDP-116 COMPUTER

## I. INTRODUCTION

This memo will cover the general organization of the interferometer operating system for the DDP-116 on-line computer. It will contain the programming philosophy, simplified flow charts, and schematic operating instructions for the 116 programs as they exist in the summer of 1968. Facilities only partially implemented will be described, but noted as incomplete, and the final form may be somewhat different than described here. Detailed operating instructions are to be found in the control room, as is an up-to-date symbolic listing of the program. The control room documentation should be consulted on any matter in which up-to-date information is essential. Extensive supplements to this memo will not be issued.

A. The DDP-116

The interferometer 116 has a core memory of 8192 (8 K) 16 bit words, which is paged in 512 word blocks. Addressing is within a block. The memory cycle time is 1.7  $\mu$ s. Memory reference instructions require 2 memory cycles, except JMP, and operate and test instructions require one cycle. There is one index register. Indexing carries a timing penalty of 2.04  $\mu$ s. The 116 has hard wired multiply and divide instructions. Input-Output may be done either through the A register or through a direct multiplexed channel (DMC). Each device is addressed in its particular way, some only through the A, some only through the DMC, some through both.

The DDP-116 has the following I-O devices:

1. The teletype. This will read and punch paper tape and print type-script, all at approximately ten characters per second. It is addressed only through the A register.
2. Card reader. Reads, but does not punch, cards in either BCD or binary modes. Addressed only through A register. Operates at 200 cards/minute.
3. Magnetic tape transport. Reads and writes 7 track magnetic tape at 200 or 556 characters/inch, checking parity. The tape is transported at 45 inches/second. The MTT may be addressed either through the A register or through the DMC.

4. Disk drive. (Flat drum) The disk revolves at approximately 60 rps, so that one may wait up to 16 milliseconds for the record of interest to revolve under the recording heads (one per track), at which time the data is transmitted serially at  $1.5 \times 10^6$  bits/second. We have 192 tracks holding 1536 words each, a total capacity of 294,912 words. The disk may be addressed only through the DMC. The data rate on the disk is so fast that concurrent computation may not be done during disk operation, and difficulties may be encountered if computation is done while the interface is waiting for the record to revolve under the head.

5. External interrupt lines. Only one of the available 8 lines is connected to an external device at the moment -- it is connected to a 50 cycle sidereal clock pulse.

6. Discrete input lines. These are of two types, one of which senses voltages applied, the other sensing the settings of an internal relay which is set by the external device. There are 14 voltage sensing registers and 8 relay registers. Each register contains 16 lines, and may be addressed through the A register.

7. Discrete output lines. These are 15 latching relay registers, which are set by output from the A register, and are used to control external functions. Five milliseconds are required to latch the relays. During this time the interface is busy, and no other output register may be addressed.

8. The A-D converter. This is an eleven bit converter (it returns 14, but the last 3 don't have any significance), which can sample any one of 64 analogue lines connected to its multiplexer. The first conversion requires 25  $\mu$ s, plus 20  $\mu$ s for each sequentially succeeding conversion. It is addressed through the DMC.

9. The cathode ray tubes. These devices display characters at fixed gridpoint intervals. The CRT has its own memory and renews its image automatically. This memory can be accessed by the computer, through either the A register or the DMC, and can also be accessed by a keyboard on the CRT.

#### B. The Interferometer

Interferometer geometry will be discussed below in vector notation, or in a rectangular coordinate system, centered on the center of the earth. The z-axis points to the north celestial pole and the x-axis points to the intersection of the geographic meridian 79° 50' West with the celestial equator.

The y-axis points to the west point, to make a left-hand rectangular coordinate system. In this system the position, say, of 85-1 is  $\vec{r}_1$ , and of 85-2 is  $\vec{r}_2$ . Then the baseline vector for the 85-1-85-2 interferometer is defined as  $\vec{B} = \vec{r}_1 - \vec{r}_2$ , and we may express  $\vec{B} = (B_x, B_y, B_z)$ . If  $\vec{u}$  is a vector of unit length pointing toward a radio source,

$$\begin{aligned}\vec{u} &= (u_x, u_y, u_z) \\ &= (\cos \delta \cos H, \cos \delta \sin H, \sin \delta)\end{aligned}$$

where H is the hour angle measured at 79° 50' west longitude. The delay of the signal in one antenna relative to the other is now

$$\Delta = \frac{1}{c} \vec{B} \cdot \vec{u}$$

The resolution vector is the projection of B in the plane perpendicular to u,

$$\vec{R} = \vec{B} - \vec{u} \vec{B} \cdot \vec{u},$$

whence the usual u,v are given by

$$v = \vec{R} \cdot \vec{w}, \quad u = \vec{R} \cdot (\vec{w} \times \vec{u})$$

where w is the north pointing unit vector in the plane of the sky,

$$\vec{w} = \frac{1}{\sqrt{1 - u_z^2}} (u_x u_z, u_y u_z, 1 - u_z^2)$$

The appropriate algebraic formulae for expressing these relations will be developed when the reduction program is discussed.

The correlators and a large number of monitor points are fed into the A-D converter. These are listed in an interferometer group diagram dated 11/18/60, and the discrete I-0 lines are similarly listed in a diagram dated 4/27/67. Reference to these memos is essential to the understanding of large parts of the detailed listings.

The receiver block diagram is shown in Figure 1.1. The antennas are fed with a dual circular feed, and the sense of the circular polarization is selected by coaxial relays. At this point, a modulated noise signal is inserted to provide a gain calibration. After amplification in the dual degenerate parametric amplifiers, the signal is mixed with the phase controlled local oscillator signal, from which the pump is also derived. The IF's are transmitted to the control building, appropriately delayed, and correlated, producing the



fringe output given to the A/D converter. The computer causes the A/D converter to sample these voltages at a rate of 50 times per sidereal second, as determined by the station sidereal clock. The computer then interprets these sampled voltages as a quasisinusoidal fringe, and calculates the phase and amplitude. These numbers are stored on the disk temporarily, and approximately once a day are transferred to magnetic tape for the use of the Charlottesville computer.

### C. The Main Programs

The services the computer offers to the interferometer are divided into large blocks or programs, which are more or less autonomous, with perhaps a few words of communication through sector zero, or through sharing a disk area. The programs may be either disk resident, or if they are less frequently used, card resident, that is on binary punched cards that must be loaded by the operator when he wishes to execute the program.

Programs are subdivided into routines. We have employed the convention that all symbols used within a given routine should start with the same initial letter. This allows the routines to be written and debugged separately, and then assembled together with no danger of multiply defined symbols. The programs are written in load mode, and are punched to be assembled by DAP, although in practice most assemblies are done by ASM116.

The principal programs are mostly self linking through the monitor SU; that is SU calls whatever other programs are necessary, and when another program has completed its task, it calls SU. The use of sector zero as a communication sector is described in detail in Table II-1. An additional communication word is passed to SU when it is called by any other program. This word, called return code, is printed by SU when it is called. These are listed in Table I-1. The main programs are listed below.

1. SU keeps track of the observing list and makes sure that programs and constants are restored from disk. It is the calling program, calling all other programs as needed. Other programs may only call SU. SU also positions the telescopes.

2. OB takes the actual observations. It sets delay lines, switches polarizations, and reads correlator voltages. It fits the observed correlator outputs with a quasisinusoidal fringe pattern and records the data on disk for later transfer to tape. OB touches up the telescopes' positions, but if they are too far off, it returns to SU to do a better job.

3. WR prepares the observing lists, interpreting the punched cards, applying precession and nutation corrections, checking telescope limits, etc. It searches out the source name in a disk list, so that sources appearing in this list need have no other parameter specified than their name.

The data output on disk is transferred to tape for processing on the 360. The data formats are given in Table I-2. The Type 1 records give a description of the source and conditions of observation, and occur whenever SU is called. Type 2 records are the data records proper and contain the interferometer output. They are written once/minute. Type 3 records record the A/D outputs and are written once/5 minutes. Other diagnostic information is also recorded. Type 4 records are initiated by the operator, and contain a message typed in on the typewriter.

The conventional core sector assignments are given in Table I-3. Sectors 16 and 17 should not be destroyed. Sector 16 contains the loaders necessary to conveniently restart the machine in case of a foul-up, and IOCS habitually resides in sector 17.

As is discussed in sector II-B-6, the disk has 500 records of 100 words each reserved for programs and constants. The organization of this area is given in Table I-4. This area contains the entire operating system, and is copied onto tape as a backup, so that these disk-resident programs may be restored if destroyed.

TABLE I-1. RETURN CODES

Code	Meaning
-1	Cold start after reloading IOCS -- check scan number with operator.
1	Normal program return -- advance observing list, load source parameters.
2	Abnormal program return, reinitiate everything, but do not advance observing list.
3	Enter wait loop.
4	Message waiting.
6	Manual restart -- same effect as 2.
10	Excessive pointing error on 85-1, 2, 3.
20	
30	
7	Return from delay line check.

TABLE I-2. DATA FORMATS

## A. Header Records

<u>Word</u>	<u>Contents</u>	<u>Word</u>	<u>Contents</u>	<u>Word</u>	<u>Contents</u>
1	Code - 1	34		67	
2	} Source Name	35		68	
3		36		69	
4		37		70	
5		38	} Sidereal Time	71	
6	39	72			
7	Given Start Time	40	Date	73	
8	Given Stop Time	41	B <sub>z</sub> Corr 1	74	
9	Mode Character	42	" " 2	75	
10	} $\delta$	43	" " 3	76	Observer
11		44	" " 4	77	
12	} $\alpha$	45	" " 1	78	
13		46	" " 2	79	
14		47	" " 3	80	Operator
15		48	" " 4	81	
16		49	B <sub>x</sub> Corr 1	82	
17		50	" " 2	83	
18		51	" " 3	84	
19		52	" " 4	85	Console Switches
20	Scan Number	53	" " 1	86	
21		54	" " 2	87	
22	Return Code, Prev. Obs.	55	" " 3	88	
23	Ind. Dec. 85-1	56	" " 4	89	
24	Ind. H.A. 85-1	57	B <sub>y</sub> Corr 1	90	
25	Ind. Dec. 85-2	58	" " 2	91	
26	Ind. H.A. 85-2	59	" " 3	92	
27	Ind. Dec. 85-3	60	" " 4	93	
28	Ind. H.A. 85-3	61	" " 1	94	
29		62	" " 2	95	
30		63	" " 3	96	
31		64	" " 4	97	
32		65		98	
33		66		99	
				100	

Table I-2. Data Formats (Continued)

B. Data Records

Word	Contents	Word	Contents	Word	Contents
1	Code - 2	35	IF Levels	68	
2	Date	36		69	
3	Time	37	Flags	70	
4		38		71	
5	Scan Number	39		72	
6		40		73	
7		41		74	
8	Panel Switches	42		75	
9	Sync Detectors	43		76	
10		44		77	
11		45		78	
12		46		79	
13	Scan Settings	47		80	
14		48		81	
15		49		82	
16		50		83	
17	R	51		84	
18	I	52		85	
19	RMS	53		86	
20	Offset	54		87	
21	Correlator 1 Data	55		88	
22		56		89	
23		57		90	
24	Correlator 2 Data	58		91	
25		59		92	
26		60		93	
27	Correlator 3 Data	61		94	
28		62		95	
29		63		96	
30	Correlator 4 Data	64		97	
31		65		98	
32		66		99	
33	IF Levels	67		100	
34					

Diagram illustrating data flow and segmentation:

- Vertical line with arrows indicating data flow.
- Labels for data segments:
  - First 15 seconds data (Words 51-67)
  - Second 15 seconds data (Words 76-91)
  - Third 15 seconds data (Words 92-100)
  - Fourth 15 seconds data (Words 84-100)

Table I-2. Data Formats (Continued)

## C. A/D Records

<u>Word</u>	<u>Contents</u>	<u>Word</u>	<u>Contents</u>	<u>Word</u>	<u>Contents</u>	
1	Code = 3	35	Outside Temp.	68	} Time	
2	Sync Det 85-1	36	Dew Point	69		
3	" 85-2	37	Baro. Pressure	70		
4	" 85-3	38	Cable Pressure	71		
5	Water Vapor Det.	39		72		
6	Box Temp. 85-1	40		73		
7	" 85-2	41		74		
8	" 85-3	42	Master LO Level	75		
9	VCO Level 42'	43	IF Ref ( $\phi$ -lock)	76		
10		44	Link Q	77		
11		45	Link I	78		
12		46	Mixer 85-1 (1)	79		
13		47	" 85-1 (2)	80		
14		48	" 85-2 (1)	81		
15		49	" 85-2 (2)	82		
16		50	" 85-3 (1)	83		
17	ALC Det. 85-1	51	" 85-3 (2)	84		
18	" 85-2	52		85		
19	" 85-3	53		86		
20	$\phi$ -lock sin 85-1	54		87		
21	" 85-2	55		88		
22	" 85-3	56	} LO Counter	89		
23	" 42'	57			90	
24	$\phi$ -lock cos 85-1	58	Control Status	91		
25	" 85-2	59	Pol. enc 85-1	92		
26	" 85-3	60	" 85-2	93		
27	" 42'	61	" 85-3	94		
28	PLO $\phi$ error 85-1	62	} Scope Positions	95		
29	" 85-2	63			96	
30	" 85-3	64			97	
31	" 42'	65			98	
32	VCO Level 85-1	66			99	
33	" 85-2	67			100	
34	" 85-3					

TABLE I-3. CORE USE CONVENTIONS

<u>Sectors</u>	<u>Conventional Use</u>
0	Nucleus
14	Transient Area
15	Second Transient area
16	Loaders, Polarization readout routine
17	IOCS

TABLE I-4. DISK PROGRAM AREA MAP

<u>Sectors</u>	<u>Contents</u>
0-19	SU Part 1
20-39	SU Part 2
40-41	Calling routine for OB
42-47	Math Pack executing from sector 5, SU uses this
48-49	Unassigned
50-105	OB
106-115	Antenna positions with slew-WHEE and GPST
116	Unassigned
117-122	OB ant positions - PALL and GPNT
123-128	IOCS
129-149	Unassigned
150-185	WR
186-199	Unassigned
200-203	CURR - Transit Routine
204-208	OPID - " "
209-211	DATE - " "
212-216	BASE - " "
217-221	INID - " "
222-226	CRTN - " "
227-229	BASE - second part of transient routine
230-299	Unassigned
300-399	Source Position List
400	Unassigned
401	Scan Number, Baseline Constants and Pointing Constants
402-421	Observing List
422	Besselian Day Numbers
423-499	Unassigned unprotected storage

85-1

85-2 and 85-3 similar to 85-1

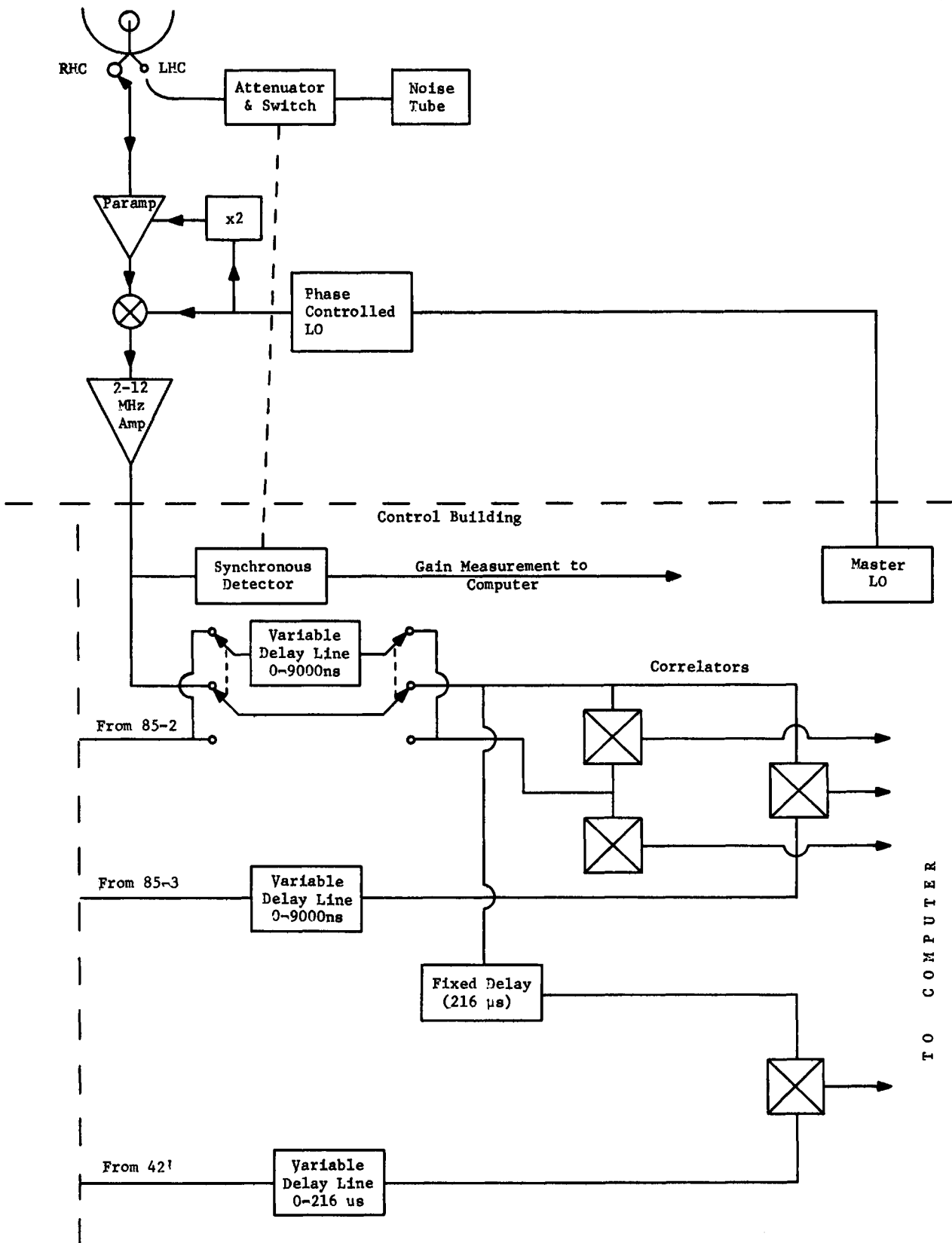


Fig. 1-1.



## II. THE UTILITY ROUTINES AND IOCS

### A. The Utility Routines

The existing utility routines are briefly described in the memo by R. L. Swensson dated May 17, 1967, with instructions for use. Most are sufficiently simple in structure that no further description need be given here. More routines will be added later. In addition to the simple utility routines, we are accumulating an increasing stock of card-loaded programs of considerable complexity, which bear some similarity to the utility routines in that they are present in the form of the object decks punched by the 360 assembler, ASM-116, and are distinguished only by their complexity. These will be described in detail later in this memo. The utility routines available at this date include:

1. Paper tape loader
2. Mag tape loader
3. Object card loader for cards produced by the IBM 360 program ASM-116
4. ADCT-ADC voltage reader and print routine
5. POLR - polarization encoder, read and print routine (also prints focus)
6. Disk to tape - creates operating system backup tape
7. Tape to disk - reloads operating system from backup tape
8. Core to disk - facility for modifying the operating system.  
System is modified in core and read back onto disk.

### B. The IOCS Routines

The IOCS routines are a standardized set of routines for doing input and output through the disk and teletype. All I-O to these devices should be handled through these routines, rather than directly, as these routines guarantee to handle interrupt logic correctly and block the disk records in the proper manner. Also in the same general heading as the IOCS routines is the handling of constants in sector zero. Since this sector can be reached from any other by direct addressing, the areas here should have fixed meaning within any program, and many of them have fixed meaning for all programs, with constants frequently needed being supplied always in sector zero. This sector is referred to as the nucleus.

In general, any problem of any complexity should incorporate the IOCS routines and the nucleus, as the services these provide are well worth the sector devoted to IOCS and the lower part of sector zero.

1. The nucleus. Several sorts of numbers are stored in sector zero for use by all programs.

- (a) Handy constants, i.e., 1, 2, and 3
- (b) The DMC addresses (these are fixed locations determined by the wiring of the machine)
- (c) The interrupt addresses (also fixed locations)
- (d) Transfer vectors, i.e., the locations of frequently used routines
- (e) Inter-sector communications areas
- (f) Inter-program communications areas

The subdivision and naming of each of these areas is described in Table II-1.

2. The manual restart routine. This routine marks the disk routine not busy and enters the exit routine described below. It is used if the computer is stopped during execution of some program. Its location is octal 17000, so a master clear, transfer to 17000 should clear any program difficulty as long as the IOCS routines are still intact.

3. The type routine. This routine will input from the teletype keyboard or output to the teletype. All trap lines are enabled during this operation, so that priority routines will continue to function during the relatively slow teletype operation. Input is deposited as ASCII eight bit code, packed two characters/word. Output is done assuming ASCII packed two characters/word. No test is made as to whether the character is a printing character or not. Output is at the rate of approximately ten characters per second. Non-printing characters make the teletype busy for a tenth of a second, though nothing is printed and no carriage motion occurs. A space is considered to be a printing character, since carriage motion occurs. A carriage return occupies two tenths of a second. During the second tenth, the interface reports not busy and any character issued at these times will be printed on the fly, somewhere near the middle of the page. So to make readable copy, the carriage return should be followed by a non-printing character. Therefore, most output messages end with a carriage return character followed by a line feed character, the octal denotation of which is 106612. This provides a blank line for the next message.

On input, two useful conventions are used. Firstly, a message is terminated if either the word count specified in the calling sequence is exceeded, or

if a carriage return is typed. In the latter case the type routine responds by issuing a line feed for you. Secondly, depressing the CTRL key and striking the U key deletes from memory the line as typed so far and makes ready to input the entire line again, issuing a carriage return and line feed. A flow chart is shown in Figure 2-1.

4. Line zero routine. Several devices interrupt on interrupt line 0 -- the teletype, the card reader, and the interval timer. This routine analyzes the cause of the interrupt, and transfers to the appropriate routine. A flow chart is shown in Figure 2-2.

5. The save routine. This routine exchanges the contents of the four addressable registers (A,B,C, and index) with that of a four word save area. It should be called as the first command of any interrupt routine, and again immediately before transferring out to the interrupt routine, to restore the contents of the registers to that existing in the interrupted routine at the time of interruption.

6. The disk routine. A disk record consists of one hundred data words and a check sum. The caller must make available a space at the end of his record for this check sum. These records are stored on disk, 15 records per track. The disk is divided into two logical units, zero and one, specified in bit one of the A register on entry to the disk routine. Unit zero is normally used for interferometer data storage. (The organization of this data is described in Table I-2 above.) Unit one contains the programs and semi-permanent notes. The first 300 records of unit one are file protected, i.e., the disk routine will refuse to write in this area. (The core to disk utility program will write in this area.) Unit one is 500 records long and unit zero is 2380 records long. Each record is individually addressable; the address is given in the low order 15 bits of the A register when the program is called.

The disk has a very fast data rate--really too fast for the DDP-116. If, during a read operation, the record requested rotates under the read heads, the service request must be answered within about 10  $\mu$ sec. As it takes the DMC about 6  $\mu$ sec to answer the request, control must be given to the DMC within about 4  $\mu$ sec. Execution of instructions longer than two cycles will often delay the initiation of the DMC beyond this amount. If the disk is not serviced promptly its character counter may lose sync, causing a permanent read error. For this reason, the disk routine hangs up in a JMP \* command, a one cycle command which

never causes trouble. However, since this delay may be rather long--up to 17 milliseconds--interrupts are enabled at this time, and an interrupt routine may take the CPU, incurring a risk of a permanent read error, but cutting the time important interrupts are likely to go without service.

Since at OB time the disk routine is used at two different interrupt levels, a two word work area must be provided for each, and some identification must be used to indicate which level is calling. A zero in the B register indicates the main line level; non-zero B indicates priority level. Each of the two levels has a two word work area in nucleus, used to store the index register and return, so that if the routine is interrupted while active at mainline, it can be used as soon as it becomes not busy (which occurs via the disk interrupt) without destroying the return. The contents of the B register are irrelevant when the routine is called in a non-shared resource environment.

A flow chart of the routine is shown in Figure 2-3.

7. The program loader. This routine, by successive calls to the disk routine, transfers several successive disk records from unit one to successive core locations.

8. The system exit routine. This routine, using the program loader, loads the first part of the program SU and executes it. The exit routine is entered with a return code (cf. Section I-B above) which is provided to SU.

9. The transmit macro. This is a handy internal routine which moves data from one core location to another.

10. The system emergency routine. When a situation arises in which the 116 feels that it cannot continue without operator intervention, it transfers to the emergency routine, which prints the calling address on the teletype (a list of the meanings of these addresses (with appropriate actions) is found in the floating instruction manual in the control room), and then proceeds to ring the teletype bell furiously until stopped.

TABLE II-1

Nucleus Symbols and Contents

Locations (octal)	Symbol	Contents
0		Index register
1	SONE	1
2	STWO	2
3	STHR	3
4	SOB	Observer initials
5	CRT1	CRT I-O routine address
6	EMRG	Panic routine address
7		Interval timer
10-11		Tape unit DMC locations
12-13		Disk DMC locations
14-15		A/D DMC locations
16-17		CRT DMC locations
20	SMSC	
21	SCLK	Internal timer interrupt location
22	SECT	Pointer to next data record area on disk
23	SWHO	Operator initials
24	SBRK	Teletype interrupt location
25	SDAT	Low order 15 bits of Greenwich sidereal day number
26	SSTD	Mask bits for line 0 interrupts
27	SMSK	Mask bits for priority interrupt system
30		Interrupt location for line 0-interval timer, teletype, and card reader
31		Interrupt location for 50 cps timing signal
32		Interrupt location for tape unit
33		Interrupt location for disk
34		Interrupt location for A/D
35		Interrupt location for CRT
36-37		Unused interrupt locations
40	TYPE	Type routine location
41	DISK	Disk routine location
42	TAPE	

Table II-1, continued

Locations (Octal)	Symbol	Contents
43	SAVE	Save routine location
44	TMT	Transmit routine location
45	SLDR	Disk program loader location
46	SXIT	System exit routine location
47	SDIN	Ready switch (used by SU, 1 = antennas slewing, used by OB, 1 = take data)
50	SCNI	
51-54	SOPN	Teletype interrupt same area
55	SOXT	Teletype interrupt return storage location
56	SWIO	
57	SBIT	Console switch settings
60	SCOR	Last calculated pointing correction
61	SPNT	Data buffer pointer -- points to next empty location on buffer. Is 0 when buffer is not initialized.
62-66	SRCE	Source name in ASCII I
67		Start time
70		Stop time
71		Mode character
72-73		$\delta$
74-75		$\alpha$
76-101		
102		Expected output
103		Gain setting
104		Scan number
105		
106-125	SDOT	Memory area for digital output lines
126-127	SAC1	Work area for disk routine main line
130-131	SAC2	Work area for disk routine interrupt level
132-137	SPOS	Antenna encoder readouts -- in order 1-DEC, 1-HA, 2-DEC, 2-HA, 3-DEC, 3-HA
144-145	B11	$B_z$ for 85-1-2

Table II-1, continued

Locations (octal)	Symbol	Contents
146-147	B12	$B_z$ for 85-1-3
150-151	B13	$B_z$ 85-2-3
152-153	B14	$B_z$ 42'
154-155	BC1	$B_x$ 85-1-2
156-157	BC2	$B_x$ 85-1-3
160-161	BC3	$B_x$ 85-2-3
162-163	BC4	$B_x$ 42'
164-165	BS1	$B_y$ 85-1-2
166-167	BS2	$B_y$ 85-1-3
170-171	BS3	$B_y$ 85-2-3
172-173	BS4	$B_y$ 42'
174-203	CB11, CB12, CB13, CB14	$B_z \sin \delta$
204-223	CBC1, CBC2 ---, CBS4	$B_x \cos \delta$ and $B_y \cos \delta$
224	CC1	Cosine instantaneous phase 85-1-2
225	CS1	Sine " " "
226-227	CC2, CS2	Cosine, sine instantaneous phase 85-1-3
230-231	CC3, CS3	" " " " 85-2-3
232-233	CC4, CS4	" " " " 42'
234	CCD1	Cosine phase increment 85-1-2
235	CSD1	Sine " " "
236-237	CCD2, CSD2	Cosine, sine phase increment 85-1-3
240-241	CCD3, CSD3	" " " " 85-2-3
242-243	CCD4, CSD4	" " " " 42'
244	CFLG	Storage for thumb switch reader
245-252	CALM	Alarm words (see Table III-3)
253-256	CDEL	Delay center constants
257-273		Unassigned
274-277	SENS	Sync det. zero readings
300	SGAN	Requested correlator gain settings, parallel feeds
301-307		Unassigned
310-371	TTYB	Teletype input buffer

Table II-1, continued

Locations (octal)	Symbol	Contents
372-536	SDBU	Data buffer at OB time
372-402	CON	Constant and day number storage for WR
416-417	CRA	Right ascension for WR
420-421	CDEC	Declination for WR
422	CAN	
423	CPT	List pointer for WR
424	CSTP	Last stop time for WR
425	CPBP	Buffer pointer for WR
536	CARD	Card reader input buffer
537-616	GCON	Antenna pointing constants



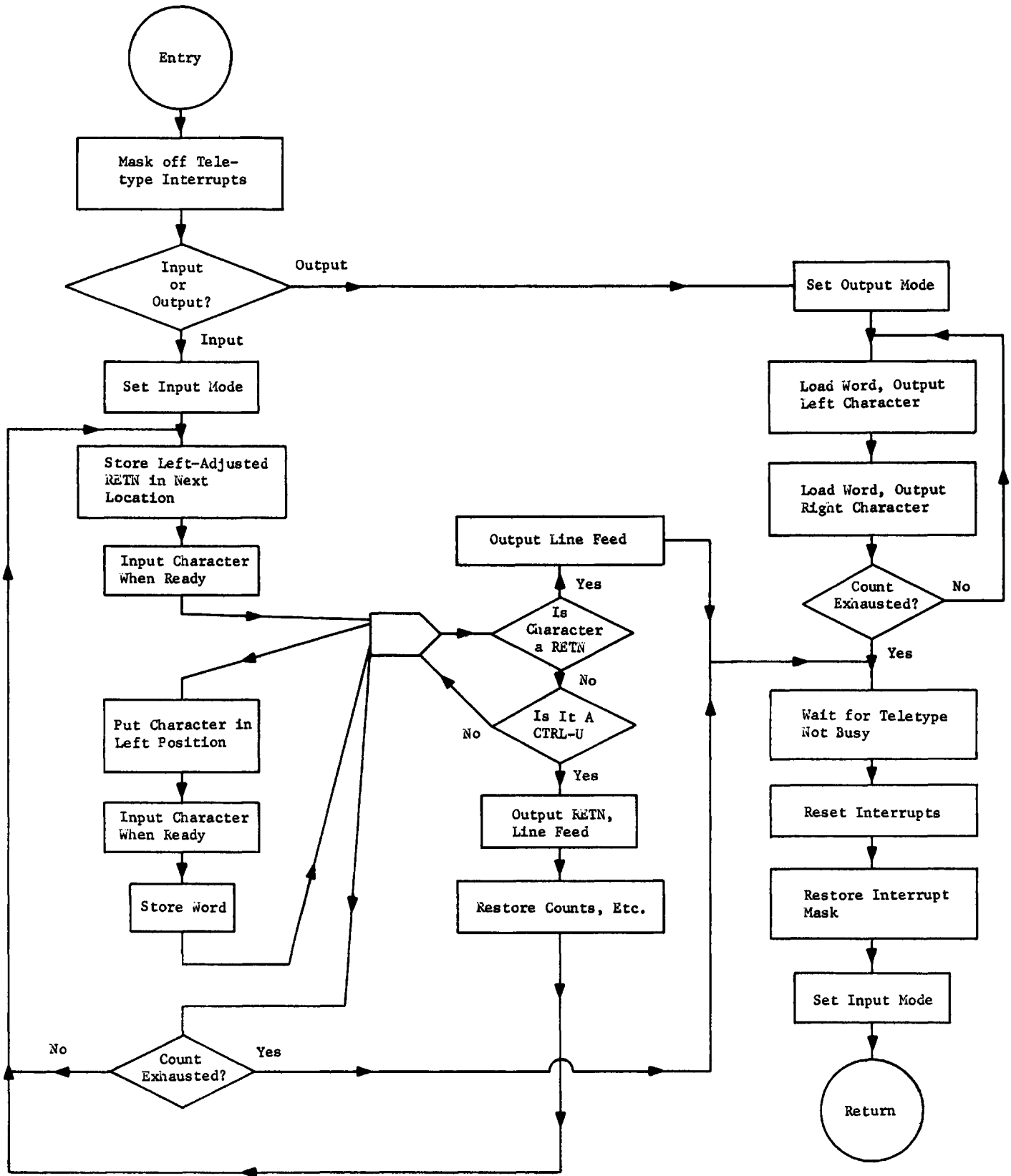


Fig. 2-1. Teletype Routine

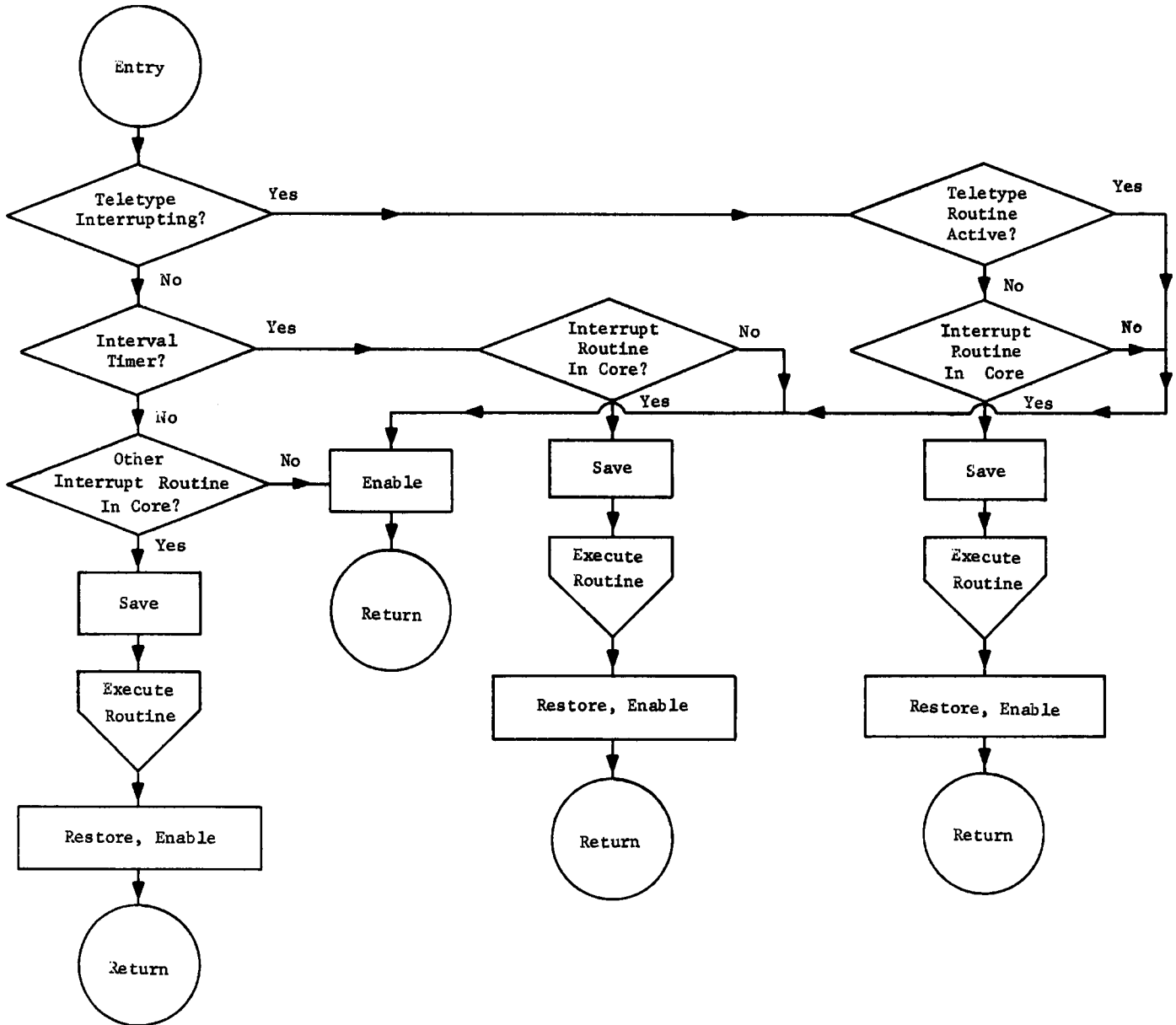


Fig. 2-2. Line Zero Trap Identifier.

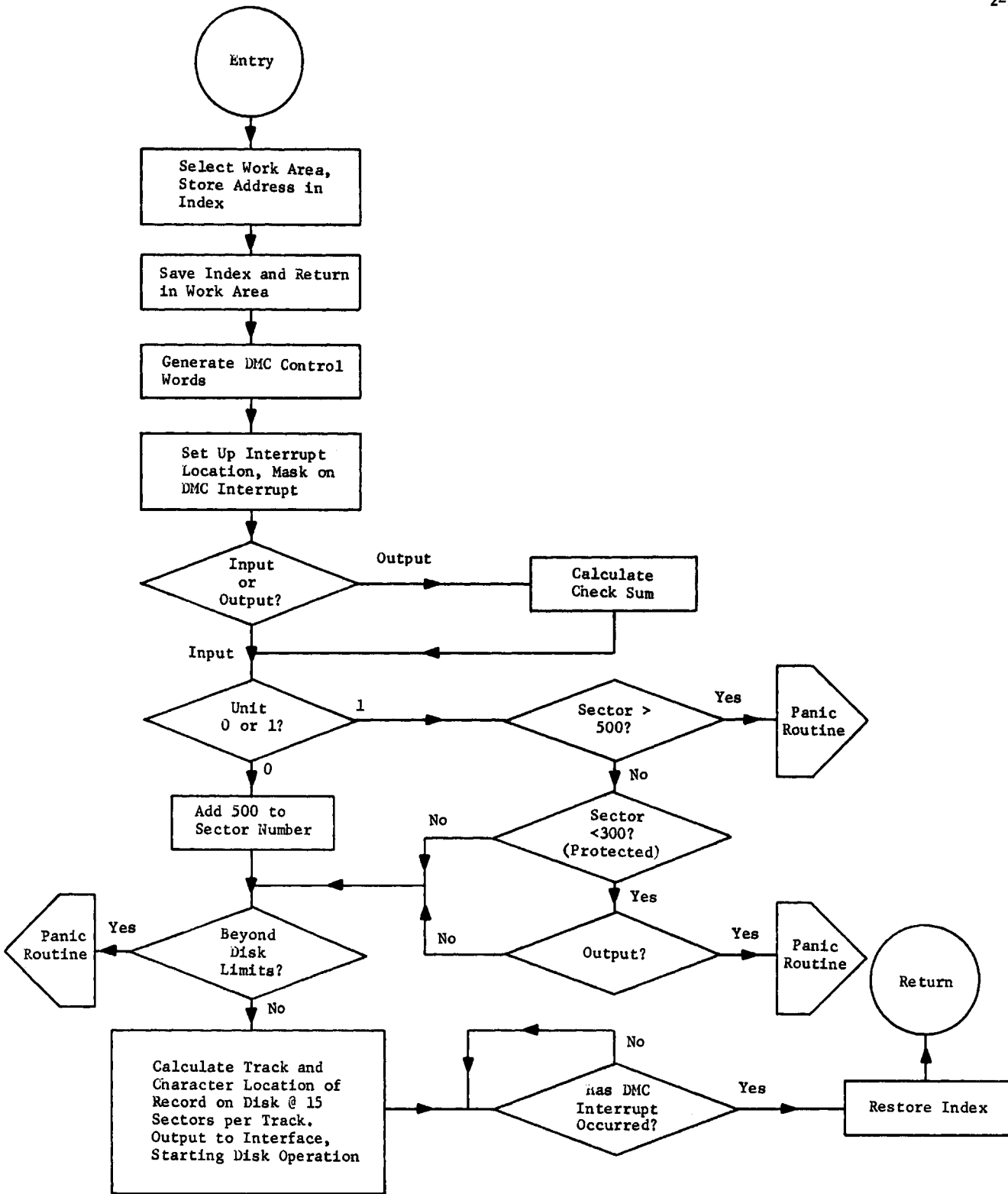


Fig. 2-3. Disk I-O Routine.  
a) Called Portion.

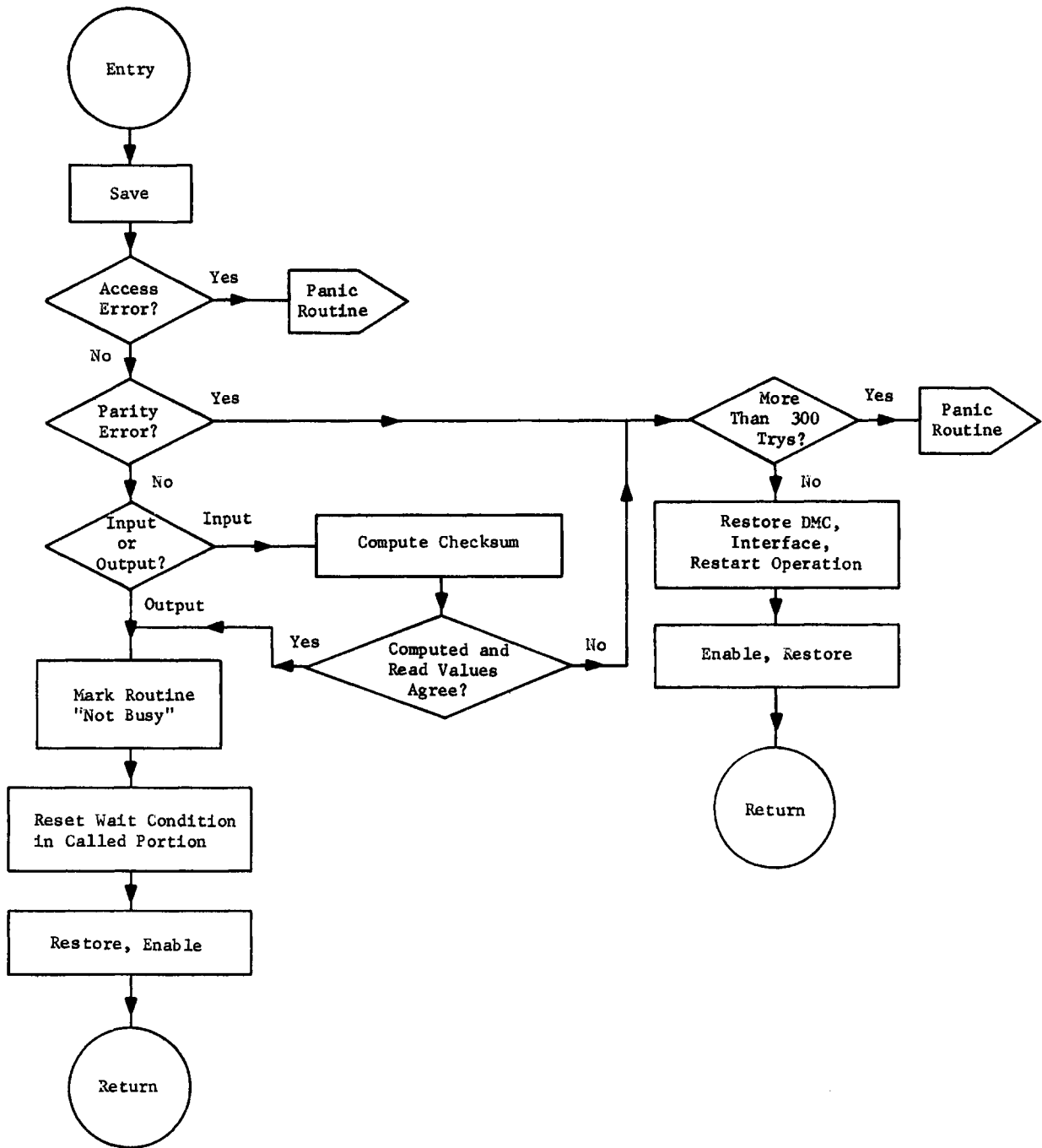


Fig. 2-3. Disk I-O Routine  
b) Interrupt Portion

### III. THE OBSERVING PROGRAM

The observing program consists of two asynchronous sub-programs which have very little to do with each other. The "priority" sub-program has the duty of reading the correlator outputs and reducing the correlator data. It also sets the delay lines, updates telescope position indications, switches polarizations, outputs to CRT displays, and outputs data to disk. The "Mainline" sub-program checks for source end time, checks for unusual conditions\*, outputs to teletype, does touchup positioning of telescopes and writes the A/D monitor line values on disk. It also converses with the operator.

In a multiprogramming system, it is necessary that all resources be either assigned uniquely to one sub-program or be co-usable. The resources of the 116 are listed in Table III-1, with the appropriate ownership. The ownership of various sectors of core not listed in Table III-1 are indicated in the core map of Table III-2.

The priority routines are slaved to the 50 cps sidereal signal from the station master clock; that is, they are entered every 20 milliseconds. Some priority routines take longer than this, so in order to free the routines entered every 20 milliseconds these routines establish a sublevel, with its own return address and save area, which may be interrupted by the 20 millisecond routines but not by the mainline routines.

The operator requests are a sublevel of the mainline program -- the operator request analysis programs are activated when a key is pressed on the teletype or the send block key on the CRT\*. No other mainline activity may occur until the operator request is completed.

#### A. The Observing "Priority" Routines

1. The constant initialization routine. This routine calculates the predicted fringe phase and leaves it in sector zero where other routines can find it. The mainline programs, before enabling the priority routines, ensure that the next interrupt received by the computer will be the first following the clock ready signal after an even second has come up. (Seconds ending in 5 and 0 are astrologically inauspicious, and hence are skipped.) The constant initialization routine is called on this interrupt and each 750<sup>th</sup> (15 second interval) thereafter. The baselines are handled in order, 42-foot, 85-1-2, 85-1-3, 85-2-3. The 42 must be handled first because it expects the information to be provided within 20 ms whereas the 85's will wait for 100 ms.

---

\*Not yet implemented, July 1968.

The initialization routine first reads the clock and adds  $0.1^s$ , because the first  $0.1^s$  of each 15 second interval is ignored to suppress the transients from polarization switching. Although this clock only reads to  $0.1^s$ , the times derived in this way will be consistent to a fraction of a millisecond, because of the initialization in selecting the proper interrupt. The time is converted to an angle (fraction of a revolution) and the true apparent R.A. subtracted to get an apparent hour angle at the time of the interrupt. The meridian of this hour angle is somewhat arbitrary (but hopefully fixed) because of the unknown transmission delays in the station clock system, but is probably close to  $79^{\circ}50'$  West longitude. The double precision sine and cosine of this hour angle are then computed.

The constants  $B_x \cos \delta$ ,  $B_y \cos \delta$ , and  $B_z \sin \delta$  have been computed by the supervisor program and left in sector zero. The initialization routine calculates the apparent predicted phase  $\phi$

$$\phi = - [(B_x \cos \delta) \cos H + (B_y \cos \delta) \sin H + B_z \sin \delta]$$

This phase is stored for use by the delay programs, and also  $S_o = \sin \phi$  and  $C_o = \cos \phi$  are computed in single precision and stored in sector zero. The program also computes in double precision the fringe rates

$$R = \frac{d\phi}{dt} = (B_x \cos \delta) \sin H - (B_y \cos \delta) \cos H.$$

These also are stored for later use; and the rate constants

$$DC = \cos R\Delta t$$

$$DS = \sin R\Delta t$$

where  $\Delta t$  is 100 milliseconds for the 85's and 20 milliseconds for the 42', are computed and truncated to single precision and stored in sector zero. These give sufficient information so that the phase may be linearly updated without taking any more trigonometric functions.

2. The data taking routines. The data input routines are entered every 20 ms via the clock interruption. The routines immediately activate the A/D converter which will then sequentially read the correlator and total power voltages, through the DMC without CPU attention. The computer then investigates the "telescope positions ready" line, bit 2 of input line 1162. If this bit has gone from "reset" to "set" in the interval since this routine was last entered,

the telescope positions are input and stored in sector zero in locations SPOS-SPOS+5 for use by other programs, the polarization encoders are read and stored, and the CRT routines are called to display the telescope positions on the CRT. If the CRT routine is busy, the display is not updated.

At the completion of these actions, interrupts are re-enabled and control is returned. In normal operation one would expect that the A/D converter would have finished operation by this time, so that one is immediately trapped into the A/D routine. This routine first checks to see if it is within the first 100 ms following the action of the data reduction subroutine. If so, no data is accumulated. During the remainder of the 15 second interval, the routine adds the values of the 85' correlator output voltages to those already accumulated in a 0.1 interval, synthesizing a 100 millisecond perfect integrator. The 42' baseline, because of the higher fringe rates, must be handled more rapidly. The quantities S and C computed by the constant initialization routine are updated by the trigonometric addition algorithm

$$C_{i+1} = C_i * DC - S_i * DS$$

$$S_{i+1} = C_i * DS + S_i * DC$$

to produce the sine and cosine of instantaneous phase, at the time of the clock interrupt. This algorithm introduces an exponentially growing error arising from the  $2^{-15}$  truncation errors in DS and DC, which for the  $N^{\text{th}}$  sample to which it applies is approximately

$$E = \exp \left[ \pm 2^{-15} N \right]$$

which limits the length of time it is permissible to go between initialization of S and C. This term amounts to 2% after 600 applications of the algorithm. We apply it here 750 times between reinitialization for the 42', only 150 times for the 85's.

The correlator line reading is then multiplied by  $S_i$ ,  $C_i$  and itself and accumulated to form the four sums

$$C = \sum C_i D_i$$

$$S = \sum S_i D_i$$

$$A = \sum D_i$$

$$Q = \sum D_i^2$$

These sums are left in core for use of the data reduction routines, which are activated every 15 seconds.

The 85' correlator data is processed in the same fashion as the 42' data, except that five 20 ms correlator samples are simply accumulated before the

reduction is done, so that the fringe phase updating and data accumulation is done on 149 samples at 0.1 intervals rather than on 745 samples at 0.02 intervals.

3. The data control routine. A clock is generated by counting the number of interrupts after the last application of the constant initialize routine. Various actions occur at fixed times within this 15 second interval. They are:

- i) The 42' delay line is reset at 0.3, 0.8, 1.3, 1.8, 2.3, 2.8 ..... 14.3, 14.8 seconds.
- ii) The 85-1,2 delay line is reset at 0.4, 1.4, 2.4, 3.4 ..... 14.4 seconds.
- iii) The 85-3 delay line is reset at 0.6, 1.6, 2.6, 3.6 ..... 14.6 seconds.
- iv) The full range of the A/D lines (rather than just the first 10) are read at 12 seconds.
- v) The constant initialization and data reduction routines are called at 15 seconds.

In addition, the 15 second section of the data control routine controls the output buffer -- if it is full after the operation of the data reduction routine, it outputs it and marks it empty. If it is empty before the operation of the data reduction routine, it initializes it, writing the 16 word preface.

It also controls the polarization switching. If the data reduction routine reduced the data from the shortest baseline -- i.e., the 85-2 - 85-3 baseline -- and the observation was initialized in either the P or Q mode, the polarization is switched. The sequence of switching is

	P Mode			Q Mode		
Scope	1	2	3	1	2	3
	L	L	R	L	L	R
	L	R	L	L	R	L
	R	L	L	R	L	L
	R	R	R	R	R	R

The first step of the first cycle of a given observation is replaced by RRR. The gain is increased to the next highest gain setting for those correlators seeing crossed polarizations.

4. The delay line control routines.

i) The 85-1,2 routine. The first time the routine is called in any 15 second interval, the instantaneous phase is obtained from the constant initialization routine, and multiplied by an appropriate constant to convert it to delay steps, and



the fringe rate is converted to delay steps/second, and saved. This is multiplied by .3 to account for the 0.3 seconds which have passed between the operation of the constant initialization routine and the first call to the delay line routine. This and an internally stored arbitrary constant (read from cards by the transient routine "BASE") are added to the geometric delay (computed from the phase), and this number is saved and also converted from twos complement binary to sign-magnitude binary and output to the delay line register.

On subsequent calls, the routine adds the integer second times the delay rate to this initial delay, and again outputs to the delay line register.

ii) The 85-3 routine. The 85-3 routine operates in much the same fashion as the 85-1,2 routine, except that it first examines the 85-1,2 delay line setting and determines if it is in the 85-2 or 85-1 IF. The antenna not using the delay line is the delay reference for the array, so that the geometric phase of the 85-2,3 or 85-1,3 baseline is selected to describe the delay of 85-3 relative to the reference antenna, as needed.

5. The data reduction routines. The data reduction routines are called immediately following the constant initialization routine, so the phases available to this routine are the instantaneous phases computed 0.1 second after the data to be reduced was taken. Denoting this by  $\phi_0$  and applying the linear rate approximation, the problem is to fit the data taken by a sine wave plus a constant. The equations of condition are

$$A_C \cos(\phi_0 - k\Delta) + A_S \sin(\phi_0 - k\Delta) + A_D = D_k$$

where  $k = 1, 2, \dots, 149$  for the 85' baselines, and  $k = 5, 6, 7, \dots, 749$  for the 42'. The least squares condition is thus

$$\left( \begin{array}{ccc} \sum_{k=N_1}^{N_2} \cos^2(\phi_0 - k\Delta) & \sum_{k=N_1}^{N_2} \sin(\phi_0 - k\Delta) \cos(\phi_0 - k\Delta) & \sum \cos(\phi_0 - k\Delta) \\ \sum_{k=N_1}^{N_2} \sin(\phi_0 - k\Delta) \cos(\phi_0 - k\Delta) & \sum_{k=N_1}^{N_2} \sin^2(\phi_0 - k\Delta) & \sum \sin(\phi_0 - k\Delta) \\ \sum \cos(\phi_0 - k\Delta) & \sum \sin(\phi_0 - k\Delta) & \sum 1 \end{array} \right) \begin{pmatrix} A_C \\ A_S \\ A_D \end{pmatrix} = X$$

$$(A_C, A_S, A_D) = \begin{pmatrix} \sum D_k \cos(\phi_0 - k\Delta) \\ \sum D_k \sin(\phi_0 - k\Delta) \\ \sum D_k \end{pmatrix}$$

where the matrix is understood to be symmetric and the range of summations is assumed to be from  $N_1$  to  $N_2$ . Defining

$$N = N_2 - N_1 + 1$$

and

$$\bar{N} = \frac{1}{2} (N_1 + N_2)$$

and applying some trigonometric identities and employing complex notation, this reduces to

$$(A_C, A_S, A_D) \left( \begin{array}{c} \frac{N}{2} + \frac{1}{2} \operatorname{Re} \Sigma \left[ e^{2i(\phi_0 - k\Delta)} \right] \frac{1}{2} \operatorname{Im} \Sigma \left[ e^{2i(\phi_0 - k\Delta)} \right] \operatorname{Re} \Sigma \left[ e^{i(\phi_0 - k\Delta)} \right] \\ \operatorname{Im} \Sigma \left[ e^{i(\phi_0 - k\Delta)} \right] \\ N \end{array} \right) \\ = \begin{pmatrix} C \\ S \\ A \end{pmatrix}$$

where the 2,2 component of the matrix has been omitted, since it is obviously  $N$  minus the 1,1 component. Employing the well-known expression for the sum of exponentials

$$\sum_{k=N_1}^{N_2} e^{i(k\delta + \zeta)} = e^{i\zeta} \frac{e^{iN_1\delta} - e^{i(N_2 + 1)\delta}}{1 - e^{i\delta}} \\ = e^{i\zeta + \bar{N}\delta} \frac{\sin \frac{N}{2} \delta}{\sin \frac{\delta}{2}}$$

This reduces to

$$(A_C, A_S, A_D) \left( \begin{array}{c} \left[ \frac{1}{2} + \frac{1}{2} \cos 2(\zeta - \bar{N}\Delta) \frac{\sin N\Delta}{N \sin \Delta} \right] \frac{1}{2} \left[ \sin 2(\zeta - \bar{N}\Delta) \frac{\sin N\Delta}{N \sin \Delta} \right] \cos (\zeta - \bar{N}\Delta) \frac{\sin \frac{N\Delta}{2}}{N \sin \frac{\Delta}{2}} \\ \sin (\zeta - \bar{N}\Delta) \frac{\sin \frac{N\Delta}{2}}{N \sin \frac{\Delta}{2}} \\ N \end{array} \right) \\ = \frac{1}{N} \begin{pmatrix} C \\ S \\ A \end{pmatrix}$$

In order that the above matrix be far from singular, it may be accumulated, term by term for more than 15 seconds. The condition matrix and the results vector are accumulated for an integer number of 15 second intervals, until the  $\int \left| \frac{d\phi}{dt} \right| dt$  exceeds  $360^\circ$ . If this condition is not met, the computer outputs zeros for this correlator, and marks the output dummy.

If data is to be reduced, the inverse of the condition matrix is calculated by the method of minors, and the results

$$(A_C, A_S, A_D) = \frac{1}{N} \begin{pmatrix} \frac{1}{2} + \frac{1}{2} \cos 2(\zeta - \bar{N}\Delta) \frac{\sin N\Delta}{N \sin \Delta} & \frac{1}{2} \sin 2(\zeta - \bar{N}\Delta) \frac{\sin N\Delta}{N \sin \Delta} & \cos(\zeta - \bar{N}\Delta) \frac{\sin \frac{N\Delta}{2}}{N \sin \frac{\Delta}{2}} \\ & & \sin(\zeta - \bar{N}\Delta) \frac{\sin \frac{N\Delta}{2}}{N \sin \frac{\Delta}{2}} \\ & & 1 \end{pmatrix}^{-1} \begin{pmatrix} C \\ S \\ A \end{pmatrix}$$

are computed. Then the RMS deviation of the points from the fitted wave form is calculated through

$$\text{RMS} = \sqrt{\frac{Q - (A_C, A_S, A_D) \cdot (C, S, A)}{N}}$$

## B. The Mainline Programs

1. The initialization program. The initialization program initializes various constants, such as clearing the results vector accumulation locations and the observation matrix accumulation locations, initializing the interrupt return locations for the clock trap, the A/D trap, the CRT trap, and the teletype trap, and resetting the interrupt counters. It also watches the clock and enables interrupts to start observing on the first interrupt following an even second, other than seconds ending in 0 and 5, which are avoided to minimize interference between disk requests from interrupt and mainline levels.

2. The mainline loop. This program simply watches the sidereal clock and does nothing unless the stop time of the source has been exceeded, in which case it calls exit, or five minutes has passed since the five minute program has been activated, in which case it is activated, or unless one of the alarm bits

has changed, in which case they are printed out. This loop will shortly be enlarged to include checks on various monitor points.

3. The five minute program. This program activates the telescope touch-up program, makes up an A/D log record, and outputs it to disk.

4. The antenna touchup program. This program adjusts antenna positions one axis at a time, using the  $0.35^\circ/\text{min}$  motor, and using the interval timer to turn on the motor on appropriate interval of time proportional to the calculated deviation from proper pointing. The routine calls exit to invoke the SU pointing routines if the initial pointing error exceeds  $100''$  or if the axis is not corrected to within  $30''$  with eight tries at running the motors.

The position touchup routine is a transient routine, i.e., it is disk resident, and it executes from sector 15, so that both it and a standard operator called transient routine may be active at the same time. Using the interval timer for interrupts, it permits computation to occur simultaneously with antenna movement.

The antenna pointing errors are computed using a 16 term interpolation formula. These formulae were suggested because a physical meaning could be assigned to each term. However, encoder errors and nonlinear deflections are absorbed into the constants to such an extent that a physical interpretation of them is to be deprecated. These formulae are

$$\begin{aligned} \Delta\alpha \cos \delta = & A_0 \cos \delta + A_1 \sin H \cos \delta + A_2 \cos H \cos \delta + \\ & + (A_3 + A_4 \sin H + A_5 \cos H) \sin \delta + \\ & + (A_6 + (A_7/\cos z + A_8) \sin P \sin z \end{aligned}$$

where  $z$  is the zenith distance and  $P$  the paralactic angle.

$$\begin{aligned} \Delta\delta = & A_9 + A_{10} \sin \delta + A_{11} \cos \delta + A_{12} \cos H + A_{13} \sin H \\ & + (A_{14}/\cos z + A_{15}) \cos P \sin z \end{aligned}$$

5. The operator conversation routines. These routines are entered whenever any key on the teletype is depressed. They first interrogate the teletype to find out what the operator wants, and then analyze his request. Some requests are executed from core resident programs -- others cause a disk resident program to be loaded into sector 14 and executed.

The commands recognized are given below. When entered from the teletype, they must be preceded with an initial character (traditionally an X) to attract the attention of the CPU. Transient routines are described in Section V below.

- i) NOTE causes the contents of the line following to be written on disk for observer information.
- ii) CURR - Transient routine to display source name and position, stop time.
- iii) SKIP - Proceed immediately to next source in the observing list, calling SU.
- iv) CONT - Continue this source beyond its stop time until SKIP is typed.
- v) WAIT - Call SU and hang up there until BEGN is typed.
- vi) LOAD - The line following is transmitted to SU for action. SU will load the named program (e.g., WR).
- vii) BASE - Execute transient routine which loads baseline constants, pointing constants, and delay line constants from cards.

TABLE III-1

<u>Resource</u>	<u>Ownership</u>
Disk and DISK routine	Co-usable
CRT and CRT routine	Co-usable
Digital input and output	Co-usable
A/D converter	Priority
Teletype and TYPE routine	Mainline
Interval timer	Mainline
Section 14 transient area	Mainline
Frequency counter	Mainline
Tape transport	Not used
Card reader	Not used

TABLE III-2

## OB Core Map

<u>Sector</u>	<u>Routines</u>	<u>Description</u>
0	Nucleus	
1	Math Pack	Double precision, add, subtract, sine, cosine, multiply, divide, single precision sine, cosine, arc tan, square root.
2	Q	Operator conversation routines.
3	N	Initialization routine, Mainline loop.
4	R	Utility routines - binary to ASCII conversion, sidereal time read and type routines.
5	K	Delay line setting routines.
6	V2	A/D interrupt routines. Take and handle data, count interrupts.
7	V1	20 ms interrupt routines. Activate A/D, input antenna positions if needed.
7	V3	15 second data handling routines.
10	T	CRT antenna position display routines.
11	E	Reduce data at 15 sec intervals.
12	E	
13	DNST	Set up initial phases and fringe rates.
14		Transient area for transient routines and A/D buffer.
15		Transient area, especially for position touchup routine.
16		Loaders, etc., - BSL1, 360 loader, MTL, calling sequences for WR, etc.
17	IOCS	I/O routines.

TABLE III-3

## Alarm Bit Assignments \*

<u>Word</u>	<u>Bit</u>	
1	1	Correlator 1-2 out of range
	2	" 1-3 " " "
	3	" 2-3 " " "
	4	" 42' out of range
	5	85-1 LO unlocked
	6	85-2 " "
	7	85-3 " "
	8	42' " "
	9	85-1 IF level out of range
	10	85-2 " " " " "
	11	85-3 " " " " "
	12	42' " " " " "
	13	Correlator 1-2 excessive RMS
	14	" 1-3 " "
	15	" 2-3 " "
	16	" 42 " "
2	1	85-1 Box temp. out of range
	2	85-2 " " " " "
	3	85-3 " " " " "
	4	Cable pressure out of range
	5	85-1 $\phi$ lock loop unlocked
	6	85-2 " " " "
	7	85-3 " " " "
	8	42' " " " "
	9	85-1 VCO level out of range
	10	85-2 " " " " "
	11	85-3 " " " " "
	12	42' " " " " "
	13	LO level out of range
	14	85-1 Mixer current out of range
	15	85-2 " " " " "

\* Not yet implemented, July 1968.



TABLE III-3, continued

<u>Word</u>	<u>Bit</u>	
	16	85-3 Mixer current out of range
3	1	L0 Frequency out of range
	2	85-1 Manual Control
	3	85-2 " "
	4	85-3 " "
	5	Receiver 85-1 Manual Control
	6	" 85-2 " "
	7	" 85-3 " "
	8	Delay 1-2 " "
	9	Delay 3 " "
	10	Correlator 1-2 " "
	11	" 1-3 " "
	12	" 2-3 " "
	13	Polarization and focus "
	14	Nearly out of disk space
	15	Delay 4 Manual Control
4	1	Fringes too weak correlator 1-2
	2	" " " " 1-3
	3	" " " " 2-3
	4	" " " " 42'
	5	Interference 85-1
	6	" 85-2
	7	" 85-3
	8	" 42'
	9	Interference correlator 1-2
	10	" " 1-3
	11	" " 2-3
	12	" " 42'
	13	Delay 1-2 out of range
	14	Delay 2-3 " " "
	15	Delay 3 " " "

OB Mainline

First Page

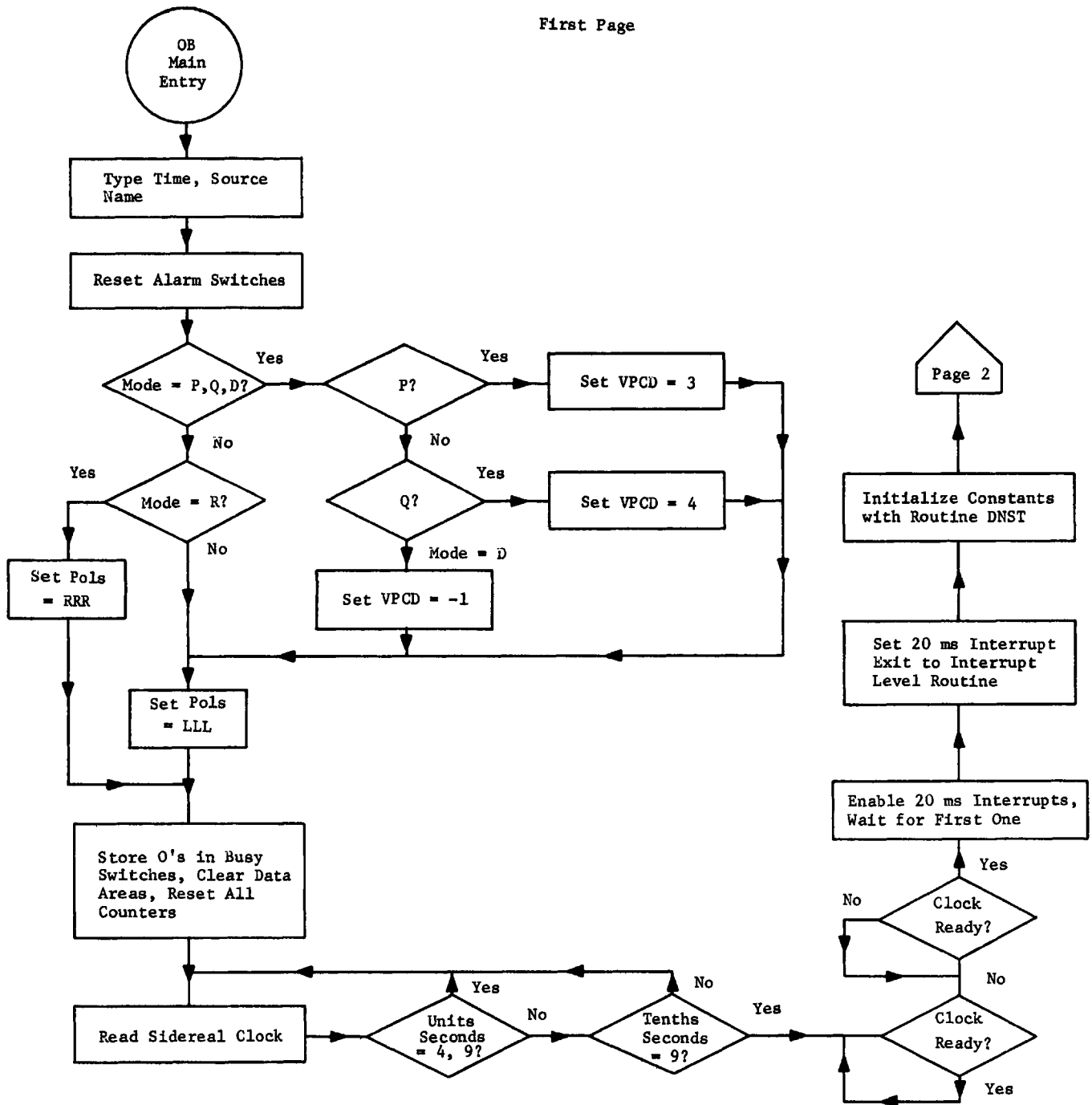


Figure 3-1. a)

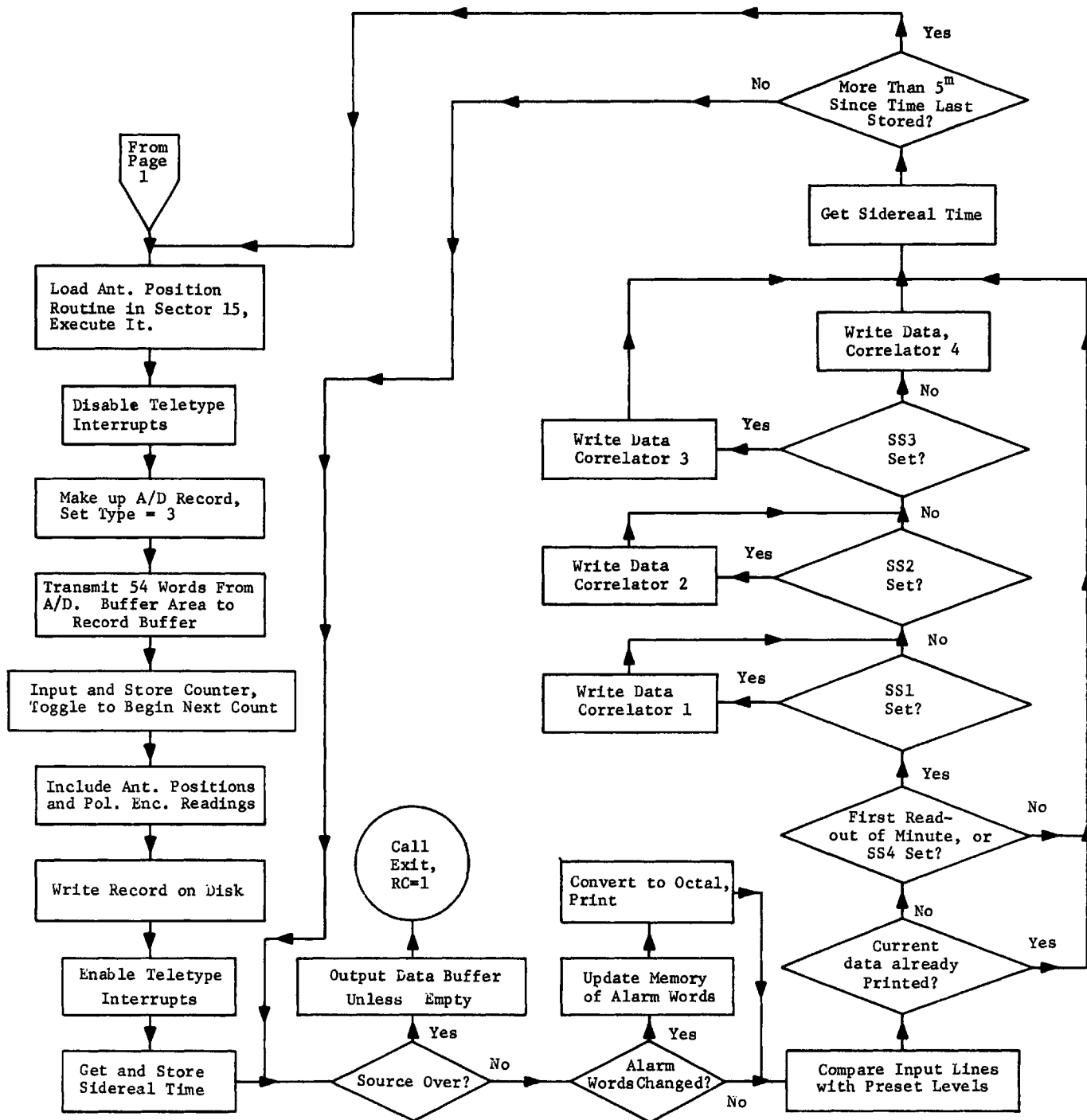
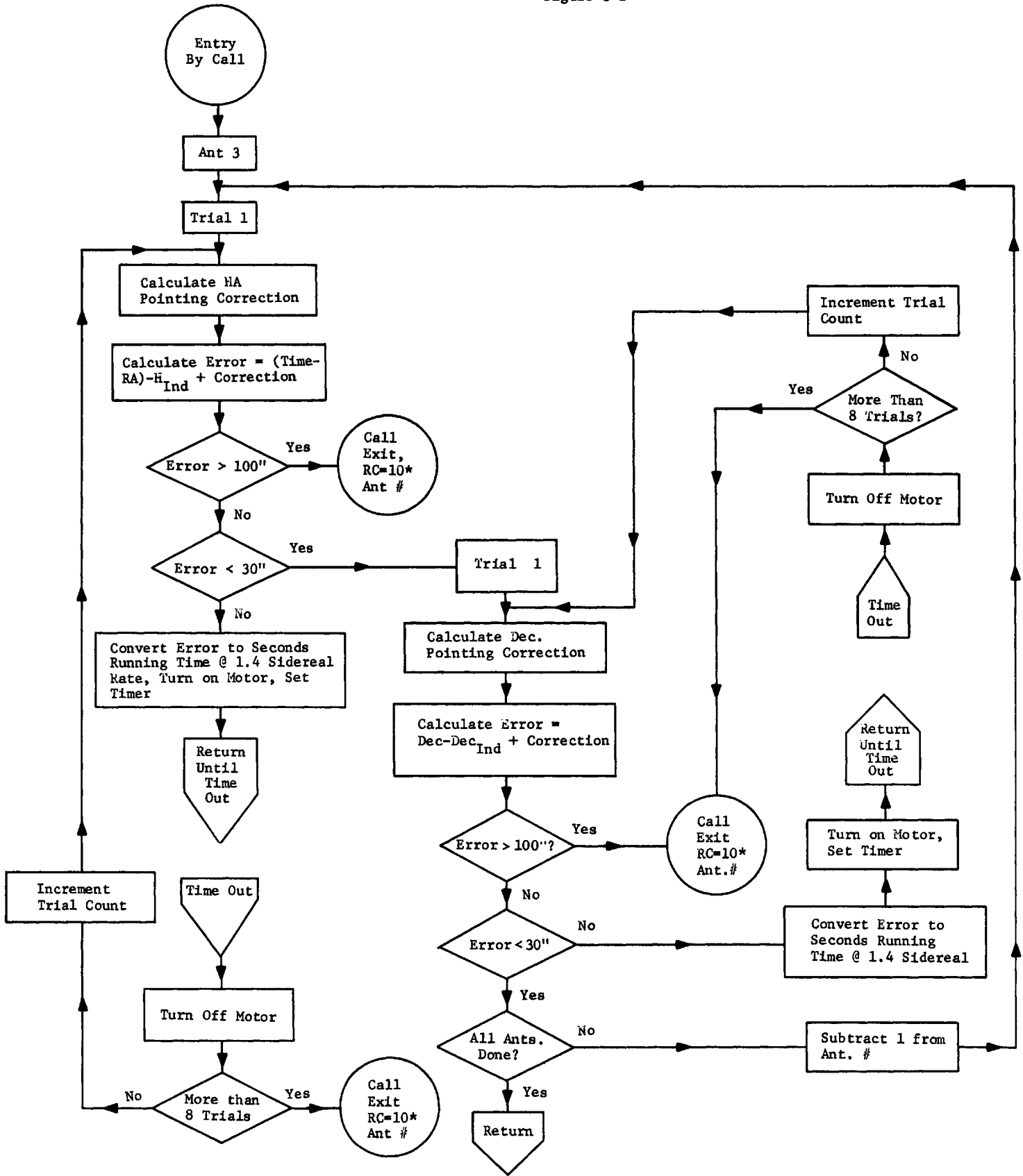


Figure 3-1. b)

Figure 3-2



20 Millisecond Interrupt Program

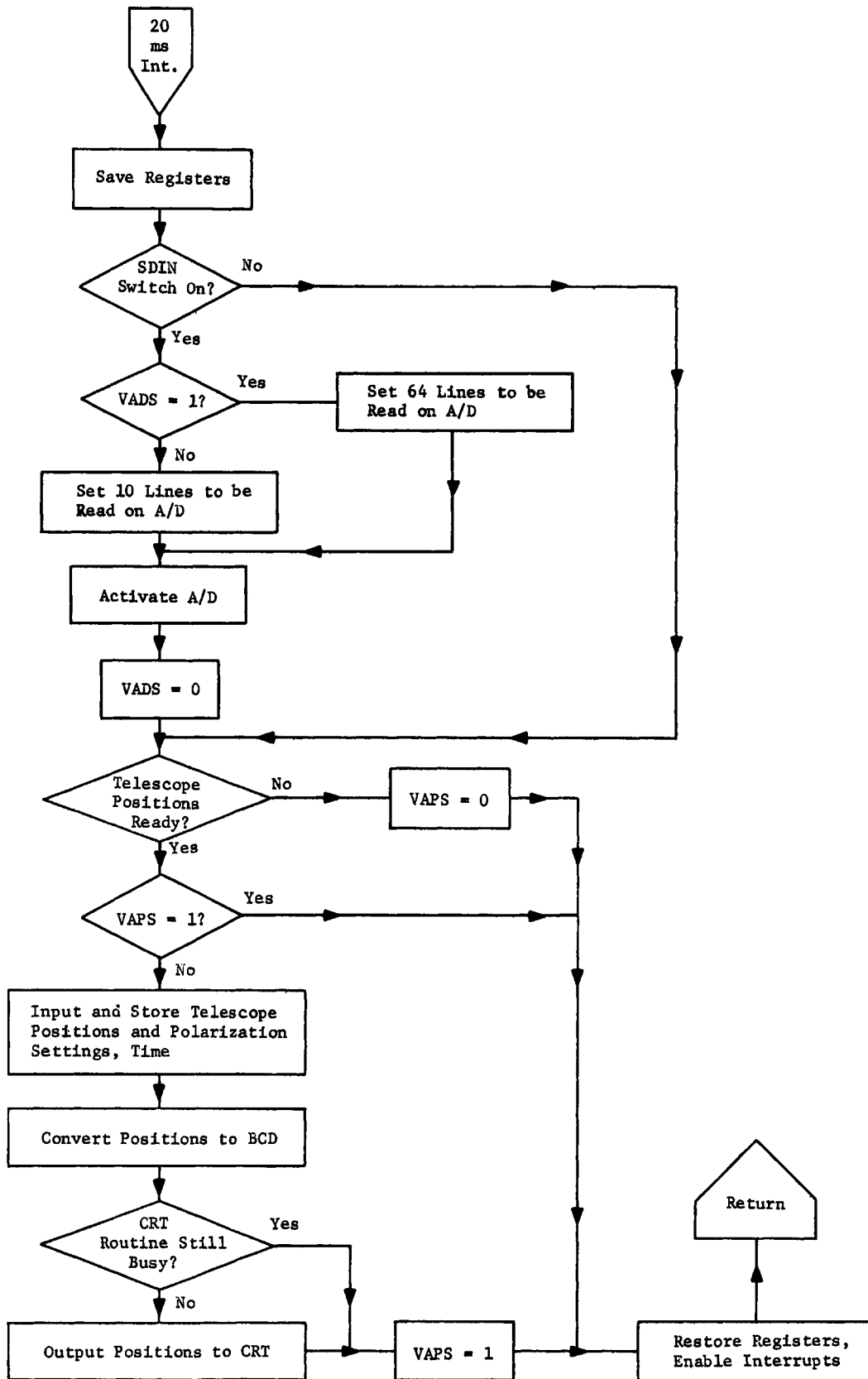
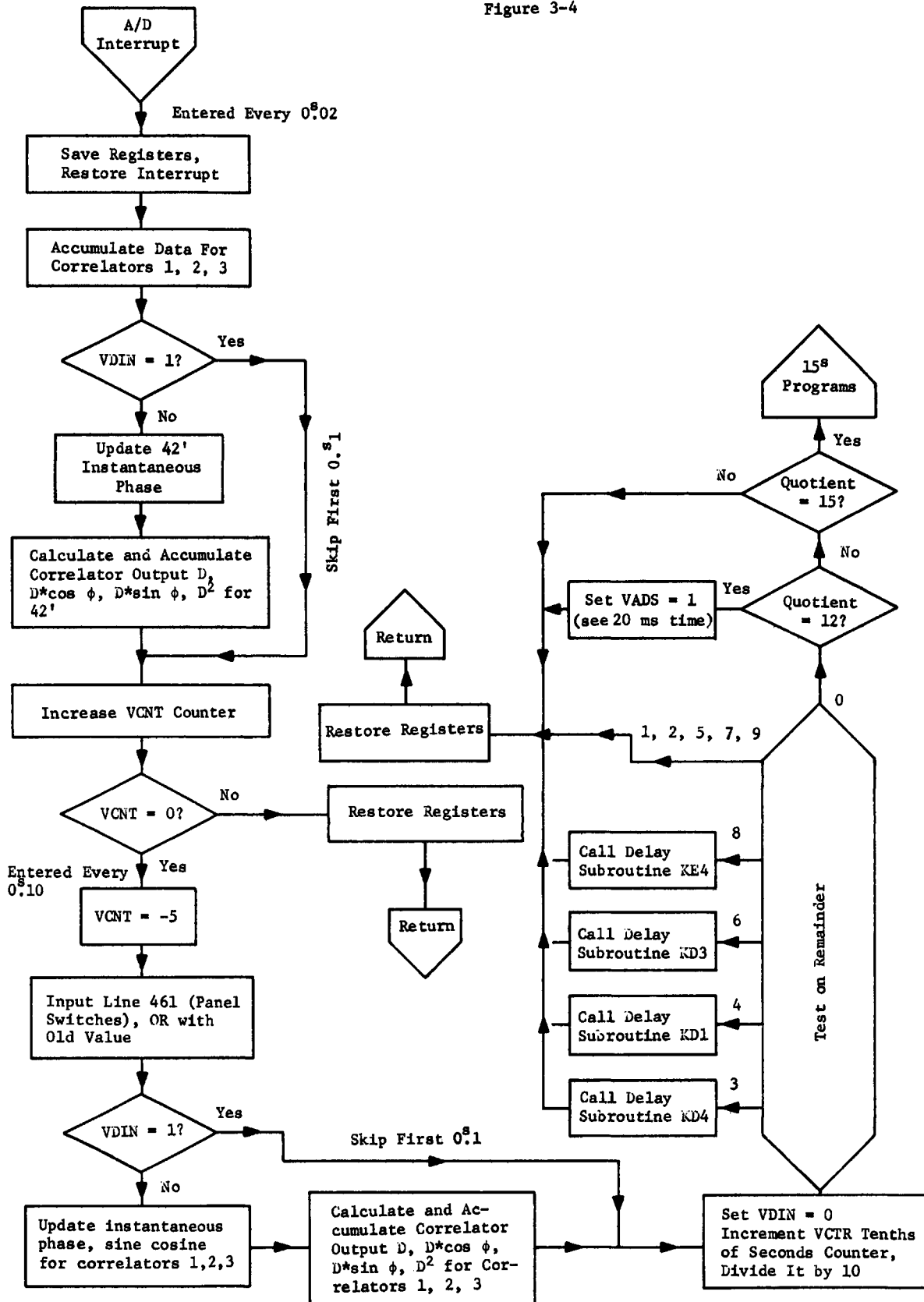


Figure 3-3.

A/D Converter Interrupt Routine

Figure 3-4



Delay Line Routines

All delay line routines are called with the number of seconds since the last running of DNST in the B register as an argument -- called "ARG" in the flow chart.

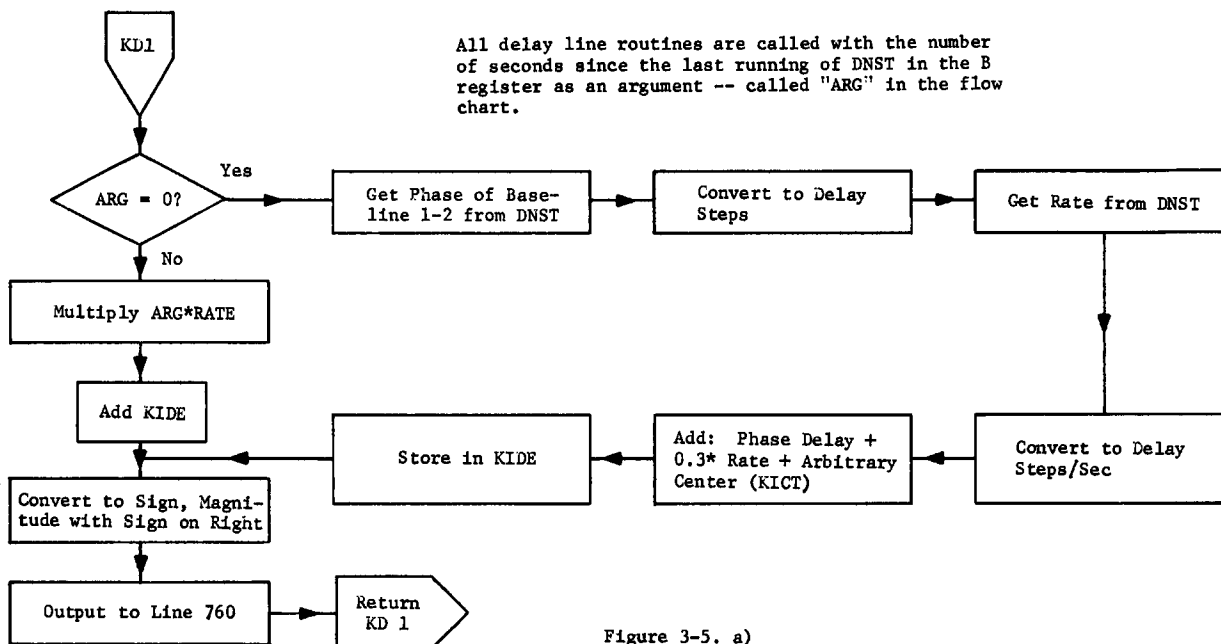


Figure 3-5. a)

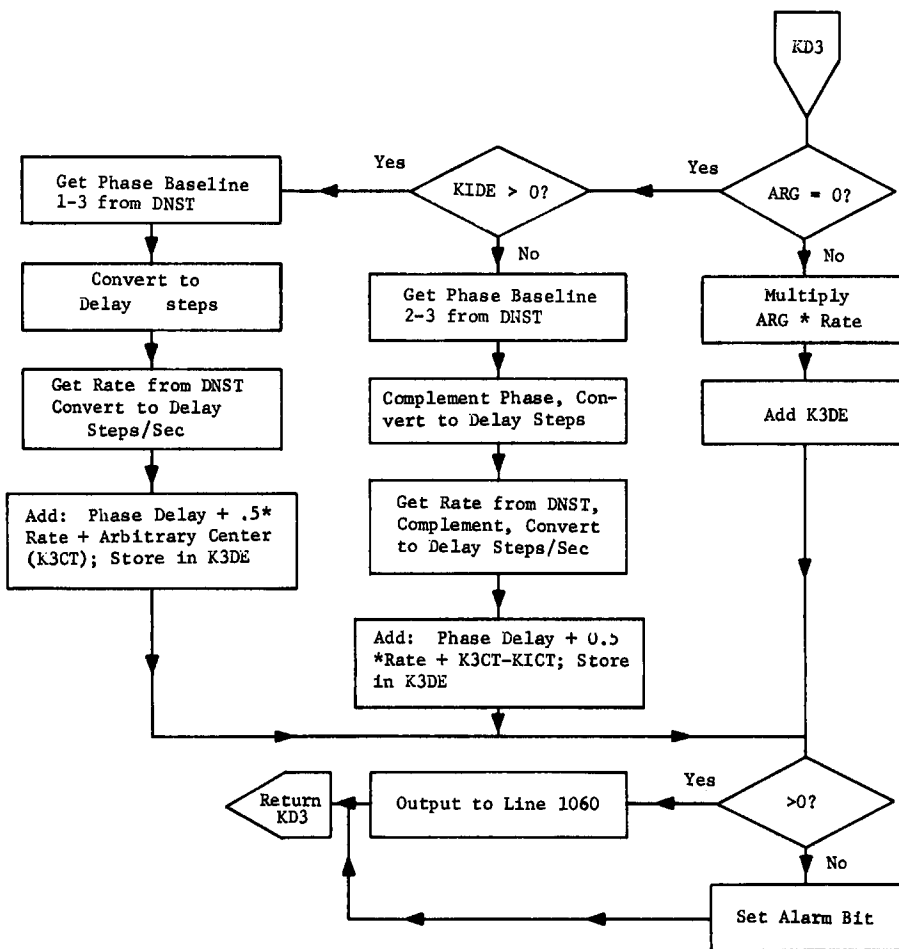


Figure 3-5. b)

Delay Line Routines - 42' Delays

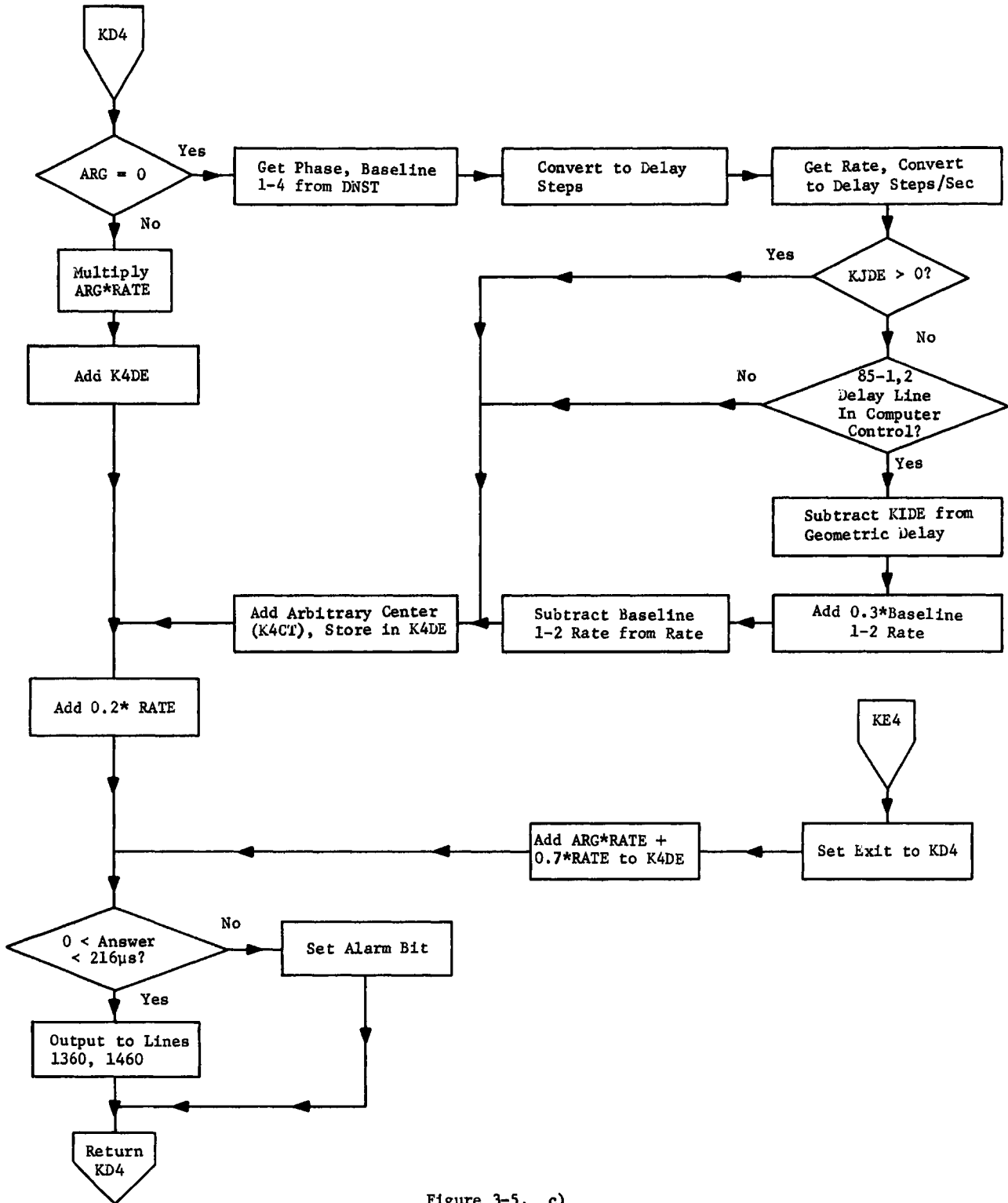


Figure 3-5. c)



15 Second Programs

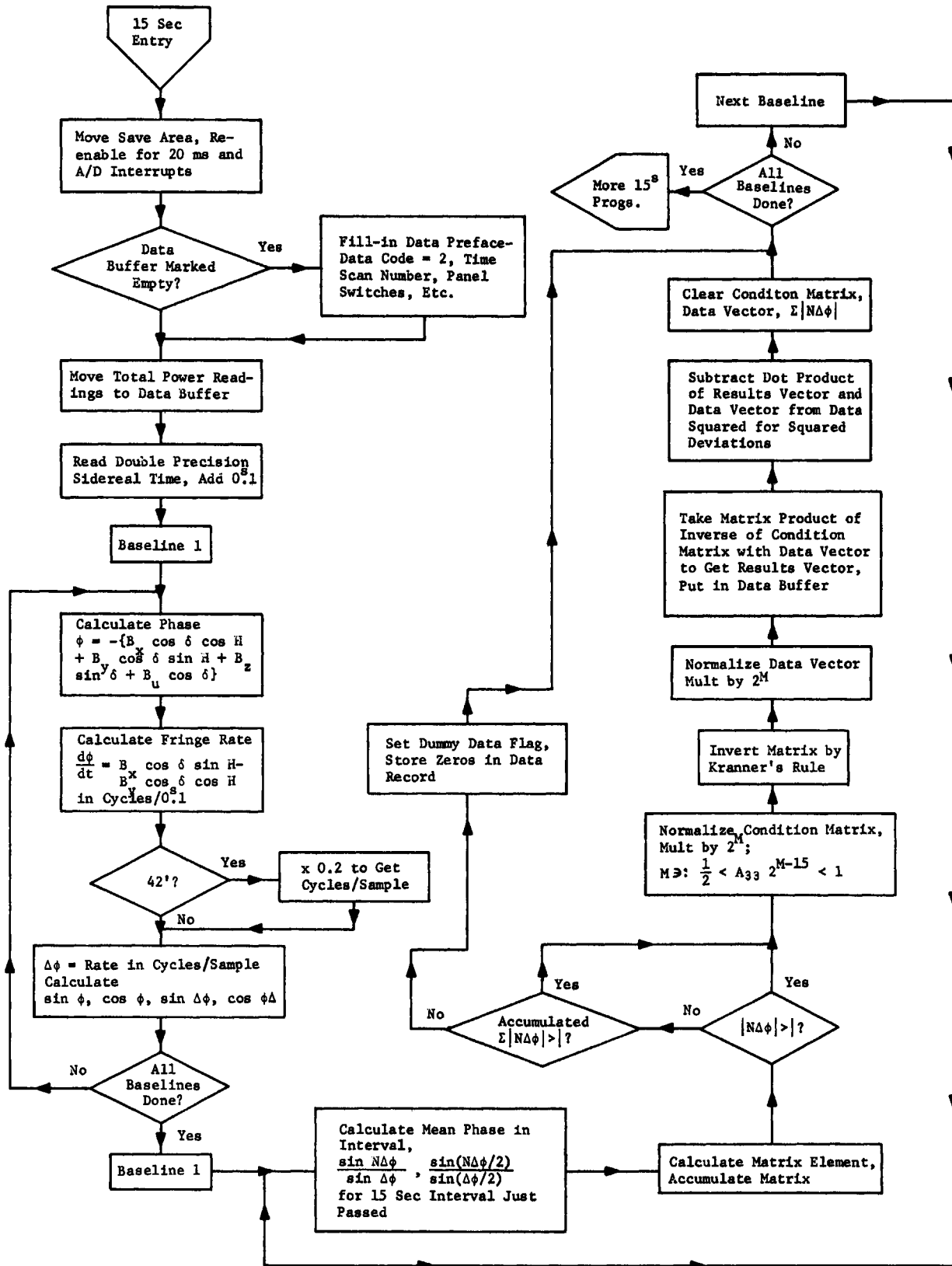


Figure 3-6. a)

## More 15 second Programs

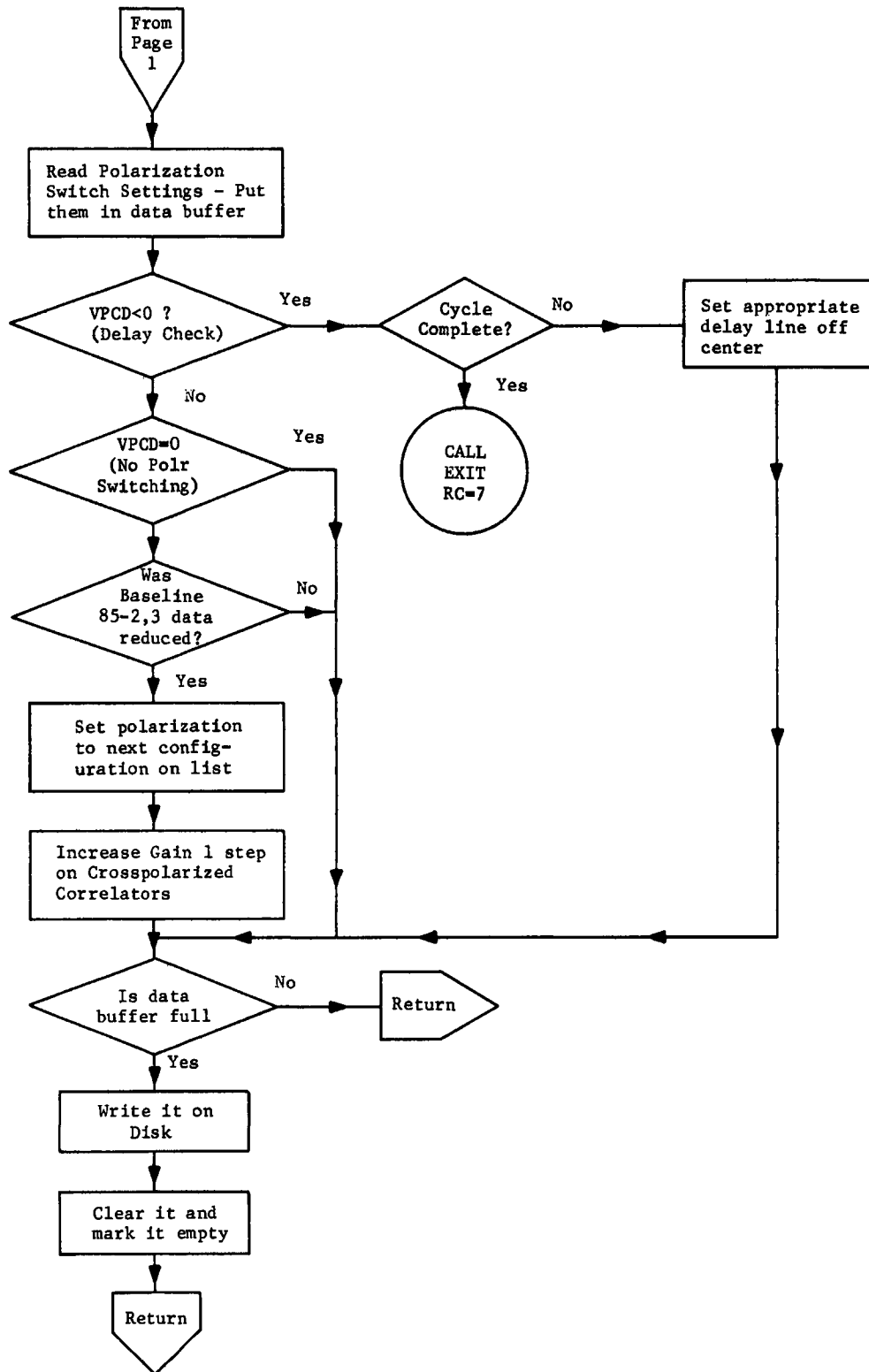


Fig. 3-6 (b)

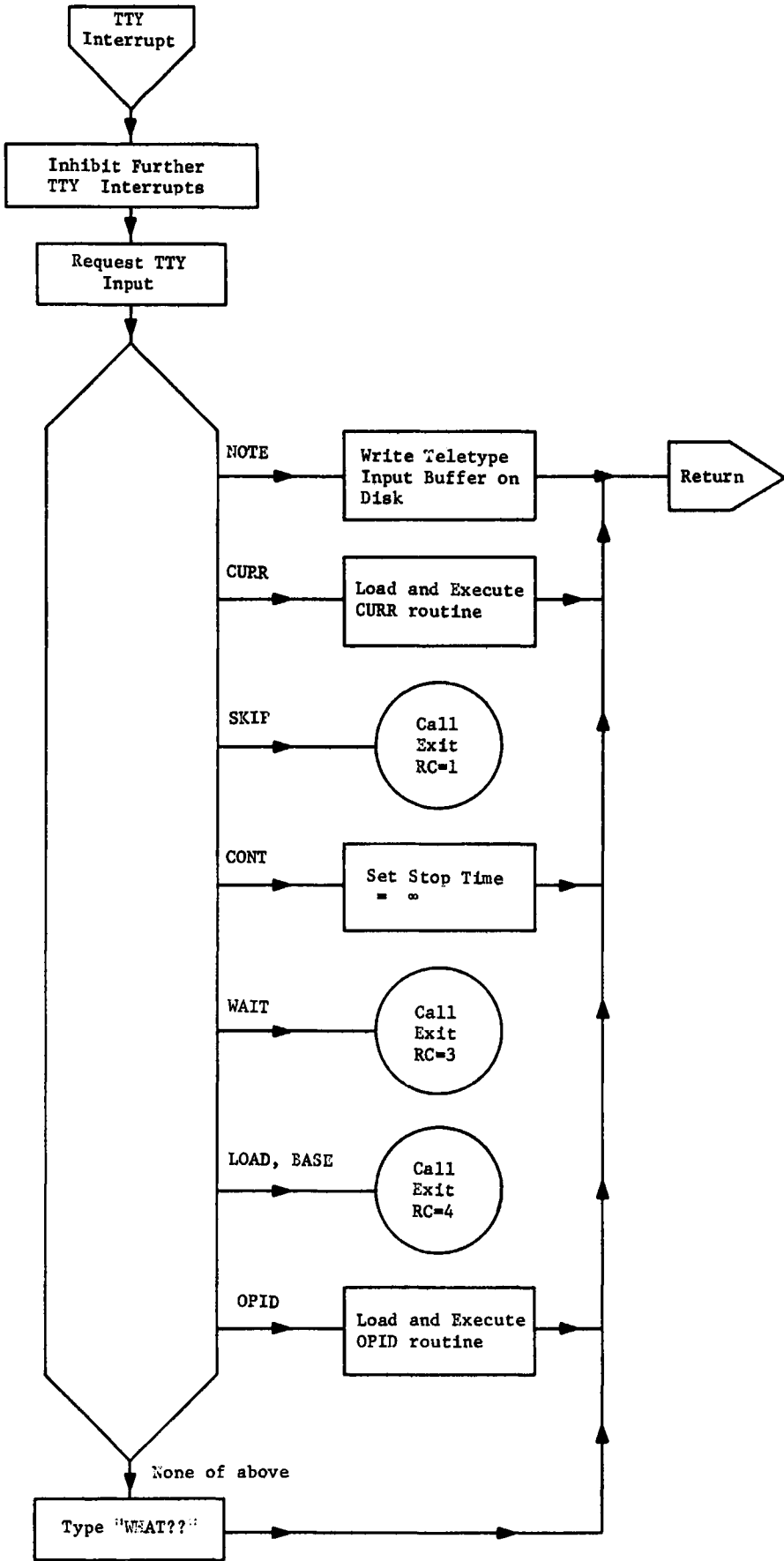


Fig. 3-7 Teletype Interrupt Routines

#### IV. THE SUPERVISOR

The supervisor initializes various constants needed by OB, controls the source list, and does the initial positioning of the antennas. It also is multiprogrammed, but at a much more rudimentary level. The priority level does nothing but slew the telescopes. It is entered every 20 milliseconds, but merely returns immediately unless new telescope positions have become available. Again, operator requests are a sublevel of the mainline--nothing but telescope positioning occurs while they are active. Many of the SU routines are in the form of pseudo-operator-requests generated by the program itself, which cause a transient (disk resident) routine to be loaded into sector 14 and executed.

##### A. NUC Reinitialize

When first called, SU restores the basic constants in NUC--the constants 1, 2, and 3, the addresses of the IOCS routines, and the IOCS routines themselves. A transient routine is called to restore the date, and the interrupt lines are checked for erroneous pending interrupts. The format record is then restored in the delay line memory of the CRT. (This record contains the beam positioning commands and the lettering and telescope numbers. The coordinates are filled in by other routines.)

At this time also, the data area of disk is checked for correctness. If the pointer to disk area is correct, the record it points to is blank; the record previous contains data. If this is not the case, the program requests assistance from the operators to find the proper place in the data area.

##### B. Observing List Control

SU then analyzes the return code, taking the actions indicated in Table I-1. If the return code is a -1, the possibility exists that intermediate term memory has been destroyed, so that SU prints the scan number and asks operator if it is OK. If he answers "NO", SU loads a transient to reload the baseline constants, as well as scan number. The observing list is advanced only on the normal OB return code.

In any case, the next source is read from the list, and the source description is transmitted to the area in nuc, SRCE, and the scan number incremented (except for return codes 6, 10, 20, and 30) and inserted.

If the source list is found empty, WR is called to refill it. If the stop time read from disk has been exceeded, the list is advanced, and the source name with the message "Already Over" is typed.

If the return code is other than 6, 10, 20, or 30, the source parameters are typed on the teletype, and the scan number is incremented. For the manual restart and excessive pointing error return codes, the data has presumably already been printed and a scan number assigned to the observation.

#### C. Constant Initialize

$B_x \cos \delta$ ,  $B_y \cos \delta$ , and  $B_z \sin \delta$  are calculated for the use of OB. The axial baseline parameter for the 42-foot contains a term  $L \cos \delta$  as well as the usual  $B_z \sin \delta$ , when  $L$  is the distance between the declination and polar axes of the 85-foot antennas, measured in wavelengths. This is calculated and applied at this time. The noise tube modulation is turned off, and the program waits 15 seconds for the synchronous detectors to settle to a zero line. (If the scope positioning is completed within this interval, the sync dets are turned back on and the old baseline is used.) This baseline is read and recorded in nuc.

#### D. Header Record

After the scope positioning is complete, a header record is written on the output disk unit with the source parameters, etc., including the antenna positions. These are recorded prior to the PALL routine touchup, but are within 1' of the final indicated positions. The format of this record is given in Table I-2.

Having progressed this far, SU calls OB.

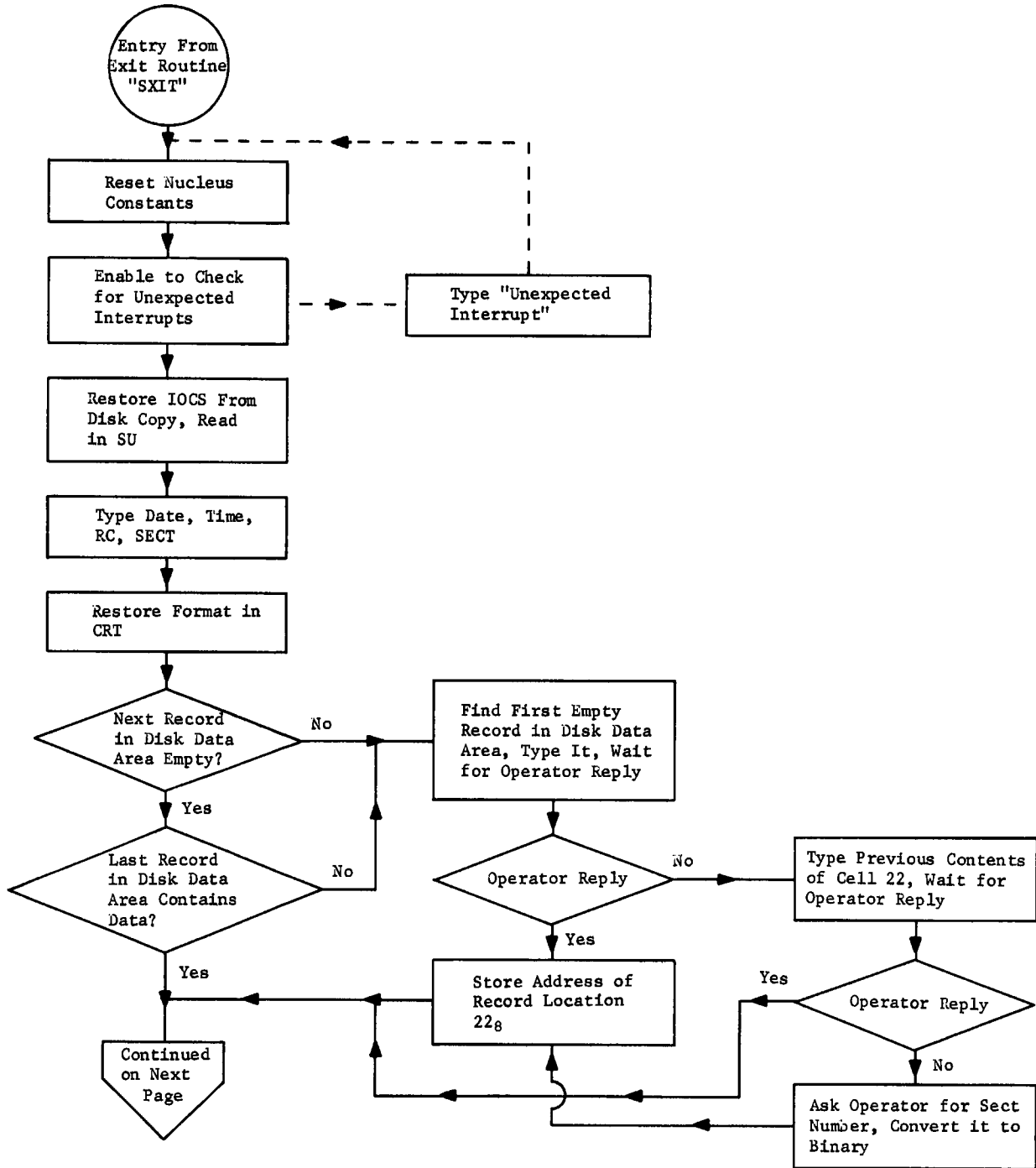


Figure 4-1 a) SU Mainline

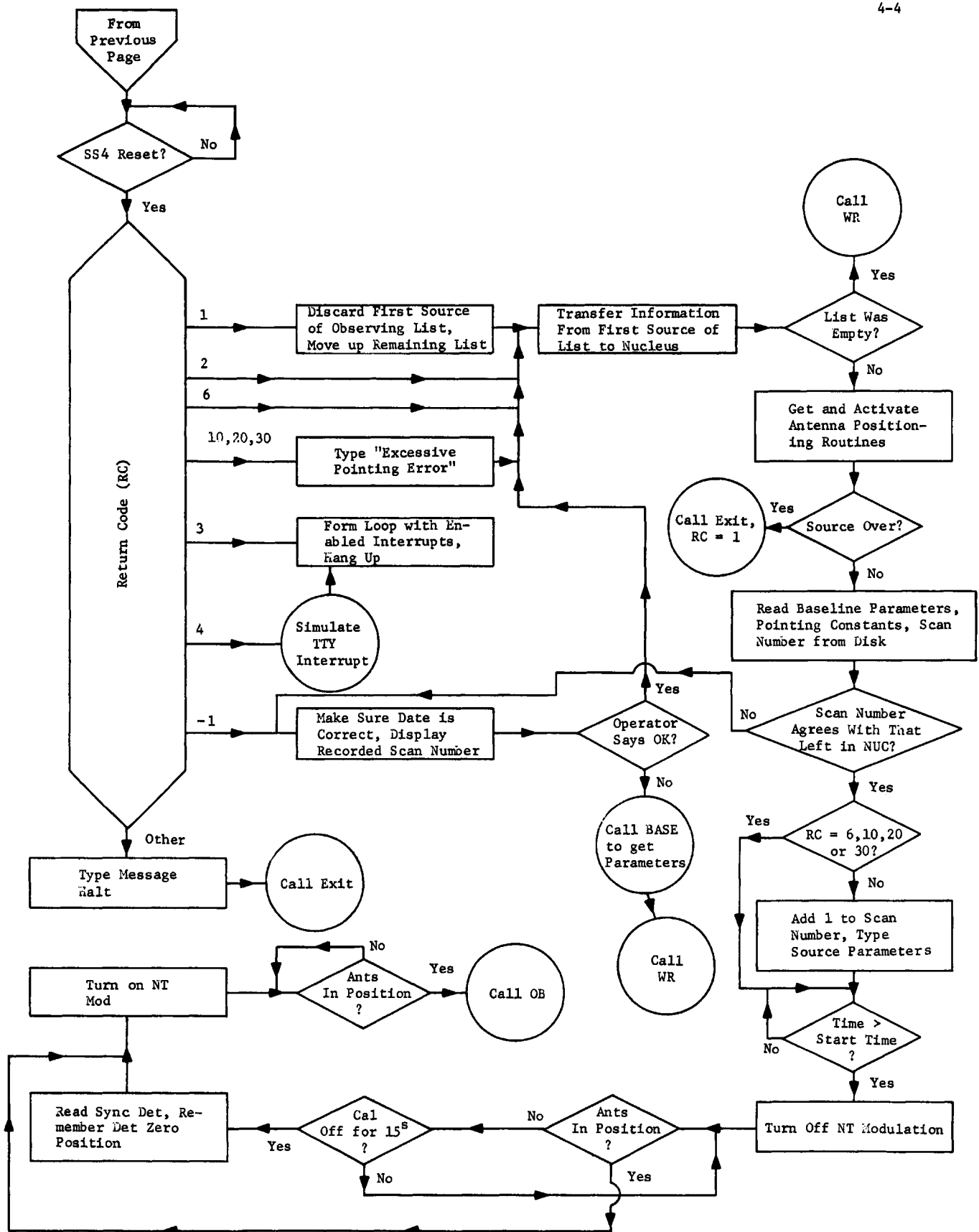


Figure 4-1 b) SU Mainline  
page 2

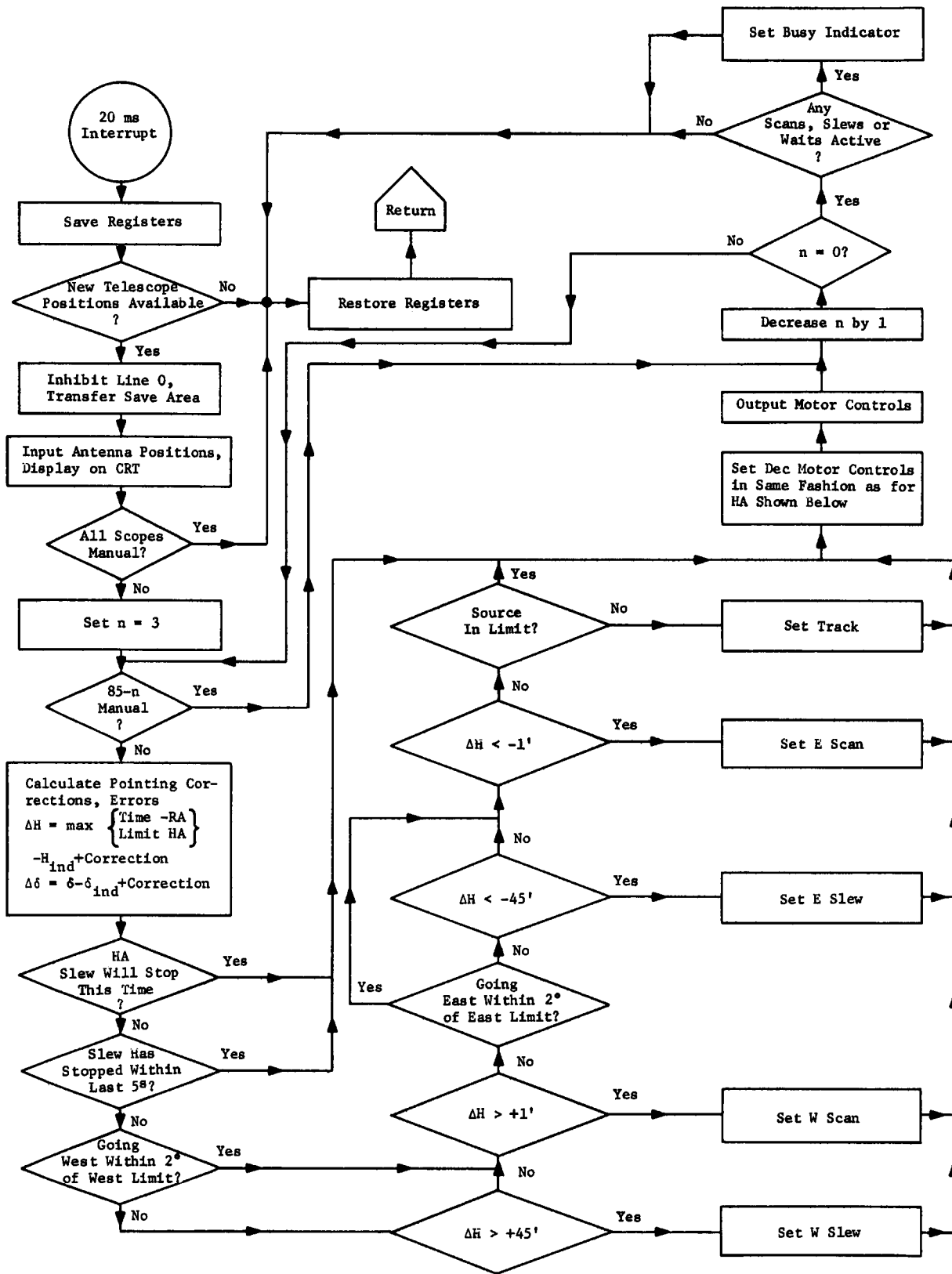


Figure 4-2. SU Antenna Positioner



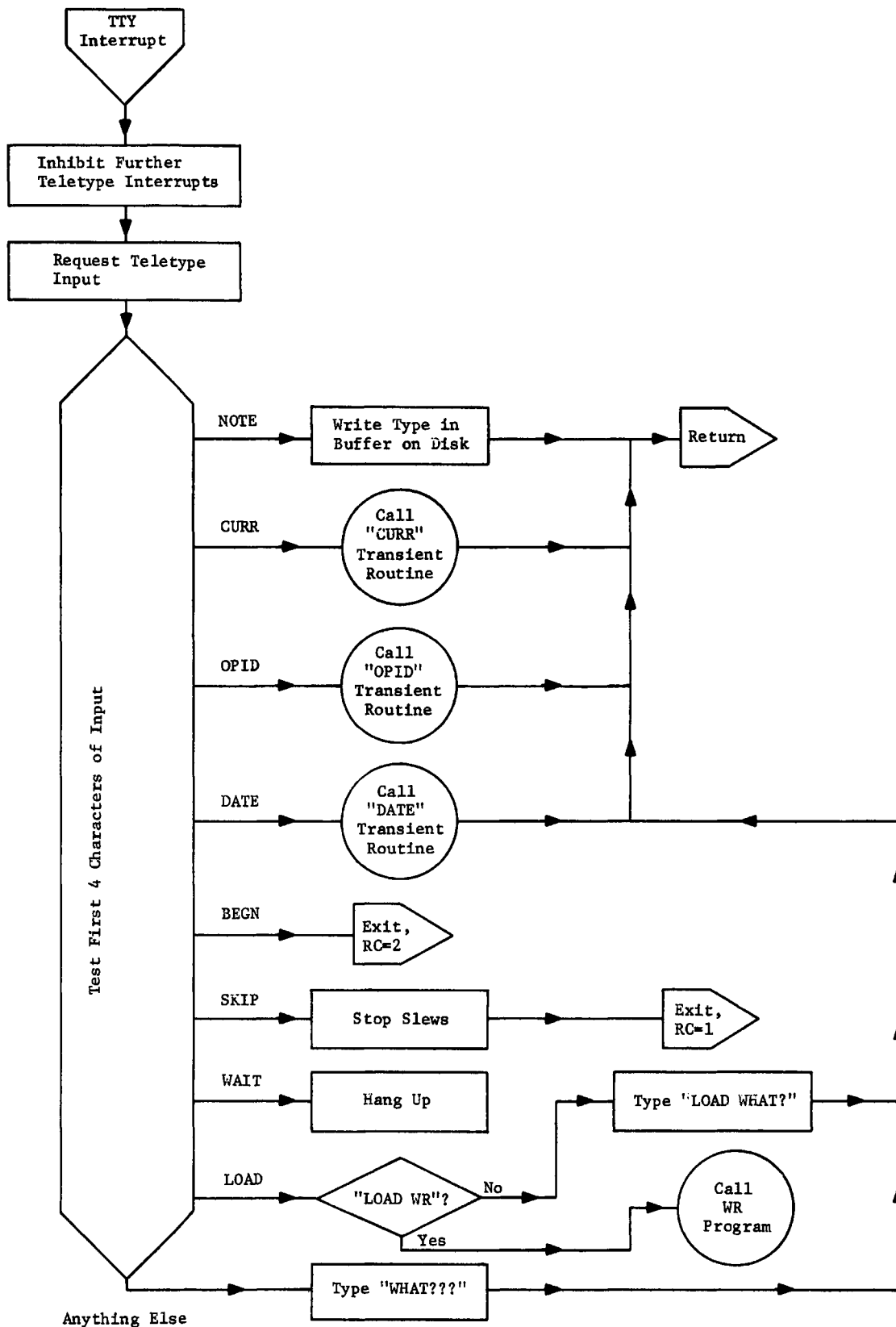


Figure 4-3. SU Operator Request Routine

## V. THE OBSERVING LIST WRITER

A. General Description

The Observing List Writer (WR) makes up a list of the sources to be observed next. This list is left on disk to be managed by SU.

WR will need the Besselian day numbers for its task. There is a record in disk memory reserved for storing them. It is first examined for their presence. If they are there, they are transferred to core; if not, the program asks the operator to enter them through the teletype.

If there is a preexisting source list, the program asks if the cards which are being inserted now are to be added to the end of the program (so that a continuing observing list may be added before the existing one is terminated), to be inserted at the beginning (so that sources may be conveniently interpolated) or to replace the existing list. These are indicated to the program by typing "FOLLOW", "PRECEDE", OR "REPLACE", respectively, on the teletype.

The program then enters a loop in which it first reads a card and corrects all the fields to the appropriate format. Then it examines a buffer which contains all of the sources previously entered. If it is not present, the program examines the disk source list. If found in either list, the parameters not specified on the card are transferred from the previous apparition or from the disk list. If the positions are not specified on the card, and are not found in one of the old lists, the program cannot proceed and calls exit. If the positions are found both places, the program notifies the operator and asks which is to be used. If the position on the card is not a 1950 position, it is immediately accepted, though the difference is still noted. This checking of internal lists is not performed if SS4 is set.

Then column 38 is examined to determine if the positions are to be accepted as are, to have the Besselian day numbers applied, or to be precessed to the appropriate year, before the application of the day numbers. General precession is performed according to the exact formula of page 31 of the Explanatory Supplement to the Ephemeris, and the Besselian day numbers are applied according to the formulae of page 493 of the American Ephemeris and Nautical Almanac. The source position is then compared with the telescope limits. A start time is inserted, being the time at which the source appears above the telescope's limits, or that given on the card, whichever is later. If the observation starts or ends below  $9\ 1/2^\circ$  elevation, WR so informs the operator.

The record describing the source is then inserted in the source list (following sources are pushed back), and the appropriate pointers updated. If a source is inserted in a source list already full, the last source in the list is lost.

The above loop is repeated for each card. When all cards have been processed, the observing list is written on disk, and SU is called through the EXIT routine.

#### B. The Card Formats

1. Columns 1-10 contain a source name. The name is left adjusted, i.e., column 1 must not contain a blank. Source names are not recognized as identical unless the blank positioning is identical also. For this reason, it is recommended that source names be written without blanks. We also suggest that unnecessary decimal points be omitted from 3C numbers, e.g., 3C2 instead of 3C2. or 3C2.0, but still 3C309.1.

2. Columns 12-23 contain the right ascension in the format HH MM SS.SSS. Leading zeros must appear. Zeros following the decimal point may be omitted, though the decimal point itself must appear.

3. Columns 25-36 contain the declination in the format SDD MM SS.SS. The sign(S) may be a blank (taken as plus) a BCD (026 punch) +, a EBCDIC (029 punch or 360 punch) +, or a -. Leading zeros must appear. The zeros following the decimal point and the point itself may be omitted.

4. Column 38 contains the epoch of the position. A blank or zero indicates a 1950 position, an M indicates a mean position for the nearest integer Besselian year. A D indicates that the position is the position of date and no precession is to be applied.

5. Columns 40-46 contain the flux in flux units in the format§SSS.SS. Leading and following zeros may be omitted. If the flux is less than 8, the correlators are run at full gain. If greater than 8, but less than 80, the correlator gain is decreased by 10. If greater than 80, the gain is decreased by 50.

6. Columns 48-50 contain an estimate of angular size, in the format AAU, where AA is two digits and U is the units, U = M is minutes, S is seconds of arc, T is tenths of seconds. If the product of baseline length and source size in radians is greater than about 4, the correlator gain is increased by one

step. If the product is greater than about 16, the gain is increased by two steps\*.

7. Column 52 contains a mode character. A blank requests observation with LLL polarization. A P requests the polarization sequence LLR, LRL, RLL, LLR..., a Q requests the polarization sequence LLR, LRL, RLL, RRR, LLR,..., an R requests observation with RRR polarization. A D requests a check on delay centers\*. All other characters are treated as blanks.

8. Columns 54-58 contain a start time in the format HH MM. A start time need not be given. If one is, the computer will wait until the time is exceeded before starting the observation, though telescopes will be positioned as soon as the request is processed.

9. Columns 60-64 contain a stop time in format HH MM. At approximately ten seconds after this time observation is terminated, and the next observation request is processed.

10. Columns 66-80 are not processed by the computer and are available to the observer for notes and comments.

11. The following columns must contain blanks:

11	31	53
14	37	56
17	39	59
24	47	62
28	51	65

12. Implicit sources of information. There is a list of common sources available on the disk with the above information supplied. The following items may be supplied implicitly:

- a.  $\alpha$
- b.  $\delta$
- c. flux
- d. size

The three sources of information are:

- a. The card itself
- b. The first card of this source in this deck
- c. The disk list

If the positional information from the card disagrees with that of the first card or the disk list, the operator will be asked which to accept (they are compared only for equinox 1950 positions; otherwise the card position is accepted). The flux and size are accepted from the card if specified on it,

---

\* Not yet implemented--7/68.

are taken from the disk list if the source appears in it, or from the first card if it does not appear in the disk list. Flux and angular size are assumed zero unless stated.

13. What must be specified?

Before the card will be processed the following quantities must be supplied:

- a. Non-blank source name
- b.  $\alpha$
- c.  $\delta$
- d. Stop time

The positions may be supplied implicitly, but the name and stop time must appear on the card.

Up to 50 cards may be read in at a time with comparison with the internal lists. If SS4 is set, up to 100 cards are read, and exit is called automatically when the hundredth card is read.

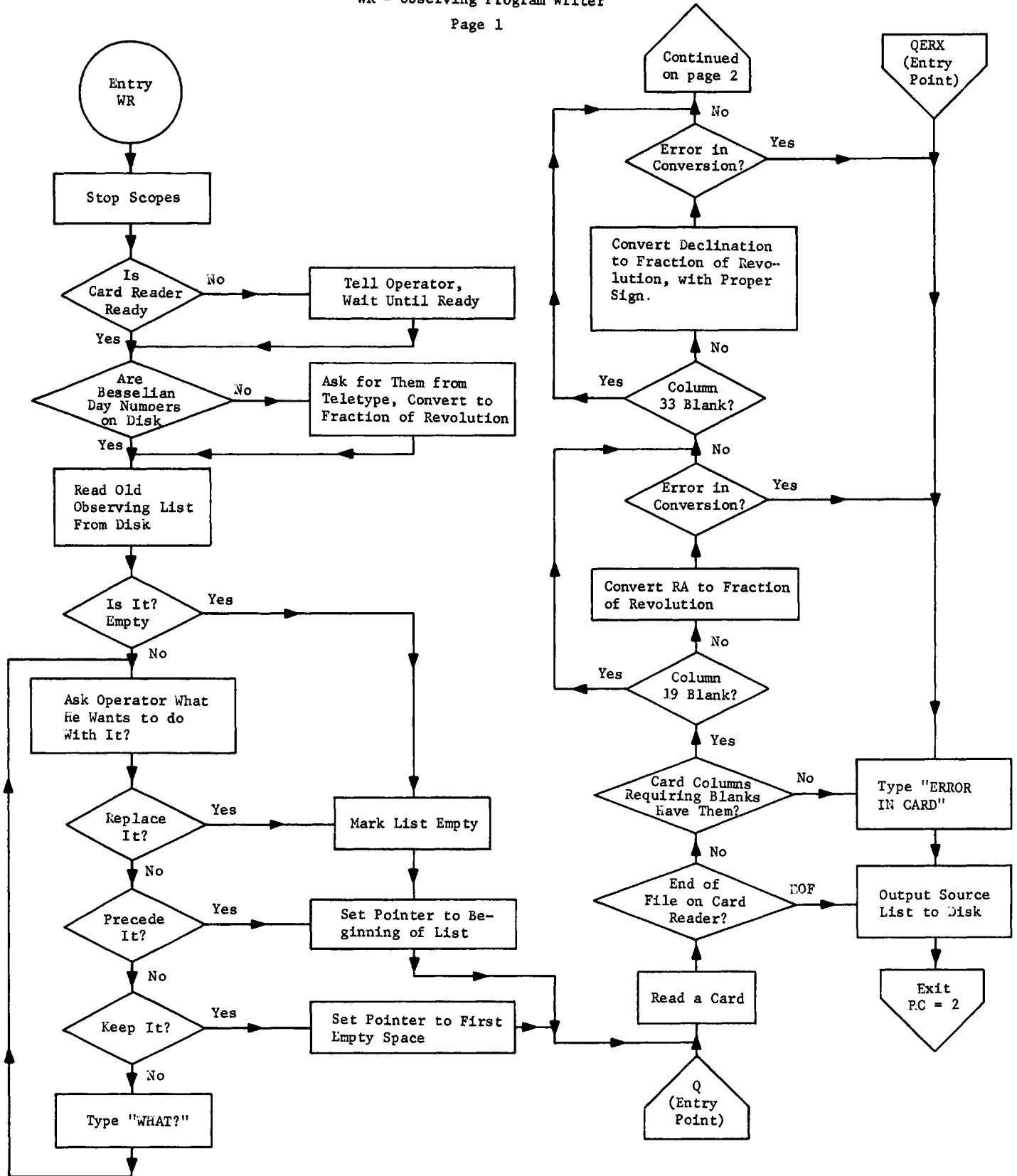


Figure 5-1 a)

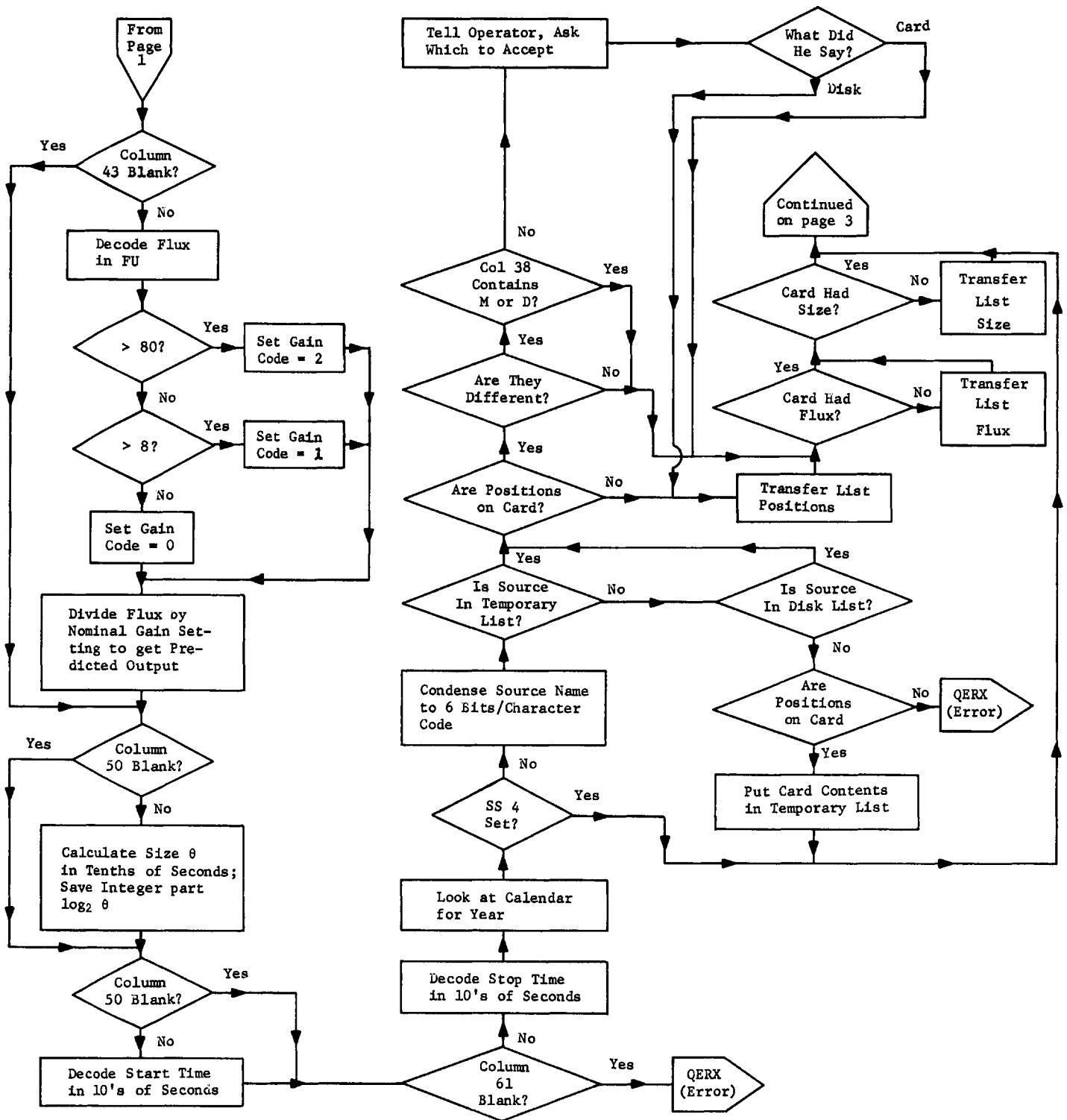


Figure 5-1 b)

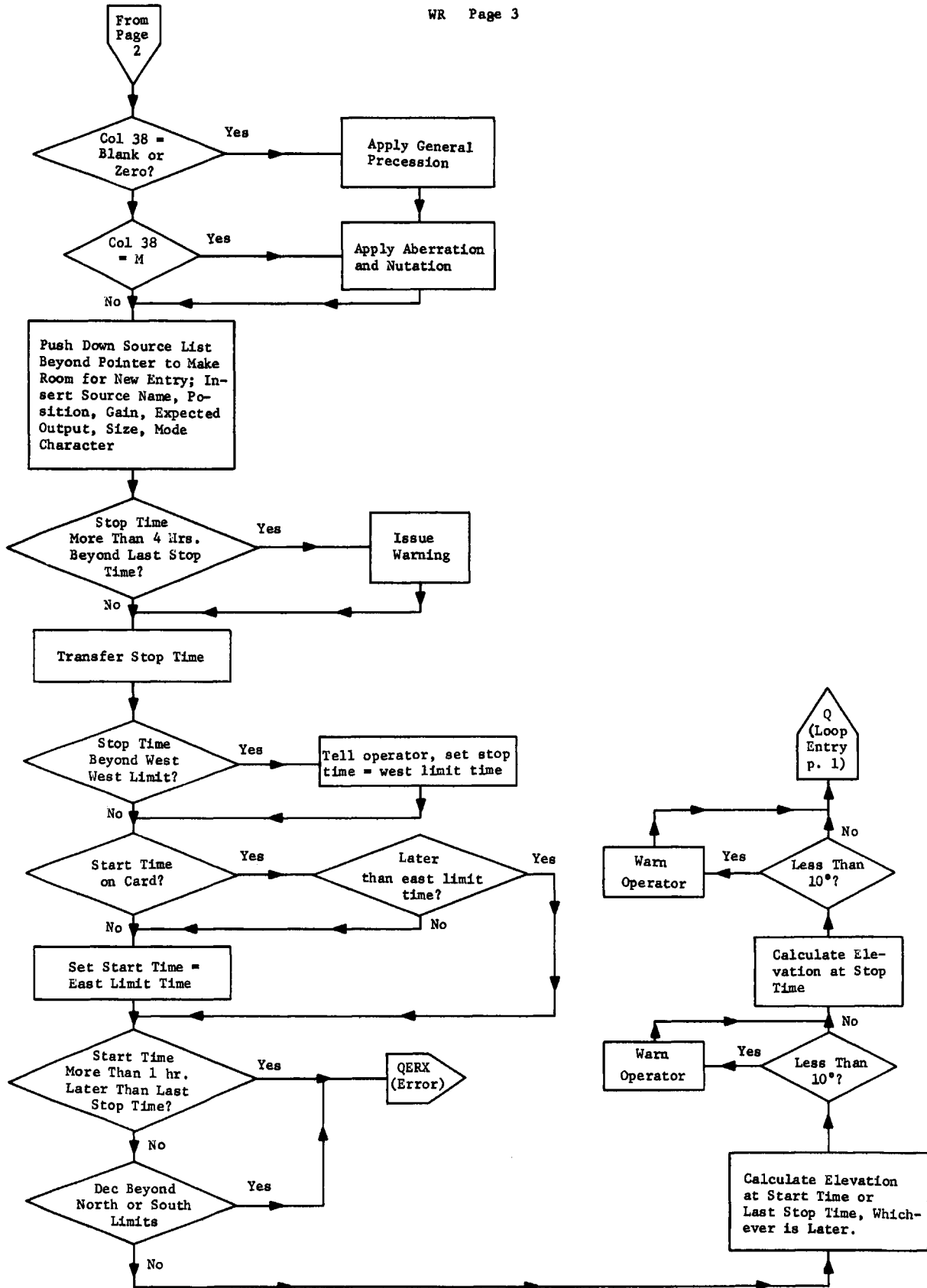


Figure 5-1. c)



## VI. THE TRANSIENT ROUTINES

General Description

The transient routines execute from Sector 14, and are called in to accomplish a specific purpose. They are executed under the operator conversation supervisor, so teletype interruptions are inhibited while they are in execution.

1. CURR writes current source parameters as copied from observing list on the teletype, making a pretty format.
2. OPID is an omnibus routine which asks the operator to enter his initials and the observer's initials.
3. DATE reads the calender on the digital input lines and converts the answer to a local sidereal day number, which is identical with the Greenwich sidereal day number between  $0^{\text{h}}$  LST and  $17^{\text{h}} 40^{\text{m}} 20^{\text{s}}$ .
4. BASE reads the baseline constants, pointing constants, delay line constants, and scan number from cards, and makes up a new constant record. The card formats are given in the figure on the next page.
5. INID checks whether the disk sector pointed to by SECT is indeed clear.
6. CRTN initializes the CRT format record, displaying the telescope numbers and coordinate tables and containing the CRT beam positioning characters.
7. FALL is the OB time antenna position. A flow chart is given in Section III.



## VII. THE STANDALONE ROUTINES

A. CP-Disk-to-Tape Data Copy Routine

This routine writes labeled tapes for the 360. The labels are written in the standard 360 label format, with an expiration date set 3 months in the future, to provide a maximum of protection for the data. It operates in a single program mode, reading from disk, then sequentially writing on tape. After the transfer is complete, zeros are written on the disk to replace the data.

B. PT-Pointing Constant Determination Program

This routine determines the pointing of the telescope. The antenna is pointed to 5 fixed positions relative to the predicted source position--two well off source, two at about the half power points, one pointed directly at the source. If we call the sync detector outputs  $A_1$ - $A_5$  for these points as follows:

Output	$A_1$	$A_2$	$A_3$	$A_4$	$A_5$
Pointing in one coordinate relative to source	-40'	-8!25	0	+8!25	+40'

we may with sufficient accuracy remove the baseline by

$$B_1 = A_2 - \frac{1}{4} (3A_1 + A_5)$$

$$B_2 = A_3 - \frac{1}{2} (A_1 + A_5)$$

$$B_3 = A_4 - \frac{1}{4} (A_1 + 3A_5)$$

If the predicted response is

$$B = A e^{-\frac{(x-a)^2}{2\sigma^2}}$$

where  $A$  is the source strength,

$a$  is the unknown pointing error, and

$\sigma$  is a known parameter describing the beamwidth,

then the unknown quantities  $A$  and  $a$  are determined with sufficient efficiency by

$$a = \frac{\sigma^2}{2b} \ln \frac{B_3}{B_1}$$

where  $b$  is the offset distance,  $8!3$ , and  $A = B_2 e^{\frac{a^2}{2\sigma^2}}$

The program uses the source list generated by WR. The antenna is driven to the source, using the standard slew routines. It is then positioned to the proper offset position relative to the position given by the old pointing constants, first in R.A., then in declination. The antenna is held on each position for 10 seconds, during which time the antenna position is constantly monitored by the standard touchup program, to servo out the effects of wind, etc. After the ten seconds are up, the integrated output of the synchronous detector is saved and the antenna is moved to its next offset position. When all five positions have been collected, the B's, as defined above, are computed, and from them  $a$  which is, of course, the change in the pointing from that given by the old constants, as well as the amplitude  $A$ .

The hour angle, pointing error, and change in pointing error are then printed on the teletype. This printing is, of course, overlapped with the collection of data on the next five point scan.

CP - Tape Copy Program

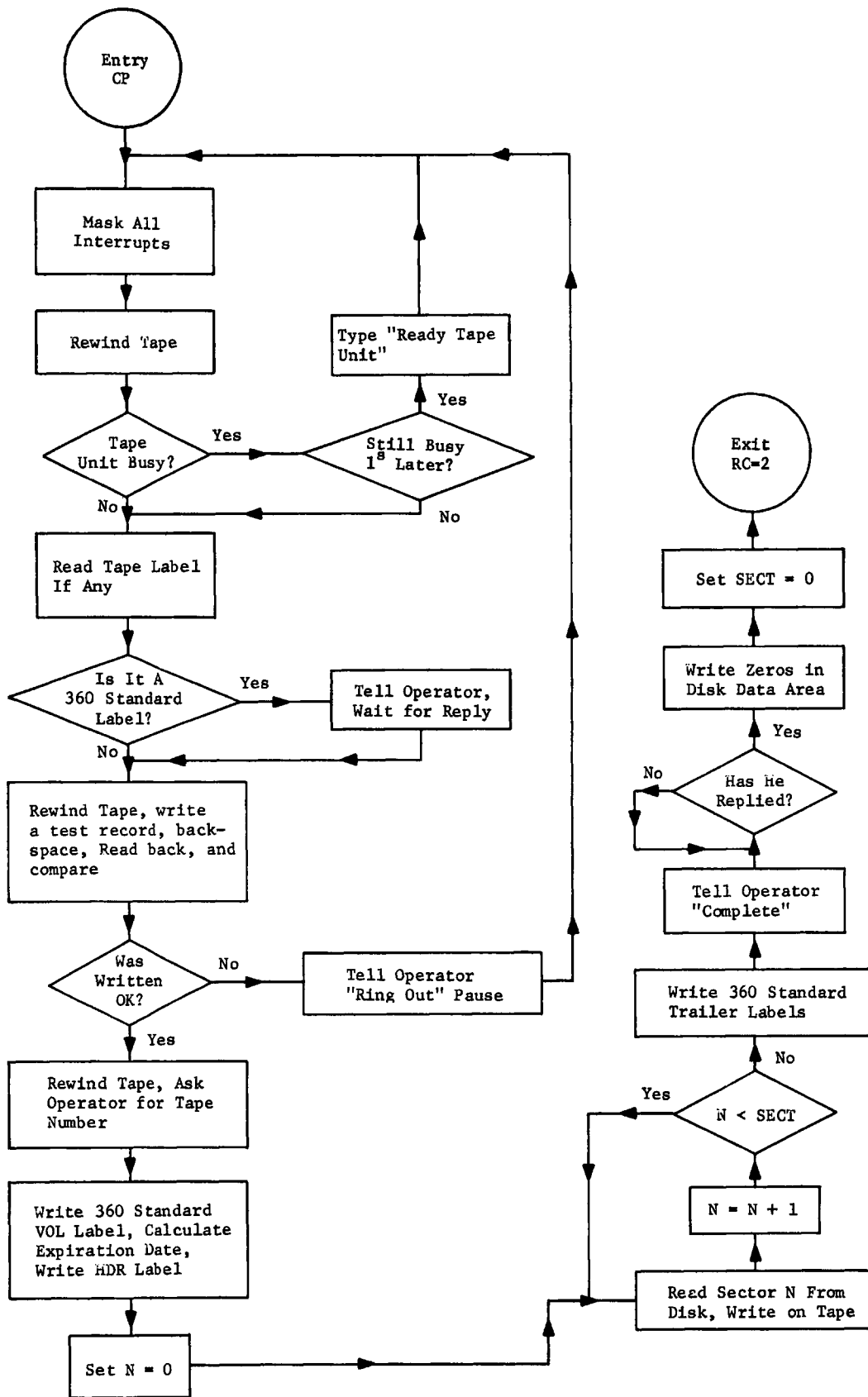
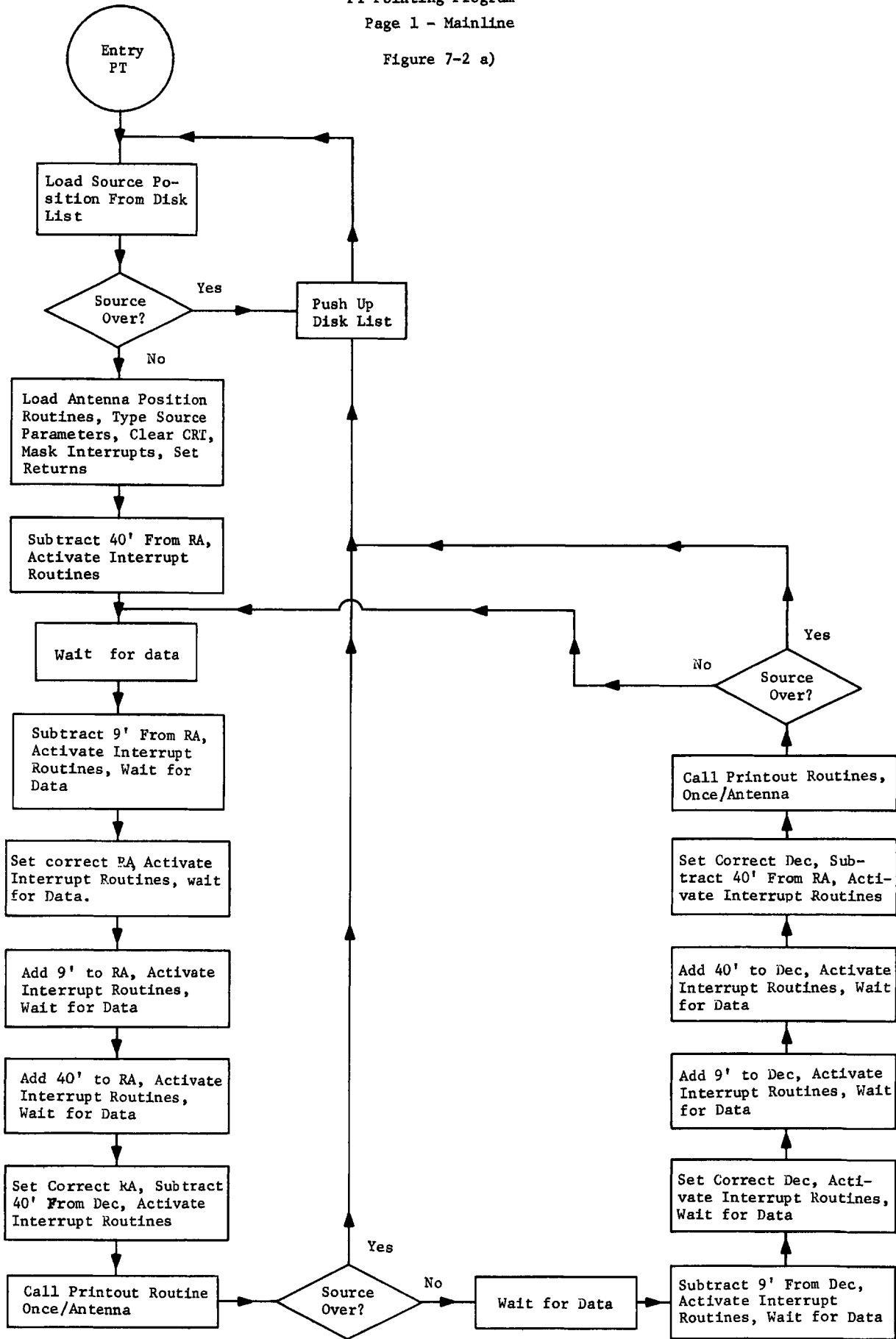


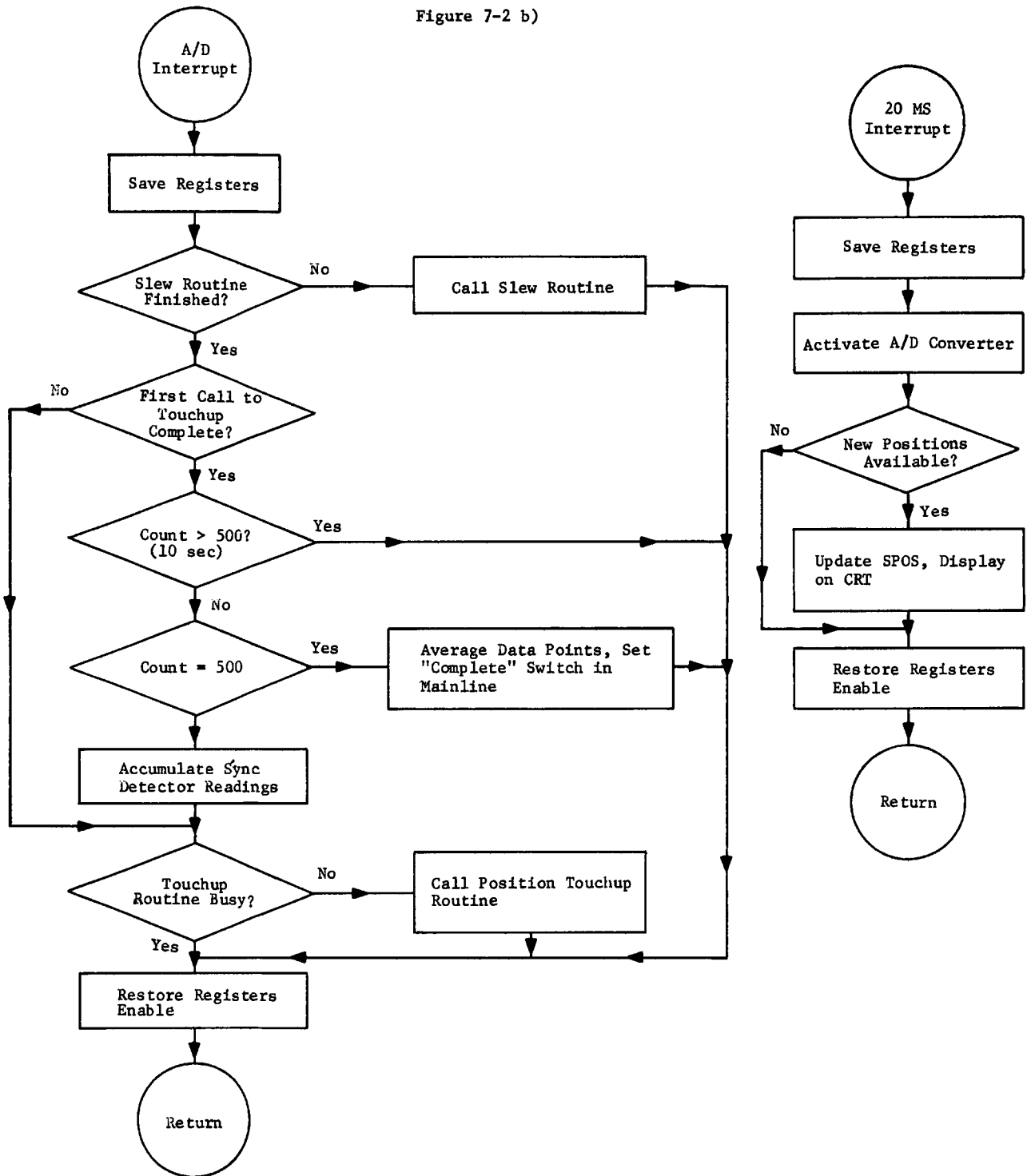
Figure 7-1

PT Pointing Program  
 Page 1 - Mainline  
 Figure 7-2 a)



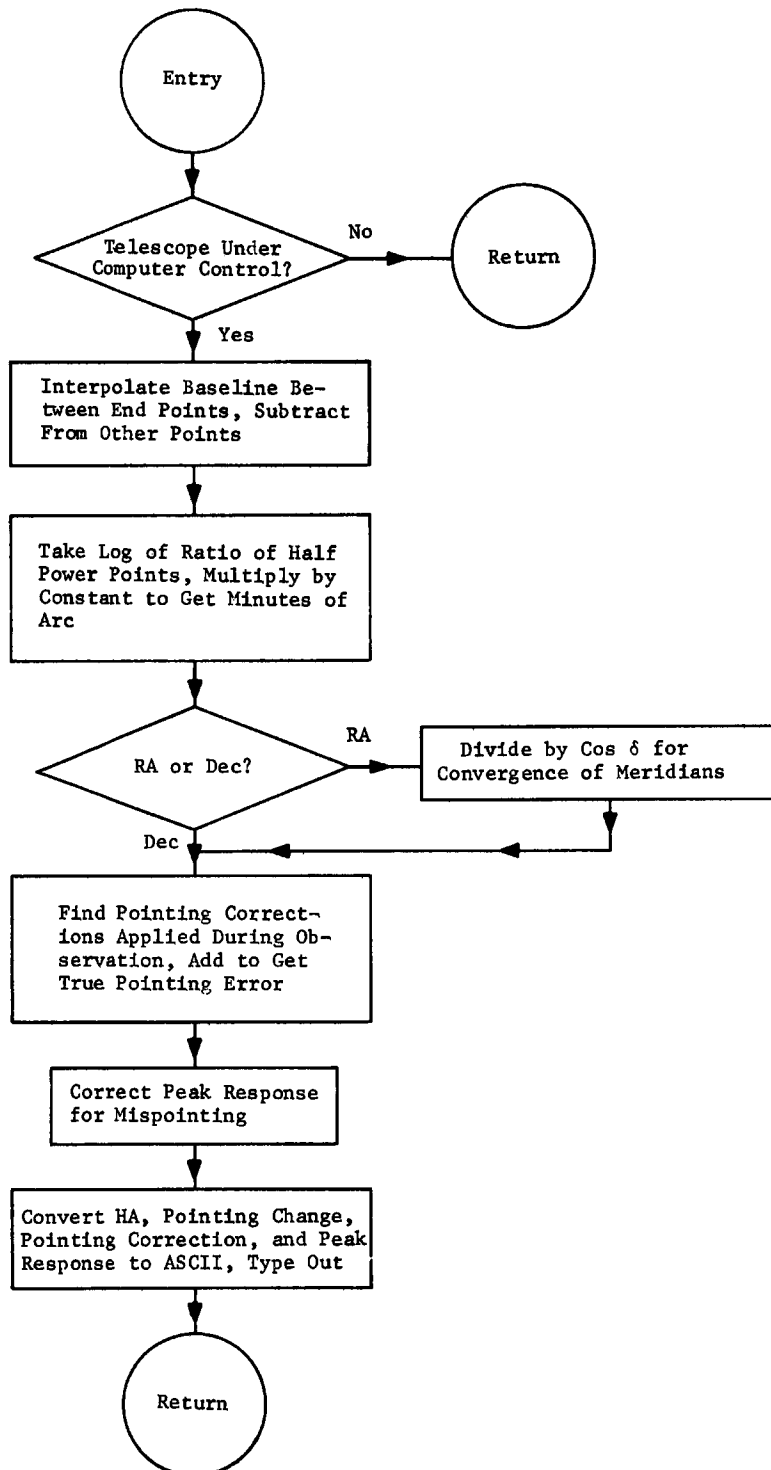
PT Interrupt Routines  
page 2

Figure 7-2 b)



PT Pointing Program  
Print Routine

Page 3 Figure 7-2 c)





VIII. INSTRUCTIONS FOR USING THE INTERFEROMETER  
COMPUTER OPERATING SYSTEM

- A. To initialize a computer with no program in core:
1. Key in loader, load BSL-1, 360 card loader (see R. L. Swensson memo).
  2. Load IOCS card deck. (Put in reader, transfer to 16200, run, start.)
  3. If program on disk is OK, program will ask if the scan number is all right. Answer "YES" or "NO".
- B. Operators coming on shift type in "XOPID" while computer is observing. Computer will ask for operator and observer initials (2 characters each).
- C. To enter an observing program:
1. The observing program writer, called WR, will be called automatically (a) when IOCS is loaded or (b) when the previous observing program is exhausted. If it is desired to call WR at any other time type "XLOAD WR".
  2. WR types "READY PROGRAM IN CARD READER" if reader is not ready.
  3. Stack up to 100 cards in the card reader.
  4. If WR types "ENTER DAY NUMBERS" you may
    - (a) Type in Besselian day numbers for tomorrow from the Ephemeris, p. 262ff. (In the Ephemeris, the signs are written only every 5th number, and apply to all below.) The format is  $\pm$ DD.DDD. Day numbers less than 10" must have an initial 0.
    - (b) Load the Besselian day number deck. (Load in reader, transfer to 16200, run.)
  5. If there is an existing observing list, WR types "CARDS IN READER SHOULD: PRECEDE, FOLLOW, OR REPLACE EXISTING LIST." Reply "PRECEDE", "FOLLOW", or "REPLACE".
  6. Set SS4 to suppress printout of source names and positions on TTY.
  7. WR processes the card deck, goes immediately to observing.
- D. Operator commands:
1. To reprint the source header (say after changing TTY paper) type "XCURR".
  2. To enter operator and observer initials type "XOPID".
  3. To go to next source immediately type "XSKIP".

4. To continue present source beyond stop time type "XCONT" (to end source type "SKIP").
  5. To temporarily stop observing type "XWAIT" (to start again, type "XBEGN").
  6. To enter new scan number, baseline parameters, or pointing corrections, type "XBASE".
  7. To load WR type "XLOAD WR".
  8. To enter a comment along with data on output, type "XNOTE (Message)".
- E. To restart after a computer stop, transfer to 17000, run, start.
- F. To dump disk to tape.
1. Load tape on tape transport.
  2. Load card object deck "CP" (put in reader, transfer to 16200, run, start).
  3. Press start. (If it says "INSERT FILE PROTECT RING" make sure ring is in the tape, transfer to 3000, start.)
  4. It will type "ENTER TAPE NUMBER - NNNN". Type in NRAO tape number with leading zero to make four digits.
  5. Tape will be written, computer will type "TRANSFER COMPLETE, PRESS CR TO CLEAR DISK." Press the return button on the teletype to erase disk (up to the time this button is pressed, data is not lost and may be recovered by starting this procedure over again). Wait for approximately 1<sup>m</sup> for printout "SECT 00000 RETURN 00002."
  6. Remove file protect ring, send tape to Charlottesville computer.
- G. Loading the disk system.
1. Load "Tape-to-Disk" program.
  2. Load appropriate systems tape on tape drive.
  3. Press start.
  4. Computer will print date tape was written. If this is the tape desired, press start.
  5. When transfer is complete, press start.
- H. Troubleshooting.
- Unexplained or unusual halts -- try in order these steps until something works:
1. Transfer to 17000, run, start.

2. Reload IOCS.

(a) If deck won't load, reload "IBM card loader" paper tape. If tape won't load, reload key-in loader, bootstrap loader. Load IOCS deck.

(b) If IOCS loads, but trouble still persists, reload system tape.

## IX. MESSAGE DICTIONARY

BELL BELL BELL BELL BELL .....

Program - IOCS

Action - Stop computer and examine location printed on teletype. The contents have the following meaning:

- 17402 Disk data area overflow - dump disk.
- 17437 Disk program area overflow - restart programs, reloading system tape if necessary. If persistent, call programmer.
- 17455 Disk access error - if persistent, call technician.
- 17504 Permanent disk read/write error. Restart program, if possible; if not, load system tape.
- 17732 Negative number of words to be transmitted. Restart program. If persistent, call programmer.
- 13361 Timing error - Computer internal clock, generated by counting 50 cycle sidereal interrupts, disagrees with sidereal clock. May be program error or noise on 0<sup>s</sup>.1 or 50 cycle sidereal lines. If persistent, call technician.

1

Program - Card loader.

Meaning - Card sequence error.

Action - Order the cards in proper sequence (last 3 columns contain sequence numbers).

2

Program - Card loader.

Meaning - Check sum error.

Action - Make sure deck is proper object deck. Reload deck in reader, master clear.

3

Program - Card loader.

Meaning - Card read error or feed error.

Action - Reload deck in reader, making sure last card is present, master clear.

ALARMS - nnnnnn ....

Program - OB

Meaning - An unusual condition has occurred - see table of alarm codes.

Action - Given with alarm code.

(source) ALREADY OVER

Program - SU

Meaning - Stop time is past, going to next source.

Action - None.

DATE NOT AVAILABLE

Program - SU

Meaning - Calendar is malfunctioning.

Action - Press start to continue observing while fixing calendar.

DISK DATA AFU

Program - SU

Meaning - Either disk has not been completely cleared, or blank records have been written on it.

Action - Computer will suggest possible SECT numbers. You may accept or reject them by typing "YES" or "NO". After a while it will ask you for a SECT number - type five digits.

DISK HH MM SS.SSS DD MM SS.SSS

Program - WR

Meaning - The source has been encountered previously in a source list stored on disk or on a previous card with the stated position.

Action - Set the proper sense switch to select which of the two positions to use.

DONE

Program - Core → Disk, Disk → Tape, Tape → Disk.

Meaning - The requested action has been completed.

Action - None.

ENTER DATE -- YY/MM/DD

Program - Disk → Tape.

Meaning - The programs stored on disk are ready to be written on mag tape to make a systems tape.

Action - Type the date in the format requested, followed by a return.

ENTER DAY NUMBERS

Program - WR

Meaning - The observing program writer wants the Besselian day numbers.

Action - Look up the Besselian day numbers in the Ephemeris, p. 262ff. Type in A, B, C, and D in the format +DD.DDD. Signs, and initial zeros for day numbers less than 10", must be supplied. Commas separate the day numbers.

ENTER 4 CARDS WITH BASELINE CONSTANTS, 3 WITH POINTING CONSTANTS, 1 WITH DELAY CONSTANTS, 1 WITH SCAN NUMBER

Program - SU

Meaning - Computer wishes to reload its operating constants.

Action - Load deck of format shown in Section VI.

ENTER TAPE NUMBER - NNNN

Program - CP

Meaning - The program wishes to label the tape.

Action - Type in the NRAO number.

ERROR IN CARD. RETURN TO OBSERVING.

Program - WR

Meaning - The card just read contained a format error. All preceding cards are accepted and the computer returns to observing.

Action - Repunch the card in the correct format.

EXCESSIVE POINTING ERROR

Program - SU

Meaning - The antenna specified in the fourth digit of the RETURN code had a pointing error exceeding 100". If persistent, possibly a motor has quit.

Action - Fix motor if needed.

IN LIMIT

Program - WR

Meaning - The stop time is beyond the west limit, stop time will be adjusted to west limit.

Action - None.

INSERT FILE PROTECT RING

Program - CP

Meaning - The tape cannot be written.

Action - Insert file protect ring, remount tape, restart program.

INVALID RETURN CODE

Program - SU

Meaning - The return specified in the line above is not recognized.

Action - Insert an appropriate return code in the A register, press start.

LOAD WHO?

Program - SU

Meaning - An invalid "LOAD" command has been typed.

Action - Type correct command.

NO VALID START TIME. WILL WAIT.

Program - SU

Meaning - The source has been delayed.

Action - When ready to begin observation of source, type "XBEGN".

OBSERVATION { BEGINS } AT n DEGREES ELEVATION.  
                  { ENDS }

Program - WR

Meaning - You're getting rather near the horizon.

Action - If n is negative, the observer may want to do something about it.

PRESS START PLEASE

Program - SU

Meaning - The supervisor has been called after a cold start.

Action - Make sure all patches and key-ins are loaded, press start.

READY PROGRAM IN CARD READER

Program - WR

Meaning - Program wishes to read an observing program from the card reader.

Action - Place observing program in reader, press start button on reader.

RETURN TO OBSERVING

Program - WR

Meaning - Program has been loaded. This occurs 1) when card reader becomes not ready, 2) when 100 cards have been read, 3) when a non-recoverable error is found in a card.

SECT nnnnn RETURN nnnnn

Program - SU

Meaning - SU has been called with the return code given. The next sector on disk to be written is the number following "SECT". There are 2379 sectors available for data recording.

SET SS2 TO ACCEPT DISK POSITION, 4 TO ACCEPT CARD

Program - WR

Meaning - A source has been provided with a position which is different from that provided on a disk source list or a previous card.

Action - Set sense switch 4 to accept the latest card position. Set sense switch 2 to accept the last encountered position (printed above in a line beginning "DISK").

SOURCE LIST EMPTY

Program - SU

Meaning - No more sources are in the observing list provided in disk. SU will call WR to get another list.

Action - Put the observing program in the card reader.

SOURCE OVER, NEXT

Program - SU

Meaning - The source next on the source list is beyond its stop time. SU will look for the next source.

Action - None.

START TIME IN LIMIT

Program - WR

Meaning - A start time before the east limit was specified in the card. Start time will be set to east limit time.

Action - None.

STOP TIMES OUT OF ORDER

Program - WR

Meaning - Cards have been shuffled or incorrectly punched. Computer returns to observing.

Action - Sort out deck before it is needed again.



TAPE BUSY OR NOT READY

Program - CP

Meaning - Tape unit not accessible to CPU.

Action - Ready tape unit, press start.

TAPE DATED YY/MM/DD

Program - Tape to Disk.

Meaning - This date was typed in when the tape was written.

Action - Press start to transfer programs to disk.

TAPE ERROR -- TRY AGAIN

Program - Tape to Disk.

Meaning - A tape error has been found.

Action - Press start to try again. If persistent, try another tape.

TAPE NOT CLEARED. PRESS CR TO OVERWRITE.

Program - CP

Meaning - Tape is labeled for 360 use.

Action - If disk data is to be put on this tape, press CR. If it is a full tape mounted by mistake, stop computer, mount proper tape, transfer to 3000.

TRY AGAIN

Program - WR

Meaning - The Besselian day numbers have been entered with a format error.

Action - Enter them again.

UNEXPECTED INTERRUPT ON LINE N

Program - SU

Meaning - A program interruption is active that should not be. Interrupt lines are:

- 0 - Card reader, Interval Timer, Teletype.
- 1 - 20 ms timing line.
- 2 - Tape Unit.
- 3 - A/D Converter.
- 4 - Disk Unit.
- 5 - CRT.

Action - Stop the computer, master clear and restart from 17000 if persistent. If it still persists, call technician.

WAIT EXCEEDS 1 HR - XXX

Program - WR

Meaning - The next source cannot be started for more than an hour after the last one. May be caused by card out of order in observing program. Computer will return to observing.

Action - Correct card for later entry.

WARNING, OBSERVATION LONGER THAN 4 HRS

Program - WR

Meaning - Stop time exceeds stop time of previous source by more than 4 hours. May be caused by cards out of order.

Action - Make sure cards are in proper order.

WHAT?

Program - WR

Meaning - Only answers permitted to questions asked are "YES" or "NO".

WHAT??

Program - OB, SU

Meaning - Operator request is not recognized.

Action - Type in the proper request.

WHAT, THEN?

Program - SU

Meaning - Operator does not approve of computer suggested SECT numbers.

Action - Type in correct 5 digit SECT number.

WHERE IS (name)

Program - WR

Meaning - The source has been given without specifying a position, and there is no position given in the disk list.

Action - Punch position in card for later entry.

WOULD YOU BELIEVE nnnnn

Program - SU

Meaning - This is the first blank record in the disk data area. If this is what SECT should be, type "YES".