PDP-11
PAPER TAPE SOFTWARE
PROGRAMMING HANDBOOK

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PROGRAMMING HANDBOOK

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Your attention is invited to the last two pages of this document. The "How To Obtain Software Information" page tells you how to keep up-to-date with DEC's software. The "Reader's Comments" page, when filled in and mailed, is beneficial to both you and DEC; all comments received are considered when documenting subsequent manuals.

Technical Changes from the previous version (DEC-11-GGPC-D) are indicated with a bar in the margin of the appropriate page.

Supporting and referenced documents:

PDP-11 BASIC Programming Manual
(order: DEC-11-XBPMA-A-D)

Copies are available from DEC's Software Distribution Center, Building 1-2, Maynard, Massachusetts 01754

PREFACE

This Handbook contains descriptions of the Paper Tape Software for the PDP-11 system. With this information you can load, dump, edit, assemble, and debug PAL-11A Assembly Language programs. Math routines and input/output functions are also available to facilitate your programming efforts.

The table of contents in the front of the Handbook directs you to the chapter of the system program desired. There you will find a detailed table of contents for reference while working with that chapter. For locating items in still more detail, an Index concludes the Handbook.

The following symbols, when used herein, have the indicated meanings:

↵ denotes pressing the RETURN key, or indicates an ASCII carriage return;

↓ denotes pressing the LINE FEED key, or indicates an ASCII line feed;

Δ denotes pressing the SPACE bar, or indicates an ASCII space;

⇥ denotes typing CTRL/TAB, or indicates an ASCII tab.

Other documentation conventions are:

1. Unless otherwise indicated, a line of user input is terminated with the RETURN key.

2. When the distinction is useful, system printout is underlined and user input is not underlined.

3. CTRL/U denotes holding down the CTRL key while typing the U key, as when using the SHIFT/key combination. The slash is shown merely to tie the actions together. CTRL is also used with certain other keys, e.g., CTRL/P. The use of the CTRL/key combinations usually prints a ↑ and the key typed, e.g., CTRL/U echoes ↑U on the printer when using ED-11 or IOX.

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CHAPTER 1

PROGRAMMING THE PDP-11 SYSTEM

1.1 INTRODUCTION

The PDP-11 is a 16-bit, general-purpose, parallel-logic computer using two's complement arithmetic. Programmers can directly address 32,768 16-bit words, or 65,536 8-bit bytes. All communication between system components is done on a single high-speed bus called the Unibus. Standard features of the system include eight general-purpose registers which can be used as accumulators, index registers, or address pointers; and a multi-level automatic priority interrupt system. A simplified block diagram of the PDP-11 System is presented in Figure 1-1.

This chapter gives the PDP-11 programmer an overview of system architecture, points out unique hardware features, and presents programming concepts basic to the use of the PDP-11. Following this is a short summary of DEC-supplied PDP-11 software.

1.2 SYSTEM FACILITIES

The architecture of the PDP-11 system and the design of its central processor provide:

- single and double operand addressing
- full word and byte addressing
- simplified list and stack processing through auto-address stepping (autoincrementing and autodecrementing)
- eight programmable general-purpose registers

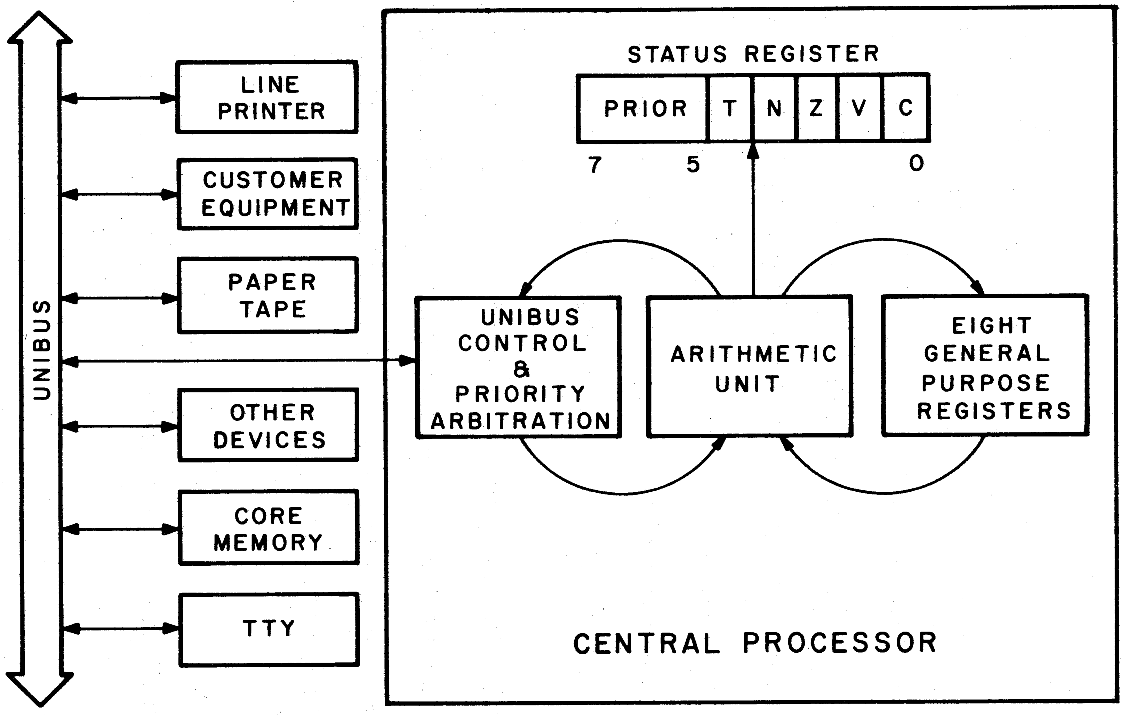


Figure 1-1. PDP-11 SYSTEM BLOCK DIAGRAM

- data manipulation directly within external device registers
- addressing of device registers using normal memory reference instructions
- asynchronous operation of memory, processor and I/O devices
- a hardware interrupt priority structure for peripheral devices
- automatic interrupt identification without device polling
- cycle stealing direct memory access for high-speed data transfer devices
- direct addressing of 32K words (65K bytes).

Two design features of the central processor serve to increase system throughput:

a. The eight programmable general-purpose registers within the central processor can be used to store data and intermediate results during the execution of a sequence of instructions. Register-to-register addressing provides reduced execution time for most instructions.

b. The ability to code two addresses within a single instruction allows operations on data within memory. This eliminates the need to load processor registers prior to data operations, and greatly reduces fetch and store operations.

1.3 STATUS REGISTER FORMAT

The Central Processor Status Register (PS) contains information on the current priority of the processor, the result of previous operations, and an indicator for detecting the execution of an instruction to be trapped during program debugging. The priority of the central processor can be set under program control to any one of eight levels. This information is held in bits 5, 6, and 7 of the PS. Four bits are assigned to monitor different results of previous instructions. These bits are set as follows:

Z -- if the result was zero
N -- if the result was negative
C -- if the operation resulted in a carry from
the most significant bit
V -- if the operation resulted in an arithmetic
overflow

The T bit is used in program debugging and can be set or cleared under program control. If this bit is set when an instruction is fetched from memory, a processor trap will occur at the completion of the instruction's execution.

unused								processor priority			T	N	Z	V	C
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Figure 1-2. Processor Status Register

1.4 UNIBUS

The Unibus is a key component of the PDP-11's unique architecture. The Central Processor, memory, and all peripheral devices share the same bus. This means that device registers can be addressed as memory, and data transfers from input to output devices can by-pass the processor. No special I/O instructions exist. All PDP-11 instructions are available for I/O operations.

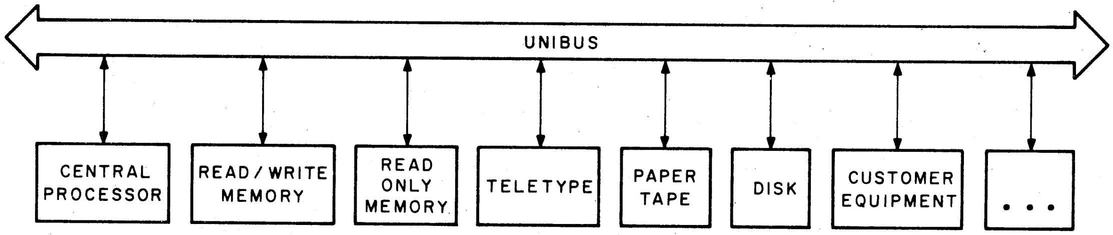


Figure 1-3 PDP-11 System Unibus Block Diagram

1.5 DEVICE INTERRUPTS

Interrupt request lines provide for device interrupts at processor priority levels 4 through 7. Attachment of a device to a specific line determines the device's hardware priority. Since multiple devices can be attached to a specific line, the priority for each is determined by position; devices closer to the Central Processor have higher priority.

Direct memory devices, such as disk units, transfer data at the Non-Processor Request level (NPR) which has a higher priority than the interrupt request lines. Data transfers between such devices and core memory are overlapped with Processor operations.

Peripheral device interrupts are linked to specific core memory locations, or "interrupt vectors", in such a way that device polling is eliminated. When an interrupt occurs, the interrupt vector supplies a new Processor Status word (i.e., new contents for the Processor Status register) and a new value for the Program Counter. The new PC value causes execution to start at the proper handler at the priority level indicated by the new Status register.

1.6 INSTRUCTION SET

The instruction set (explained fully in the PDP-11 Processor Handbook; summarized in Appendix B of this manual) provides operations that act upon 8-bit bytes and 16-bit words. Coupled with varying address modes -- Relative, Index, Immediate, Register, Autoincrement, or Autodecrement, each of which can be deferred -- more than 4ØØ unique instructions are available. Instruction length is variable -- from one to three 16-bit words, depending upon the addressing mode(s) used.

1.7 ADDRESSING

Every byte has its own unique address. It is the instruction which determines whether 8-bit bytes or 16-bit words are being referenced. Words are addressed by their low-order (even-numbered) byte. Although byte addressing can be to odd- or even-numbered addresses, referencing words at odd-numbered addresses is illegal. Bits are numbered from 0 at the lowest order bit (2^0), to 15 (for a word) or 7 (for a byte) at the highest order bit (2^{15} or 2^7).

Most data in programs is structured in some way; often by means of tables consisting of the data itself or of addresses which point to the data. The PDP-11 handles common data structures with operand addressing modes specifically designed for each kind of access. In addition, addressing for unstructured data permits direct random access to all of core. The actual formats of the modes are described in Chapter 3, on the PAL-11 Assembler.

1.7.1 Registers

Addressing in the PDP-11 is done through the general registers. These registers can be specified by preceding a number in the range 0 to 7 with a %. However, it is common practice to assign to symbols the register identities; often R0=%0, R1=%1, etc. Throughout this manual, reference to R0, R1, etc., as well as SP and PC, assumes such prior direct assignment. (See Chapter 3, Section 3.3.4.) All eight general registers are accessible to the programmer, but two of these have additional specialized functions (discussed below). R6 is the processor Stack Pointer (SP), and R7 is the Program Counter (PC).

To make use of a register as an accumulator, index register, or sequential address pointer, data needs to be transferable to and from the register. This is accomplished with Register Mode, which specifies that the instruction is to operate on the contents of the indicated register itself. For example:

```
        CLR R3          ;CLEAR REGISTER 3 OF ITS CONTENTS
```

1.7.2 Address Pointers

The instruction can be made to interpret the register contents as the address of the data to be operated upon, by specifying that Register Mode be deferred. For example, if register 3 contains 1000

```
          CLR (R3)        or        CLR  @R3
```

will clear the address 1000. Moreover, if it is desired to perform the instruction successively upon data at sequential addresses (i.e., in a table), Autoincrement Mode can be selected. This will automatically increment the contents of the register, after its use as a pointer to the next sequential byte or word address. Note that Autoincrement Mode (as well as Autodecrement Mode, mentioned below) is automatically deferred one level to cause the register contents to function as a pointer.

When it is specified that Autoincrement Mode be deferred, it is deferred two levels so that the instruction interprets the autoincremented sequential locations as a table of addresses rather than as a table of data, as in nondeferred Autoincrement Mode. The instruction then operates upon the data at the addresses specified by the table entries.

Each execution of the following ADD instructions increments the value of the register contents by two, to the next word address (always an even number).

```
ACCUM:  ADD (RØ)+,(R1)+   ;IF RØ INITIALLY CONTAINS 1ØØØ,
                 .        ;AND R1 INITIALLY CONTAINS 145Ø,
                 .        ;THE VALUES AT LOCATIONS 1ØØØ,
                 .        ;1ØØ2, ETC., ARE ADDED TO THOSE AT
                 .        ;LOCATIONS 145Ø, 1452, ETC., AND
                 .        ;THE RESULT STORED AT 145Ø, ETC.
        JMP ACCUM
```

```
ACCUM: ADD @(R3)+,R2      ;IF R3 INITIALLY CONTAINS 1ØØØ,
                 .        ;AND LOCATION 1ØØØ CONTAINS 342Ø,
                          ;THE VALUE AT LOCATION 342Ø IS
                 .        ;ADDED TO THE CONTENTS OF R2 AND
                          ;THE RESULT IS STORED THERE.  AT
                 .        ;NEXT EXECUTION OF THE INSTRUC-
                          ;TION, R3=1ØØ2.
                 .
          JMP ACCUM
```

Byte instructions (such as TSTB (R2)+) using Autoincrement Mode, increment the register contents by one.

In addition to this capability of incrementing a register's contents after their use as a pointer, an address mode complementary to this exists. *Autodecrement Mode* decrements the contents of the specified register *before* the contents are used as a pointer. This mode, too, can be *deferred* an additional level if the table contains addresses rather than data.

1.7.3 Stack Operations

Both Autoincrement and Autodecrement Modes are used in stack operations. Stacks, also called push-down or LIFO (Last-In-First-Out) lists, are important for temporarily saving values which might otherwise be altered. Their characteristic is that the most recent piece of data saved is the first to be restored. The PDP-11 processor makes use of stack structure to save and restore the state of the machine on interrupts, traps, and subroutines (see below). To save, data is "pushed" onto a stack by autodecrementing the contents of a register (e.g., MOV R3,-(R6)); to restore, data is "popped" from a stack by autoincrementing (e.g., MOV (R6)+,R3). The register being used as the Stack Pointer always points to the top word of the stack.

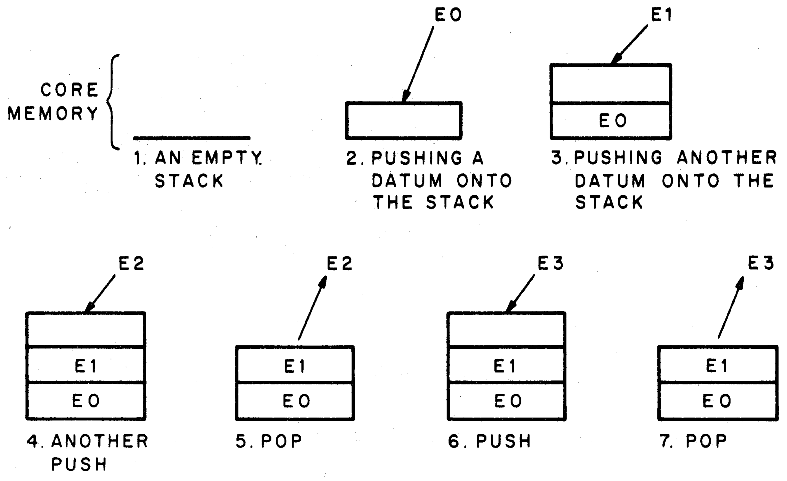


Figure 1-4. Illustration of Push and Pop Operations

1.7.4 Random Access of Tables

Direct access to an entry in the middle of a stack, or indeed any kind of table, is accomplished through Index Mode. The contents of a register are added to a base (fetched from the word or second word following the instruction) to calculate an address. With this facility, a fixed-order element of several tables, or several elements of a single table may be accessed.

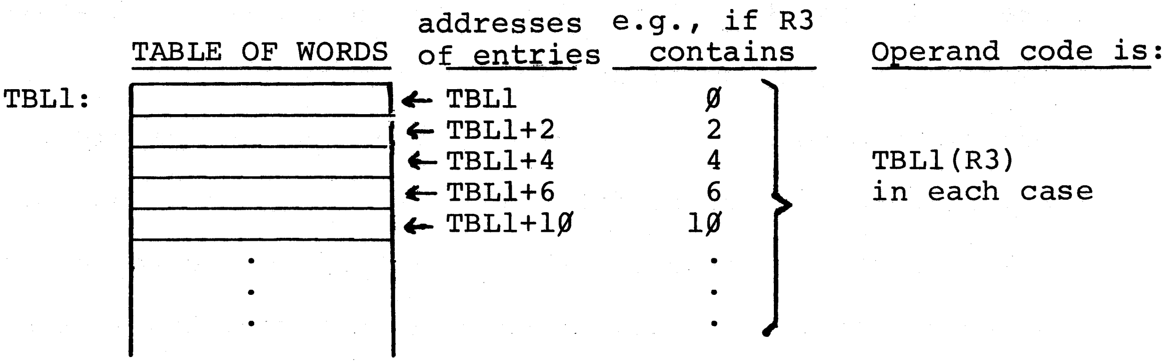


TABLE OF WORDS	addresses of entries	e.g., if R3 contains	Operand code is:
TBL1:	TBL1	Ø	TBL1(R3) in each case
	TBL1+2	2	
	TBL1+4	4	
	TBL1+6	6	
	TBL1+1Ø	1Ø	
.		.	
.		.	
.		.	

When deferred Index Mode is specified (e.g., @TBL1(R3)), the calculated address contains a pointer to the data, rather than the data itself. Byte tables are discussed in Section 1.8.

1.7.5 Summary of Address Modes

The address modes may now be summarized as follows:

Non-deferred Modes

Assembler Syntax	Mode	Typical Use
Rn	Register	Accumulator
(Rn)+	Autoincrement	Sequential pointer to data in a table; popping data off a stack
-(Rn)	Autodecrement	Sequential pointer to data in a table; pushing data on a stack.
A(Rn)	Index	Random access to stack or table entry.

Deferred Modes

Assembler Syntax	Mode	Typical Use
@Rn or (Rn)	Deferred Register	Pointer to an address
@(Rn)+	Deferred Autoincrement	Sequential pointer to addresses in a table; popping address pointers off a stack.
@-(Rn)	Deferred Autodecrement	Sequential pointer to addresses in a table; pushing address pointers on a stack
@A(Rn)	Deferred Index	Random access to table of address pointers.

1.7.6 Accessing Unstructured Data

Addressing of unstructured data becomes greatly facilitated through the use of the Program Counter (R7) as the specified register in these modes. This is particularly true of Autoincrement and Index Modes, which are mentioned below, but discussed more fully in Chapter 3, the PAL-11 Assembler.

Autoincrement Mode using R7 is the way immediate data is assembled. This mode causes the operand itself to be fetched from the word (or second word) following the instruction. It is designated by preceding a numeric or symbolic value with #, and is known as Immediate Mode. The instruction

```
            ADD #5Ø,R3
```

causes the value $5Ø_8$ to be added to the contents of register 3. If the # is preceded by @, the immediate data is interpreted as an absolute address, i.e., an address that remains constant no matter where in memory the assembled instruction is executed.

Index Mode using R7 is the normal way memory addresses are assembled. This is relative addressing because the number of byte locations between the Program Counter (which contains the address of the current word+2) and the data referenced (destination minus PC) is placed in the word (or second word) following the instruction. It is this value that is indexed by R7 (the Program Counter). ((Destination-PC)+PC=Destination.) Relative Mode is designated by specifying a memory location either numerically or symbolically (e.g., TST 1ØØ or TST A). If a memory address specification is preceded by @, it is in deferred Relative Mode and the contents of the location are interpreted by the instruction as a pointer to the address of the data.

1.8 INSTRUCTION CAPABILITY

The twelve ways of specifying an operand demonstrate the flexibility of the PDP-11 in accessing data according to how it is structured, and even if it is not structured. Each instruction adds to this versatility by acting on an operand in a way particularly suited to its task. For example, the task of adding, moving, or comparing implies the use of two operands in any of the twelve addressing forms; whereas the task of clearing, testing, or negating implies only one operand. Examples:

```
ADD #12,GROUP(R2)          CLR R3
MOV MEM1,MEM2              TST SUM
CMP (R4)+,VALUE            NEG @-(R5)
```

Some instructions have counterparts which operate on byte data rather than on full words. These byte instructions are easily recognized by the suffixing of the letter B to the word instruction. MOV is one such word instruction; e.g., MOVB #12,GROUP(R2) would move an 8-bit value of 12_8 to the 8-bit byte at the address specified. One implication of byte instructions is that in Autoincrement or Autodecrement Mode, a table of *bytes* is being scanned. The Autoincrement or Autodecrement therefore goes by one in byte instructions, rather than by two. However, because of their specialized processor functions, R6 and R7 in these modes *always* increment or decrement by two.

Forms other than single- or double-operand instructions include Operate instructions such as HALT and RESET, which take no operands; Branch instructions, which transfer program control under specified conditions (see Section 3.7); Subroutine calls and returns; and Trap instructions (see Appendix B for complete instruction set).

1.9 PROCESSOR USE OF STACKS

Because of the nature of last-in-first-out data structures, the same stack can be used to nest multiple levels of interrupts, traps, and subroutines.

1.9.1 Subroutines

In Subroutine calls (JSR Reg,Dest) the contents of the specified register are saved on the stack (the processor always uses R6 as its Stack Pointer) and the value of the PC (return address following subroutine execution) becomes the new value of the register. This allows any arguments following the call to be referenced via the register. The command RTS Reg causes the return from the subroutine by moving the register value into the PC. It then pops the saved register contents back into the register. (Return from a subroutine is made through the same register that was used in its call.)

1.9.2 Interrupts

When the processor acknowledges a device interrupt request, the device sends an interrupt vector address to the processor. The processor then pushes the current Status (PS) and PC onto the stack and picks up a new PS and PC (the interrupt vector) from the address specified by the device. Another acknowledged interrupt before dismissal will cause the PS and PC of the running device service routine to be pushed onto the stack and the address and status of the new service routine to be loaded into the PC and PS. A process can be resumed by popping the old PC and PS from the Stack into the current PC and PS with the Return from Interrupt (RTI) instruction.

1.9.3 Traps

Traps are processor generated interrupts. Error conditions, certain instructions, and the completion of an instruction fetched while the T bit was set cause traps. As in interrupts, the current PC and Status are saved on the stack and a new PC and Status are loaded from the appropriate trap vector. The instruction RTI provides for a return from an interrupt or trap by popping the top two words of the stack back into the PC and PS.

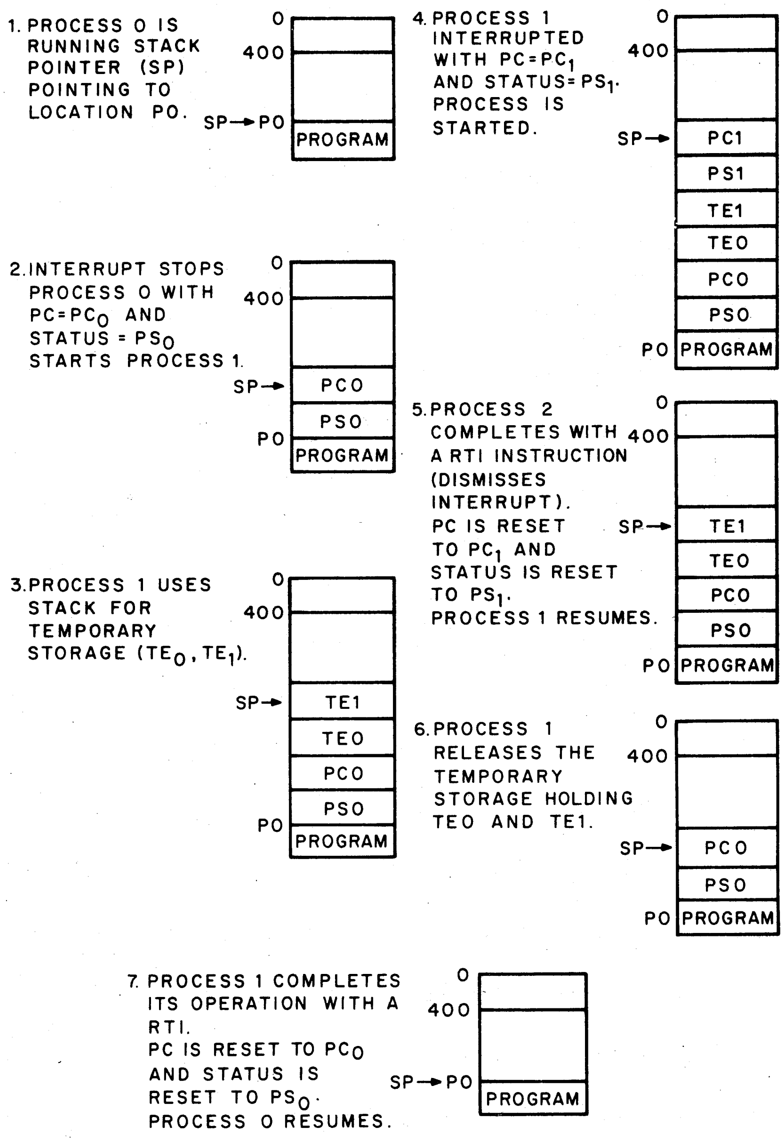

1. PROCESS 0 IS RUNNING STACK POINTER (SP) POINTING TO LOCATION PO.
0
400
SP→PO
PROGRAM
2. INTERRUPT STOPS PROCESS 0 WITH PC=PC$_0$ AND STATUS = PS$_0$ STARTS PROCESS 1.
0
400
SP→
PCO
PSO
PO
PROGRAM
3. PROCESS 1 USES STACK FOR TEMPORARY STORAGE (TE$_0$, TE$_1$).
0
400
SP→
TE1
TEO
PCO
PSO
PO
PROGRAM
4. PROCESS 1 INTERRUPTED WITH PC=PC$_1$ AND STATUS= PS$_1$. PROCESS IS STARTED.
0
400
SP→
PC1
PS1
TE1
TEO
PCO
PSO
PO
PROGRAM
5. PROCESS 2 COMPLETES WITH A RTI INSTRUCTION (DISMISSES INTERRUPT). PC IS RESET TO PC$_1$ AND STATUS IS RESET TO PS$_1$. PROCESS 1 RESUMES.
0
400
SP→
TE1
TEO
PCO
PSO
PO
PROGRAM
6. PROCESS 1 RELEASES THE TEMPORARY STORAGE HOLDING TEO AND TE1.
0
400
SP→
PCO
PSO
PO
PROGRAM
7. PROCESS 1 COMPLETES ITS OPERATION WITH A RTI. PC IS RESET TO PC$_0$ AND STATUS IS RESET TO PS$_0$. PROCESS 0 RESUMES.
0
400
SP→PO
PROGRAM

Figure 1-5. Nested Device Servicing

1.10 PAPER TAPE SYSTEM SOFTWARE

The paper tape system and utility programs described herein require at least 4K of core memory (except for the 8K version of the PAL-11A Assembler) and an ASR-33 Teletype.

An optional high-speed paper-tape reader and punch is available, as is a line printer. The operation of these input/output devices is explained in Chapter 2.

Following are abstracts of the paper-tape software programs described in this handbook.

1. Bootstrap Loader -- used to load into core memory, programs punched on paper tape in bootstrap format. It is primarily used to load the Absolute Loader and Dump programs (see Chapter 6).
2. Absolute Loader -- used to load into core memory, programs punched on paper tape in absolute binary format. This not only includes the binary tapes of subsequently listed programs but also any user program assembled using the PAL-11A Assembler or dumped by the DUMPAB program (see Chapter 6).
3. PAL-11A -- the absolute assembler for PDP-11 Paper Tape Software system (see Chapter 3).
4. ED-11 -- the text editor for the PDP-11 Paper Tape Software system. It is primarily intended for use in producing source program tapes, but may be used for any text generating and editing purposes (see Chapter 4).
5. ODT-11 and ODT-11X -- these are on-line debugging programs, enabling you to check out any object program. You can run all or any portion of an object program, and make corrections or modifications to it by typing commands to ODT while at the Teletype (see Chapter 5).

6. IOX -- which stands for Input/Output Executive, provides asynchronous I/O service for Teletype I/O devices and the high-speed paper tape reader and punch. (IOXLPT allows also for a line printer.) It enables you to write simple I/O requests specifying devices and data forms to accomplish interrupt-controlled data transfer concurrently with the execution of a running user program. It is an integral part of PAL-11A and ED-11 (see Chapter 7).

7. FPMP-11--which stands for Floating-Point and Math Package, PDP-11, is a comprehensive set of subroutines which enable you to perform arithmetic operations. The subroutines may be used by any PDP-11 object program (see Chapter 8 for overview).

8. DUMPTT and DUMPAB -- are core dump programs which provide dumping of specified areas of core either in octal on the Teletype or in absolute binary on paper tape (see Chapter 6).

CHAPTER 2

THE SYSTEM CONFIGURATION

CHAPTER 2

THE SYSTEM CONFIGURATION

This chapter explains the operation of the computer console, Teletype, high-speed reader/punch, and line printer.

2.1 PDP-11 CONSOLE

The PDP-11 console is designed to achieve convenient control of the system. Through switches and keys on the console, programs and information can be manually inserted or modified. Indicator lamps display the status of the computer at all times. The PDP-11 console is shown in Figure 2-1, and each switch, key, and display lamp is explained below.

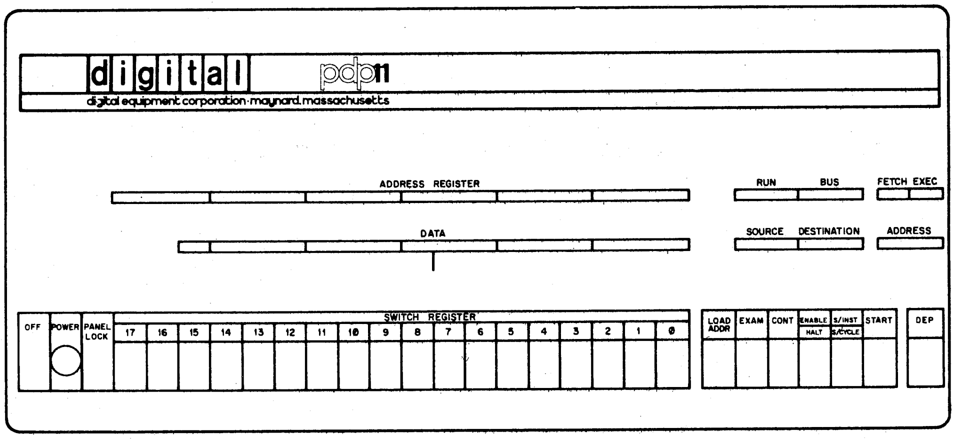


Figure 2-1. The PDP-11 Console

2.1.1 Elements of the Console

The console has the following indicators and switches:

1. A bank of eight indicators, indicating the following conditions or operations:

   a. Fetch
   b. Execute
   c. Bus
   d. Run
   e. Source
   f. Destination
   g. Address (two bits)

2. An 18-bit ADDRESS REGISTER display

3. A 16-bit DATA Register display

4. An 18-bit Switch Register

5. Control Switches:

   a. LOAD ADDR (Load value set in Switch Register into address register)
   b. EXAM (Examine contents of location)
   c. CONT (Continue execution)
   d. ENABLE/HALT (Enable or halt execution)
   e. S-INST/S-CYCLE (Single Instruction-Single Cycle execution)
   f. START (Start execution)
   g. DEP (Deposit value set in Switch Register into specified memory location)

2.1.1.1 Register Displays

The operator's console has an 18-bit ADDRESS REGISTER display and a 16-bit DATA Register display. The ADDRESS REGISTER display is tied directly to the output of an 18-bit flip-flop register called the Bus Address Register. This register displays the address of data examined or deposited.

2.1.1.2 Switch Register

The PDP-11 is capable of referencing 16-bit addresses. However, the Unibus has expansion capability for 18-bit addresses. Therefore, to access the entire 18-bit address scheme, the Switch Register is 18-bits wide. These bits are assigned as 0 through 17. The highest two bits are used only for addressing.

A switch in the up position is considered to have a 1 value. A switch in the down position is considered to have a 0 value. The condition of the switches can be loaded into the ADDRESS REGISTER or any memory location using the appropriate control switch described below.

1. LOAD ADDR — Transfers the contents of the 18-bit Switch Register into the ADDRESS REGISTER.

2. EXAM — Displays the contents of the location specified by the ADDRESS REGISTER.

3. DEP

   Deposits the contents of the low-order 16-bits of the Switch Register into the address displayed in the ADDRESS REGISTER. (This switch is actuated by raising it.)

4. ENABLE/HALT

   Allows or prevents running of programs. For a program to run, the switch must be in the ENABLE position (up). Placing the switch in the HALT position (down) will halt the system at the end of the current instruction or cycle, depending on the position of the S-INST/S-CYCLE switch.

5. START

   Begins execution of a program when the ENABLE/HALT switch is in the ENABLE position. When the START switch is depressed it asserts a system initialization signal, actually starting the system when the switch is released. The processor will start executing at the address which was last loaded by the LOAD ADDR switch.

6. CONT

   Allows the computer to continue without initialization from whatever state it was in when halted.

7. S-INST/S-CYCLE

   Determines whether a single instruction or a single cycle is performed when the CONT switch is depressed while the computer is in the halt mode.

When the system is running a program, the LOAD ADDR, EXAM, and DEPosit functions are disabled to prevent disrupting the running program.

2.1.1.3 Indicator Lights

The indicator lights signify specific computer functions, operations, or states. Each is explained below.

1. FETCH

   Indicates that the central processor is in the state of fetching an instruction.

2. EXECUTE

   Indicates that the central processor is in the state of executing an instruction.

3. BUS

   Indicates that a peripheral is controlling the bus. It is lit when Bus Busy (BBSY) is asserted, unless the processor (including the console) is asserting BBSY.

4. RUN — Indicates that the processor is running. (While executing a RESET command [20 ms.] the RUN light is not on.)

5. SOURCE — Indicates that the central processor is obtaining source data. (Not lit when data is from an internal register.)

6. DESTINATION — Indicates that the central processor is obtaining destination data. (Not lit when data is from an internal register.)

7. ADDRESS — Identifies the source or destination address cycle of the central processor. When references to the addresses are made via the Unibus, the lights tell the computer's source or destination cycle. For an internal register reference, the address is always zero.

2.1.2 Operating the Control Switches

When the PDP-11 has been halted at the end of an instruction, it is possible to examine and update the contents of locations. (You cannot EXAMine or DEPosit at the end of a single cycle unless the cycle coincides with the end of the instruction.) To examine a specific location, set the Switch Register to correspond to the location's address, and press LOAD ADDR, which will transfer the contents of the Switch Register into the ADDRESS REGISTER. The location of the address to be examined is then displayed in the ADDRESS REGISTER. You can then depress EXAM, and the data in that location will appear in the DATA register.

If you attempt to examine data from or deposit data into a nonexistent memory location, an error will occur and the DATA register will reflect location 000004, the trap location for references to nonexistent locations. To verify this condition, deposit some number other than four in the location. If four is still indicated, either nothing is assigned to that location or whatever is assigned is not working properly.

By depressing EXAM again, the ADDRESS REGISTER will be incremented by two to the next word address, and the contents of this next location may be examined. The ADDRESS REGISTER will always indicate the address of the data displayed in the DATA register.

The examine function is such that if LOAD ADDR is depressed and then EXAM, the ADDRESS REGISTER will not be incremented. In this case, the location reflected in the ADDRESS REGISTER is examined directly. However, on successive depressings of EXAM only, the ADDRESS REGISTER is incremented.

If you find an incorrect entry in the DATA register, you can enter the correct data there by putting it in the Switch Register and raising the DEP switch. The ADDRESS REGISTER will not increment when this data is deposited. Therefore, by pressing the EXAM switch you can examine (verify) the data just deposited. However, pressing EXAM again will increment the register to the next word address.

When doing consecutive examines or deposits, the address will increment by two, to successive word locations. However, when examining the general-purpose registers (R0-R7), the system only increments by one. The reason for this is that once the Switch Register is set properly, you can use the automatic stepping feature of EXAM to examine general-purpose registers from the computer console.

To start a program after it is loaded into core, load the starting address of the program into the Switch Register, press LOAD ADDR, and after ensuring that the ENABLE/HALT switch is in the ENABLE position, depress START. The program should start to run as soon as the START switch is released.

Normally, when the system is running, not only will the RUN light be on but other lights (FETCH, EXECUTE, SOURCE, etc.) will be flickering. If the RUN light is on and none of the other lights are flickering, the system could be executing a WAIT instruction which waits for an interrupt.

While in the halt mode, if you wish to do a single instruction, place the S-INST/S-CYCLE switch in the S-INST position and depress CONT. When CONT is pressed, the console momentarily passes control to the processor, allowing it to execute one instruction before regaining control. Each time the CONT switch is pressed the computer will execute one instruction. If you wish to have the computer perform a single cycle, place the S-INST/S-CYCLE switch in the S-CYCLE position and press CONT. The computer will then perform one complete cycle and halt.

To start the program again, place the ENABLE/HALT switch in the ENABLE position and press CONT.

2.2 OPERATING THE TELETYPE

The ASR-33 Teletype (TTY) is the basic input/output device for PDP-11 computers. It consists of a printer, keyboard, paper tape reader, and paper tape punch, all of which can be used either on-line under program control or off-line. The Teletype controls (Figure 2-2) are described as they apply to the operation of the computer.

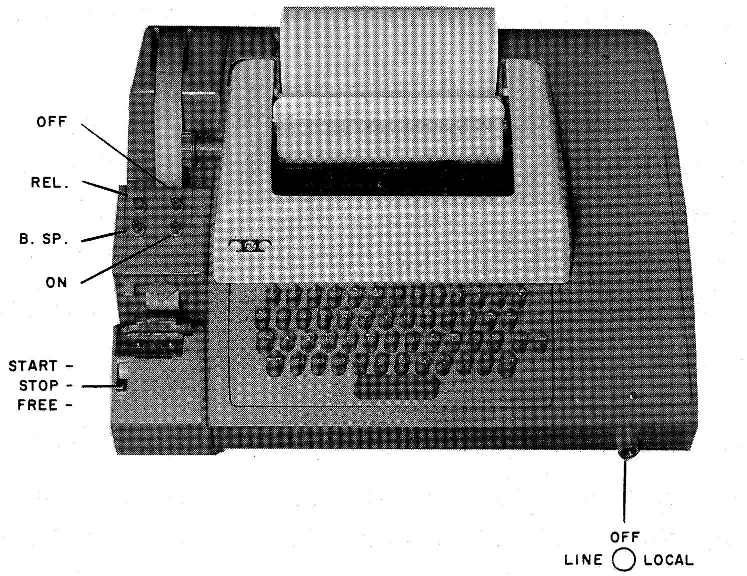


Figure 2-2. ASR-33 Teletype Console

2.2.1 Power Controls

LINE - The Teletype is energized and connected to the computer as an input/output device, under computer control.

OFF - The Teletype is de-energized.

LOCAL - The Teletype is energized for off-line operation.

2.2.2 Printer

The printer provides a typed copy of input and output at 10 characters per second, maximum.

2.2.3 Keyboard

The Teletype keyboard is similar to a typewriter keyboard. However, certain operational functions are shown on the upper part of some of the keytops. These functions are activated by holding down the CTRL key while depressing the desired key. For example, when using the Text Editor, CTRL/U causes the current line of text to be ignored.

Although the left and right square brackets are not visible on the keyboard keytops, they are shown in Figure 2-3 and are generated by typing SHIFT/K and SHIFT/M, respectively. The ALT MODE key is identified as ESC (ESCape) on some keyboards.

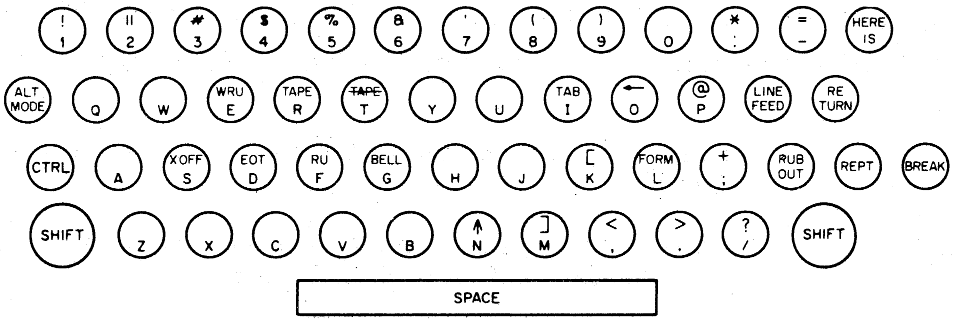


Figure 2-3. ASR-33 Teletype Keyboard

2.2.4 Paper Tape Reader

The paper tape reader (LSR) is used to read data punched on eight channel perforated paper tape at a rate of 10 characters per second, maximum. The reader controls are shown in Figure 2-2 and described below.

START — Activates the reader; reader sprocket wheel is engaged and operative.

STOP — Deactivates the reader; reader sprocket wheel is engaged but not operative.

FREE — Deactivates the reader; reader sprocket wheel is disengaged.

The following procedure describes how to properly position paper tape in the low-speed reader.

a. Raise the tape retainer cover.

b. Set reader control to FREE.

c. Position the leader portion of the tape over the read pens with the sprocket (feed) holes over the sprocket (feed) wheel and with the arrow on the tape (printed or cut) pointing outward.

d. Close the tape retainer cover.

e. Make sure that the tape moves freely.

f. Set reader control to START, and the tape will be read.

2.2.5 Paper Tape Punch

The paper tape punch (LSP) is used to perforate eight-channel rolled oiled paper tape at a maximum rate of 10 characters per second. The punch controls are shown in Figure 2-2 and described below.

RELease — Disengages the tape to allow tape removal or loading.

B.SP — Backspaces the tape one space for each firm depression of the B.SP button.

ON (LOCK ON) — Activates the punch.

OFF (UNLOCK) — Deactivates the punch.

Blank leader/trailer tape is generated by:

1. Turning the TTY switch to LOCAL
2. Turning the LSP on
3. Typing the HERE IS key
4. Turning the LSP off
5. Turning the TTY switch to LINE.

2.3 OPERATING THE HIGH-SPEED PAPER TAPE READER AND PUNCH UNITS

A high-speed paper tape reader and punch unit is pictured in Figure 2-4 and descriptions of the reader and punch units follow.

2.3.1 Reader Unit

The high-speed paper tape reader is used to read data from eight-channel fan-folded (non-oiled) perforated paper tape photoelectrically at a maximum rate of 300 characters per second. Primary power is applied to the reader when the computer POWER switch is turned on. The reader is under program control. However, tape can be advanced past the photoelectric sensors without causing input by pressing the reader FEED button.

2.3.2 Punch Unit

The high-speed paper tape punch is used to record computer output on eight-channel fan-folded paper tape at a maximum rate of 50 characters per second. All characters are punched under program control from the computer. Blank tape (feed holes only, no data) may be produced by pressing the FEED button. Primary power is available to the punch when the computer POWER switch is turned on.

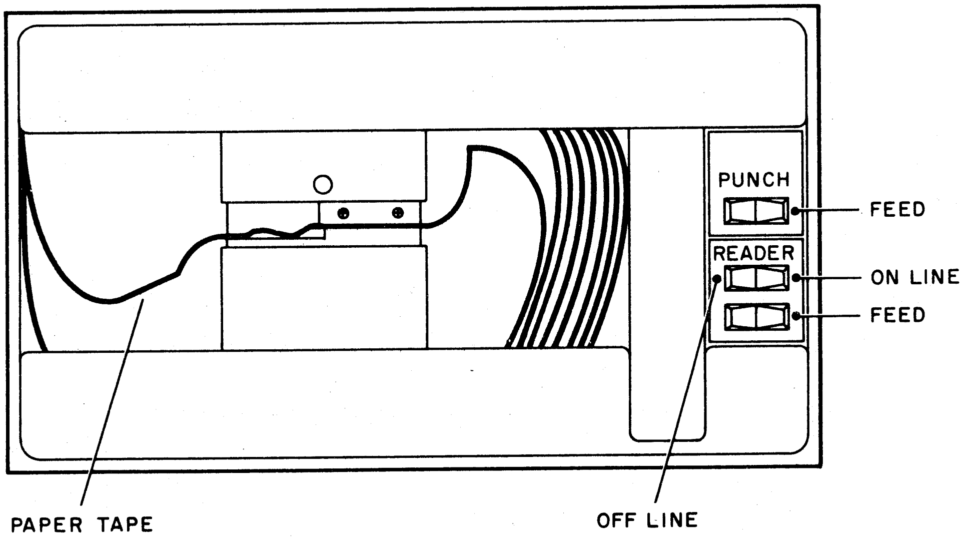


Figure 2-4. High-Speed Paper Tape Reader/Punch

Paper tape is loaded into the reader as explained below.

1. Raise tape retainer cover.
2. Put tape into right-hand bin with channel one of the tape toward the rear of the bin.
3. Place several folds of blank tape through the reader and into the left-hand bin.

4. Place the tape over the reader head with feed holes engaged in the teeth of the sprocket wheel.

5. Close the tape retainer cover.

6. Depress the tape feed button until leader tape is over the reader head.

CAUTION

Oiled paper tape should not be used in the high-speed reader or punch - oil collects dust and dirt which can cause reader or punch errors.

2.4 THE LP11 LINE PRINTER

The LP11 is a line printer with 80 column capacity, capable of printing more than 300 lines per minute at a full 80 columns, and more than 1100 lines per minute at 20 columns. The print rate is dependent upon the data and the number of columns to be printed.

Characters are loaded into the printer memory via the Line Printer Buffer (LPB) serially. When the memory becomes full (20 characters) the characters are automatically printed. This continues until the 80 columns have been printed or a carriage return, line feed, or form feed character is recognized.

Figure 2-5 illustrates the printer control panel on which are mounted three indicator lights and three toggle switches.

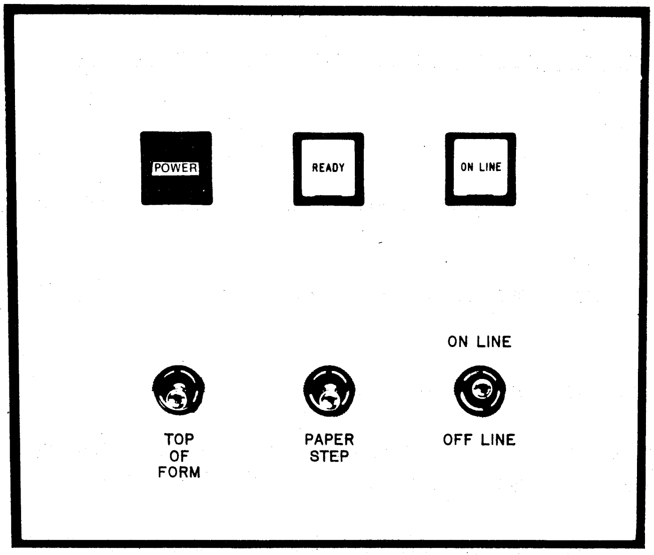


Figure 2-5. Line Printer Control Panel

Operation of the lights and switches is as follows:

POWER light

Glows red to indicate main power switch (located inside cabinet) is at ON position and power is available to the printer.

READY light

Glows white, shortly after the POWER light goes on to indicate that internal components have reached synchronous state and the printer is ready to operate.

ON LINE light

Glows white to indicate that ON LINE/OFF LINE toggle switch is in ON LINE position.

ON/OFF (main power) switch

This switch controls line current to the printer. To gain access to it, the printer front panel is unlatched, by pushing the circular button on the right hand edge, and opened to the left on its hinges. The switch is located to the left of center approximately fourteen inches below the top. If power is available, the red POWER light on the control panel will glow when the switch is positioned at ON.

The switch is on when in the up position. The ON and OFF labels are printed on the stem of the switch. A group of two switches and three indicator lights, above the main power switch, are for the use of technicians in making initial adjustments to the printer.

TOP OF FORM switch

This switch is tipped toward the front of the cabinet to roll up the form to the top of the succeeding page. It is spring returned to center position, and produces a single top-of-form operation each time it is actuated. The switch is effective only when the printer is off line.

PAPER STEP switch

Operates similarly to TOP OF FORM but produces a single line step each time it is actuated. It is only effective with printer off line.

ON LINE/OFF LINE switch

This two-position toggle switch is spring-returned to center. When momentarily positioned at ON LINE it logically connects the printer to the computer and causes the ON LINE light to glow. Positioned momentarily at OFF LINE, the logical connection to the computer is broken, the ON LINE light goes off, and the TOP OF FORM and PAPER STEP switches are enabled.

2.5 INITIALIZING THE SYSTEM

Before using the computer system, it is good practice to initialize all units as specified below.

a. Main power cord is properly plugged in

b. Computer POWER key is ON

c. Console switches are set:

   ENABLE/HALT to HALT
   SR=000000

d. Teletype is turned to LINE

e. Low-speed punch is OFF

f. Low-speed reader is set to FREE

g. High-speed reader/punch is ON

The system is now initialized and ready for your use.

CHAPTER 3

WRITING PAL-11A

ASSEMBLY LANGUAGE PROGRAMS

CHAPTER 3

WRITING PAL-11A ASSEMBLY LANGUAGE PROGRAMS

PAL-11A (Program Assembly Language for the PDP-11's Absolute Assembler) is the "heart" of the PDP-11/20 Paper Tape Software system. It enables you to write source (symbolic) programs using letters, numbers, and symbols which are meaningful to you. The source programs, generated either on-line using the Text Editor (ED-11), or off-line, are then assembled into object programs (in absolute binary) which are executable by the computer. The object program is produced after two passes through the Assembler; an optional third pass produces a complete octal/symbolic listing of the assembled program. This listing is especially useful for documentation and debugging purposes.

This chapter explains not only how to write PAL-11A programs but also how to assemble the source programs into computer-acceptable object programs. All facets of the assembly language are explained and illustrated with many examples, and the chapter concludes with assembling procedures. In explaining how to write PAL-11A source programs it is necessary, especially at the outset, to make frequent forward references. Therefore, we recommend that you first read through the entire chapter to get a "feel" for the language, and then reread the chapter, this time referring to appropriate sections as indicated, for a thorough understanding of the language and assembling procedures.

Some notable features of PAL-11A are:

1. Selective assembly pass functions
2. Device specification for pass functions
3. Optional error listing on Teletype
4. Double buffered and concurrent I/O (provided by IOX)
5. Alphabetized, formatted symbol table listing

The PAL-11A Assembler is available in two versions: a 4K version and an 8K version.

The assembly language applies equally to both versions. The 4K version provides symbol storage for about 176 user-defined symbols, and the 8K version provides for about 1256 user-defined symbols (see Section 3.3).

In addition, the 8K version allows a line printer to be used for the program listing and/or symbol table listing.

The following discussion of the PAL-11A Assembly Language assumes that you have read the PDP-11 Processor Handbook, with emphasis on those sections which deal with the PDP-11 instruction set, formats, and timings -- a thorough knowledge of these is vital to efficient assembly language programming.

3.1 CHARACTER SET

A PAL-11A source program is composed of symbols, numbers, expressions, symbolic instructions, assembler directives, argument separators, and line terminators written using the following ASCII[1] characters.

1. The letters A through Z. (Upper and lower case letters are acceptable, although upon input, lower case letters will be converted to upper case letters.)
2. The numbers 0 through 9.
3. The characters . and $ (reserved for system software).
4. The separating or terminating symbols:

   : = % # @ ( ) , ; " ' + - & !

   carriage return tab space line feed form feed

3.2 STATEMENTS

A source program is composed of a sequence of statements, where each statement is on a single line. The statement is terminated by a carriage return character and must be immediately followed by either a line feed or form feed character. Should a carriage return character be present and not be followed by a line feed or form feed, the Assembler will generate a Q error (Section 3.10) and that portion of the line following the carriage return will be ignored. Since the carriage return is a required statement terminator, a line feed or form feed not immediately preceded by a carriage return will have one inserted by the Assembler.

It should be noted that, if the Editor (ED-11) is being used to create the source program (see Section 4.4.4), a typed carriage return (RETURN

[1] ASCII stands for American Standard Code for Information Interchange.

key) automatically generates a line feed character.

A statement may be composed of up to four fields which are identified by their order of appearance and by specified terminating characters as explained below and summarized in Appendix B. The four fields are:

```
        Label          Operator        Operand         Comment
```

The label and comment fields are optional. The operator and operand fields are interdependent -- either may be omitted depending upon the contents of the other.

3.2.1 Label

A label is a user-defined symbol (see Section 3.3.2) which is assigned the value of the current location counter. It is a symbolic means of referring to a specific location within a program. If present, a label always occurs first in a statement and must be terminated by a colon. For example, if the current location is 100_8, the statement

```
        ABCD:    MOV A,B
```

will assign the value 100_8 to the label ABCD so that subsequent reference to ABCD will be to location 100_8. More than one label may appear within a single label field; each label within the field will have the same value. For example, if the current location is 100, multiple labels in the statement

```
        ABC:    $DD:   A7.7:    MOV A,B
```

will equate each of the three labels ABC, $DD, and A7.7 with the value 100_8. ($ and . are reserved for system software.)

The error code M (multiple definition of a symbol) will be generated during assembly if two or more labels have the same first six characters.

3.2.2 Operator

An operator follows the label field in a statement, and may be an instruction mnemonic or an assembler directive (see Appendix B). When it is an instruction mnemonic, it specifies what action is to be performed on any operand(s) which follows it. When it is an assembler directive, it specifies a certain function or action to be performed during assembly.

The operator may be preceded only by one or more labels and may be followed by one or more operands and/or a comment. An operator is legally terminated by a space, tab, or any of the following characters.

```
        #  +  -  @  (  "  '  %  !  &  ,  ;
        line feed      form feed     carriage return
```

The use of each character above will be explained in this chapter.

Consider the following examples:

```
        MOV   A,B                  ;→| (TAB) terminates operator MOV
        MOV@A,B                    ;@ terminates operator MOV
```

When the operator stands alone without an operand or comment, it is terminated by a carriage return followed by a line feed or form feed character.

3.2.3 Operand

An operand is that part of a statement which is operated on by the operator -- an instruction mnemonic or assembler directive. Operands may be symbols, expressions, or numbers. When multiple operands appear within a statement, each is separated from the next by a comma. An operand may be preceded by an operator and/or label, and followed by a comment.

The operand field is terminated by a semicolon when followed by a comment, or by a carriage return followed by a line feed or form feed character when the operand ends the statement. For example,

```
        LABEL:     MOV GEORGE,BOB     ;THIS IS A COMMENT
```

where the space between MOV and GEORGE terminated the operator field and began the operand field; the comma separated the operands GEORGE and BOB; the semicolon terminated the operand field and began the comment.

3.2.4 Comments

The comment field is optional and may contain any ASCII character except null, rubout, carriage return, line feed or form feed. All other characters, even those with special significance are ignored by the Assembler when used in the comment field.

The comment field may be preceded by none, any, or all of the other three fields. It must begin with the semicolon and end with a carriage return followed by a line feed or form feed character. For example,

```
LABEL:    CLR HERE          ;THIS IS A $1.00 COMMENT
```

Comments do not affect assembly processing or program execution, but they are useful in program listings for later analysis, checkout or documentation purposes.

3.2.5 Format Control

The format is controlled by the space and tab characters. They have no effect on the assembling process of the source program unless they are embedded within a symbol, number, or ASCII text; or are used as the operator field terminator. Thus, they can be used to provide a neat, readable program. A statement can be written

```
LABEL:MOV(SP)+,TAG;POP VALUE OFF STACK
```

or, using formatting characters it can be written

```
LABEL:    MOV (SP)+,TAG      ;POP VALUE OFF STACK
```

which is much easier to read.

Page size is controlled by the form feed character. A page of n lines is created by inserting a form feed (CTRL/FORM keys on the keyboard) after the nth line. If no form feed is present, a page is terminated after 56 lines,

3.3 Symbols

There are two types of symbols, permanent and user-defined. Both are stored in the Assembler's symbol table. Initially, the symbol table contains the permanent symbols, but as the source program is assembled, user-defined symbols are added to the table.

3.3.1 Permanent Symbols

Permanent symbols consist of the instruction mnemonics (see Appendix B.3) and assembler directives (see Section 3.8). These symbols are a permanent part of the Assembler's symbol table and need not be defined before being used in the source program.

3.3.2 User-Defined Symbols

User-defined symbols are those defined as labels (see Section 3.2.1) or by direct assignment (see Section 3.3.3). These symbols are added to the symbol table as they are encountered during the first pass of the assembly. They can be composed of alphanumeric characters, dollar signs, and periods only; again, dollar signs and periods are reserved for use by the system software. Any other character is illegal and, if used, will result in the error message I (see Section 3.11). The following rules also apply to user-defined symbols:

1. The first character must not be a number.
2. Each symbol must be unique within the first six characters.
3. A symbol may be written with more than six legal characters but the seventh and subsequent characters are only checked for legality, and are not otherwise recognized by the Assembler.
4. Spaces and tabs must not be embedded within a symbol.

A user-defined symbol may duplicate a permanent symbol. The value associated with a permanent symbol that is also user-defined depends upon its use:

1. A permanent symbol encountered in the operator field is associated with its corresponding machine op-code.
2. If a permanent symbol in the operand field is also user-defined, its user-defined value is associated with the symbol. If the symbol is not found to be user-defined, then the corresponding machine op-code value is associated with the symbol.

3.3.3 Direct Assignment

A direct assignment statement associates a symbol with a value. When a direct assignment statement defines a symbol for the first time, that symbol is entered into the Assembler's symbol table and the specified value is associated with it. A symbol may be redefined by assigning a new value to a previously defined symbol. The newly assigned value will replace the previous value assigned to the symbol.

The general format for a direct assignment statement is

```
symbol = expression
```

The following conventions apply:

1. An equal sign (=) must separate the symbol from the expression defining the symbol.
2. A direct assignment statement may be preceded by a label and may be followed by a comment.
3. Only one symbol can be defined by any one direct assignment statement.
4. Only one level of forward referencing is allowed.

Example of the two levels of forward referencing (illegal):

```
X = Y
Y = Z
Z = 1
```

X and Y are both undefined throughout pass 1 and will be listed on the printer as such at the end of that pass. X is undefined throughout pass 2, and will cause a U error message.

Examples:

```
    A = 1              ;THE SYMBOL A IS EQUATED WITH THE VALUE 1

    B = 'A-1&MASKLOW   ;THE SYMBOL B IS EQUATED WITH THE EXPRES-
                       ;SION'S VALUE.

C:  D = 3              ;THE SYMBOL D IS EQUATED WITH 3.  THE
E:  MOV #1,ABLE        ;LABELS C AND E ARE EQUATED WITH THE
                       ;NUMERICAL MEMORY ADDRESS OF THE MOV
                       ;COMMAND.
```

3.3.4 Register Symbols

The eight general registers of the PDP-11 are numbered 0 through 7. These registers may be referenced by use of a register symbol, that is, a symbolic name for a register. A register symbol is defined by means of a direct assignment, where the defining expression contains at least one term preceded by a % or at least one term previously defined as a register symbol.

```
          RØ=%Ø                     ;DEFINE RØ AS REGISTER Ø
          R3=RØ+3                   ;DEFINE R3 AS REGISTER 3
          R4=1+%3                   ;DEFINE R4 AS REGISTER 4
          THERE=%2                  ;DEFINE "THERE" AS REGISTER 2
```

It is important to note that all register symbols must be defined before they are referenced. A forward reference to a register symbol will generally cause phase errors (see Section 3.10).

The % may be used in any expression thereby indicating a reference to a register. Such an expression is a register expression. Thus, the statement

```
          CLR %6
```

will clear register 6 while the statement

```
          CLR 6
```

will clear the word at memory address 6. In certain cases a register can be referenced without the use of a register symbol or register expression. These cases are recognized through the context of the statement and are thoroughly explained in Sections 3.6 and 3.7. Two obvious examples of this are:

```
          JSR   5,SUBR               ;THE FIRST OPERAND FIELD MUST
                                     ;ALWAYS BE A REGISTER.

          CLR  X(2)                  ;ANY EXPRESSION ENCLOSED IN
                                     ;( ) MUST BE A REGISTER.  IN
                                     ;THIS CASE, INDEX REGISTER 2.
```

3.4 EXPRESSIONS

Arithmetic and logical operators (see Section 3.4.2) may be used to form expressions. A term of an expression may be a permanent or user-defined symbol, a number, ASCII data, or the present value of the assembly location counter represented by the period. Expressions are evaluated from left to right. Parenthetical grouping is not allowed.

Expressions are evaluated as word quantities. The operands of a .BYTE directive (Section 3.8.5) are evaluated as word expressions before truncation to the low-order eight bits.

A missing term or expression will be interpreted as 0. A missing operator will be interpreted as +. The error code Q (Questionable syntax) will be generated for a missing operator. For example,

```
          A +    -1ØØ              ;OPERAND MISSING
```

will be evaluated as A + 0 - 100, and

```
          TAG ! LA 177777          ;OPERATOR MISSING
```

will be evaluated as TAG ! LA+177777.

3.4.1 Numbers

The Assembler accepts both octal and decimal numbers. Octal numbers consist of the digits 0 through 7 only. Decimal numbers consist of the digits 0 through 9 followed by a decimal point. If a number contains an 8 or 9 and is not followed by a decimal point, the N error code (see Section 3.10) will be printed and the number interpreted as decimal. Negative numbers may be expressed as a number preceded by a minus sign rather than in a two's complement form. Positive numbers may be preceded by a plus sign although this is not required.

If a number is too large to fit into 16 bits, the number is truncated from the left. In the assembly listing the statement will be flagged with a Truncation (T) error.

3.4.2 Arithmetic and Logical Operators

The arithmetic operators are:

+	indicates addition or a positive number
-	indicates subtraction or a negative number

The logical operators are defined and illustrated below.

&	indicates the logical AND operation
!	indicates the logical inclusive OR operation

AND

Ø	&	Ø	=	Ø
Ø	&	1	=	Ø
1	&	Ø	=	Ø
1	&	1	=	1

OR

Ø	!	Ø	=	Ø
Ø	!	1	=	1
1	!	Ø	=	1
1	!	1	=	1

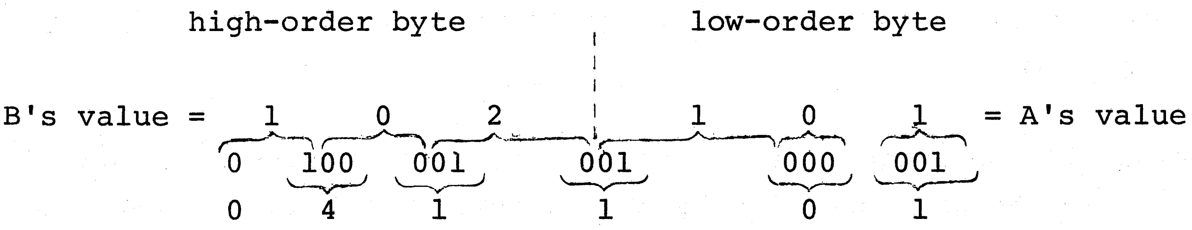
3.4.3 ASCII Conversion

When preceded by an apostrophe, any ASCII character (except null, rubout, carriage return, line feed, or form feed) is assigned the 7-bit ASCII value of the character (see Appendix A). For example,

```
'A
```

is assigned the value 101_8.

When preceded by a quotation mark, two ASCII characters (not including null, rubout, carriage return, line feed, or form feed) are assigned the 7-bit ASCII values of each of the characters to be used. Each 7-bit value is stored in an 8-bit byte and the bytes are combined to form a word. For example, "AB will store the ASCII value of A in the low-order (even) byte and the value of B in the high-order (odd) byte:



```
"AB = Ø411Ø1
```

3.5 ASSEMBLY LOCATION COUNTER

The period (.) is the symbol for the assembly location counter. (Note difference of Program Counter. . ≠ PC. See Section 3.6.) When used in the operand field of an instruction, it represents the address of the first word of the instruction. When used in the operand field of an assembler directive, it represents the address of the current byte or word. For example,

```
A:  MOV #.,RØ          ;. REFERS TO LOCATION A, I.E.,
                       ;THE ADDRESS OF THE MOV INSTRUCTION
```

(# is explained in Section 3.6.9).

At the beginning of each assembly pass, the Assembler clears the location counter. Normally, consecutive memory locations are assigned to each byte of object data generated. However, the location where the object data is stored may be changed by a direct assignment altering the location counter.

```
.=expression
```

The expression defining the period must not contain forward references or symbols that vary from one pass to another. Examples:

```
                .=5ØØ

FIRST:      MOV    .+10,COUNT    ;THE LABEL FIRST HAS THE VALUE 500(8)
                                 ;.+10 EQUALS 510(8).  THE CONTENTS
                                 ;OF THE LOCATION 510(8) WILL BE DE-
                                 ;POSITED IN LOCATION COUNT.

                .=52Ø            ;THE ASSEMBLY LOCATION COUNTER NOW
                                 ;HAS A VALUE OF 520(8).

SECOND:     MOV    .,INDEX       ;THE LABEL SECOND HAS THE VALUE 520(8).
                                 ;THE CONTENTS OF LOCATION 520(8),
                                 ;THAT IS, THE BINARY CODE FOR THE
                                 ;INSTRUCTION ITSELF, WILL BE DEPOSITED
                                 ;IN LOCATION INDEX.
```

Storage area may be reserved by advancing the location counter. For example, if the current value of the location counter is 1000, the direct assignment statement

```
.=.+1ØØ
```

will reserve 100_8 bytes of storage space in the program. The next instruction will be stored at 1100.

3.6 ADDRESSING

The Program Counter (register 7 of the eight general registers) always contains the address of the next word to be fetched; i.e., the address of the next instruction to be executed, or the second or third word of the current instruction.

In order to understand how the address modes operate and how they assemble (see Section 3.6.11), the action of the Program Counter must be understood. The key rule is:

Whenever the processor implicitly uses the Program Counter (PC) to fetch a word from memory, the Program Counter is automatically incremented by two after the fetch.

That is, when an instruction is fetched, the PC is incremented by two, so that it is pointing to the next word in memory; and, if an instruction uses indexing (see Sections 3.6.7, 3.6.8, and 3.6.10), the processor uses the Program Counter to fetch the base from memory. Hence, using the rule above, the PC increments by two, and now points to the next word.

The following conventions are used in this section:

a. Let E be any expression as defined in Section 3.4.

b. Let R be a register expression. This is any expression containing a term preceded by a % character or a symbol previously equated to such a term.

Examples:

```
R0 = %0            ;GENERAL REGISTER 0
R1 = R0 + 1        ;GENERAL REGISTER 1
R2 = 1 + %1        ;GENERAL REGISTER 2
```

c. Let ER be a register expression or an expression in the range 0 to 7 inclusive.

d. Let A be a general address specification which produces a 6-bit address field as described in the PDP-11 Handbook.

The addressing specification, A, may now be explained in terms of E, R, and ER as defined above. Each will be illustrated with the single operand instruction CLR or double operand instruction MOV.

3.6.1 Register Mode

The register contains the operand.

Format: R

Example:

```
                R0 = %0             ;DEFINE R0 AS REGISTER 0
                CLR   R0            ;CLEAR REGISTER 0
```

3.6.2 Deferred Register Mode

The register contains the address of the operand.

Format: @R or (ER)

Example:

```
                CLR   @R1           ;CLEAR THE WORD AT THE
                   or               ;ADDRESS CONTAINED IN
                CLR   (1)           ;REGISTER 1.
```

3.6.3 Autoincrement Mode

The contents of the register are incremented immediately after being used as the address of the operand.[1]

Format: (ER)+

Examples:

```
                CLR   (R0)+         ;CLEAR WORDS AT ADDRESSES
                CLR   (R0+3)+       ;CONTAINED IN REGISTERS 0, 3, AND 2 AND
                CLR   (2)+          ;INCREMENT REGISTER CONTENTS
                                    ;BY TWO.
```

[1] a. Both JMP and JSR instructions using mode 2 (non-deferred Autoincrement Mode) autoincrement the register before its use.

b. In double operand instructions of the addressing form %R,(R)+ or %R,-(R) where the source and destination registers are the same, the source operand is evaluated as the autoincremented or autodecremented value; but the destination register, at the time it is used, still contains the originally intended effective address.

For example, if Register 0 contains 100, the following occurs:

```
MOV  RØ,(Ø)+    ;THE QUANTITY 102 IS MOVED TO LOCATION 100
MOV  RØ,-(Ø)    ;THE QUANTITY 76 IS MOVED TO LOCATION 76
```

The use of these forms should be avoided, as they are not guaranteed to remain in future PDP-11's.

3.6.4 Deferred Autoincrement Mode

The register contains the pointer to the address of the operand. The contents of the register are incremented after being used.

Format: @(ER)+

Example:

```
        CLR  @(3)+          ;CONTENTS OF REGISTER 3 POINT
                            ;TO ADDRESS OF WORD TO BE CLEARED
                            ;BEFORE BEING INCREMENTED BY TWO
```

3.6.5 Autodecrement Mode

The contents of the register are decremented before being used as the address of the operand.[1]

Format: -(ER)

Examples:

```
        CLR -(R0)           ;DECREMENT CONTENTS OF REG-
        CLR -(R0+3)         ;ISTERS 0, 3, AND 2 BEFORE USING
        CLR -(2)            ;AS ADDRESSES OF WORDS TO BE CLEARED
```

3.6.6 Deferred Autodecrement Mode

The contents of the register are decremented before being used as the pointer to the address of the operand.

Format: @-(ER)

[1] See previous footnote.

Example:

```
          CLR  @-(2)          ;DECREMENT CONTENTS OF REG. 2
                              ;BEFORE USING AS POINTER TO ADDRESS
                              ;OF WORD TO BE CLEARED
```

3.6.7 Index Mode

Format: E(ER)

The value of an expression E is stored as the second or third word of the instruction. The effective address is calculated as the value of E plus the contents of register ER. The value E is called the base.

Examples:

```
          CLR  X+2(R1)        ;EFFECTIVE ADDRESS IS X+2 PLUS
                              ;THE CONTENTS OF REGISTER 1

          CLR  -2(3)          ;EFFECTIVE ADDRESS IS -2 PLUS
                              ;THE CONTENTS OF REGISTER 3
```

3.6.8 Deferred Index Mode

An expression plus the contents of a register gives the pointer to the address of the operand.

Format: @E(ER)

Example:

```
          CLR @14(4)          ;IF REGISTER 4 HOLDS 100, AND LOCA-
                              ;TION 114 HOLDS 2000, LOC. 2000 IS
                              ;CLEARED
```

3.6.9 Immediate Mode and Deferred Immediate (Absolute) Mode

The immediate mode allows the operand itself to be stored as the second or third word of the instruction. It is assembled as an autoincrement of register 7, the PC.

Format: #E

Examples:

```
          MOV  #100, R0       ;MOVE AN OCTAL 100 TO REGISTER 0
          MOV  #X, R0         ;MOVE THE VALUE OF SYMBOL X TO
                              ;REGISTER 0
```

The operation of this mode is explained as follows:

The statement MOV #100,R3 assembles as two words. These are:

```
Ø 1 2 7 Ø 3
Ø Ø Ø 1 Ø Ø
```

Just before this instruction is fetched and executed, the PC points to the first word of the instruction. The processor fetches the first word and increments the PC by two. The source operand mode is 27 (autoincrement the PC). Thus, the PC is used as a pointer to fetch the operand (the second word of the instruction) before being incremented by two, to point to the next instruction.

If the #E is preceded by @, E specifies an absolute address.

3.6.10 Relative and Deferred Relative Modes

Relative Mode is the normal mode for memory references.

Format: E

Examples:

```
CLR  100          ;CLEAR LOCATION 100

MOV  X,Y          ;MOVE CONTENTS OF LOCATION X TO
                  ;LOCATION Y
```

This mode is assembled as Index Mode, using 7, the PC, as the register. The base of the address calculation, which is stored in the second or third word of the instruction, is not the address of the operand. Rather, it is the number which, when added to the PC, becomes the address of the operand. Thus, the base is X - PC. The operation is explained as follows.

If the statement MOV 100,R3 is assembled at location 20, then the assembled code is:

```
Location 20:     Ø 1 6 7 Ø 3
Location 22:     Ø Ø Ø Ø 5 4
```

The processor fetches the MOV instruction and adds two to the PC so that it points to location 22. The source operand mode is 67; that is, indexed by the PC. To pick up the base, the processor fetches the word pointed to by the PC and adds two to the PC. The PC now points to location 24. To calculate the address of the source operand, the base is added to the designated register. That is, Base + PC = 54 + 24 = 100, the operand address.

Since the Assembler considers . as the address of the first word of the instruction, an equivalent statement would be

```
MOV  100 -.- 4(PC),R3
```

This mode is called relative because the operand address is calculated relative to the current PC. The base is the distance (in bytes) between the operand and the current PC. If the operator and its operand are moved in memory so that the distance between the operator and data remains constant, the instruction will operate correctly.

If E is preceded by @, the expression's value is the pointer to the address of the operand.

3.6.11 Table of Mode Forms and Codes (6-bit (A) format only - see Section 3.7)

Each instruction takes at least one word. Operands of the first six forms listed below do not increase the length of an instruction. Each operand in one of the other forms however, increases the instruction length by one word.

	Form	Mode	Meaning
None of these forms increase the instruction length.	R	Øn	Register
	@R or (ER)	1n	Register n deferred
	(ER)+	2n	Autoincrement
	@(ER)+	3n	Autoincrement deferred
	-(ER)	4n	Autodecrement
	@-(ER)	5n	Autodecrement deferred
Any of these forms adds a word to the instruction length	E(ER)	6n	Index
	@E(ER)	7n	Index deferred
	#E	27	Immediate
	@#E	37	Absolute memory reference
	E	67	Relative
	@E	77	Relative deferred reference

Notes:

1. An alternate form for @R is (ER). However, the form @(ER) is equivalent to @0(ER).

2. The form @#E differs from the form E in that the second or third word of the instruction contains the absolute address of the operand rather than the relative distance between the operand and the PC. Thus, the statement CLR @#100 will clear location 100 even if the instruction is moved from the point at which it was assembled.

3.7 INSTRUCTION FORMS

The instruction mnemonics are given in Appendix B. This section defines the number and nature of the operand fields for these instructions.

In the table that follows, let R, E, and ER represent expressions as defined in Section 3.4, and let A be a 6-bit address specification of the forms:

```
E         @E
R         @R    or   (R)
(ER)+     @(ER)+
-(ER)     @-(ER)
E(ER)     @E(ER)
#E        @#E
```

Table 3-1. Instruction Operand Fields

Instruction	Form	Example
Double Operand	Op A,A	MOV (R6)+,@Y
Single Operand	Op A	CLR -(R2)
Operate	Op	HALT
Branch	Op E where $-128_{10} \le (E-.-2)/2 \le 127_{10}$	BR X+2 BLO .-4
Subroutine Call	JSR ER,A	JSR PC,SUBR
Subroutine Return	RTS ER	RTS PC
EMT/TRAP	Op or Op E where $0 \le E \le 377_8$	EMT EMT 31

The branch instructions are one word instructions. The high byte contains the op code and the low byte contains an 8-bit signed offset (7 bits plus sign) which specifies the branch address relative to the PC. The hardware calculates the branch address as follows:

a) Extend the sign of the offset through bits 8-15.

b) Multiply the result by 2. This creates a word offset rather than a byte offset.

c) Add the result to the PC to form the final branch address.

The Assembler performs the reverse operation to form the byte offset from the specified address. Remember that when the offset is added to the PC, the PC is pointing to the word following the branch instruction; hence the factor -2 in the calculation.

Byte offset = (E-PC)/2 truncated to eight bits.

Since PC = .+2, we have

Byte offset = (E-•-2)/2 truncated to eight bits.

The EMT and TRAP instructions do not use the low-order byte of the word. This allows information to be transferred to the trap handlers in the low-order byte. If EMT or TRAP is followed by an expression, the value is put into the low-order byte of the word. However, if the expression is too big ($>377_8$) it is truncated to eight bits and a Truncation (T) error occurs.

3.8 ASSEMBLER DIRECTIVES

Assembler directives (sometimes called pseudo-ops) direct the assembly process and may generate data. They may be preceded by a label and followed by a comment. The assembler directive occupies the operator field. Only one directive may be placed in any one statement. One or more operands may occupy the operand field or it may be void -- allowable operands vary from directive to directive.

3.8.1. .EOT

The .EOT directive indicates the physical End-Of-Tape though not the logical end of the program. If the .EOT is followed by a single line feed or form feed, the Assembler will still read to the end of the tape, but will not process anything past the .EOT directive. If .EOT is followed by at least two line feeds or form feeds, the Assembler will stop before the end of the tape. Either case is proper, but it should be understood that even though it appears as if the Assembler has read too far, it actually hasn't.

If a .EOT is embedded in a tape, and more information to be assembled follows it, .EOT must be immediately followed by at least two line feeds or form feeds. Otherwise, the first line following the .EOT will be lost.

Any operands following a .EOT directive will be ignored. The .EOT directive allows several physically separate tapes to be assembled as one program. The last tape is normally terminated by a .END directive (see Section 3.8.3) but may be terminated with .EOT (see .END emulation in Section 3.9.4).

3.8.2 .EVEN

The .EVEN directive ensures that the assembly location counter is even by adding one if it is odd. Any operands following a .EVEN directive will be ignored.

3.8.3 .END

The .END directive indicates the logical and physical end of the source program. The .END directive may be followed by only one operand, an expression indicating the program's entry point.

At load time, the object tape will be loaded and program execution will begin at the entry point indicated by the .END directive. If the entry point is not specified, the Loader will halt after reading in the object tape.

3.8.4 .WORD

The .WORD assembler directive may have one or more operands, separated by commas. Each operand is stored in a word of the object program. If there is more than one operand, they are stored in successive words. The operands may be any legally formed expressions. For example,

```
.=142Ø
SAL=Ø
.WORD 177535,.+4,SAL      ;STORED IN WORDS 142Ø, 1422, AND
                          ;1424 WILL BE 177535, 1426, AND Ø.
```

Values exceeding 16 bits will be truncated from the left, to word length.

A .WORD directive followed by one or more void operands separated by commas will store zeros for the void operands. For example,

```
        .=143Ø                  ;ZERO, FIVE, AND ZERO ARE STORED
        .WORD ,5,               ;IN WORDS 143Ø, 1432, AND 1434.
```

An operator field left blank will be interpreted as the .WORD directive if the operand field contains one or more expressions. The first term of the first expression in the operand field must not be an instruction or assembler directive unless preceded by a +, -, or one of the logical operators ! or &. For example,

```
        .=44Ø                   ;THE OP-CODE FOR MOV, WHICH IS Ø1ØØØØ,
        LABEL:  +MOV,LABEL      ;IS STORED IN LOCATION 44Ø.  44Ø IS
                                ;STORED IN LOCATION 442.
```

Note that the default .WORD will occur whenever there is a leading arithmetic or logical operator, or whenever a leading symbol is encountered which is not recognized as an instruction mnemonic or assembler directive. Therefore, if an instruction mnemonic or assembler directive is misspelled, the .WORD directive is assumed and errors will result. Assume that MOV is spelled incorrectly as MOR:

```
        MOR  A,B
```

Two error codes can result: a Q will occur because an expression operator is missing between MOR and A, and a U will occur if MOR is undefined. Two words will be generated; one for MOR A and one for B.

3.8.5 .BYTE

The .BYTE assembler directive may have one or more operands separated by commas. Each operand is stored in a byte of the object program. If multiple operands are specified, they are stored in successive bytes. The operands may be any legally formed expression with a result of 8 bits or less. For example,

```
        SAM=5                   ;STORED IN LOCATION 41Ø WILL BE
        .=41Ø                   ;Ø6Ø (THE OCTAL EQUIVALENT OF 48).
        .BYTE 48.,SAM           ;IN 411 WILL BE ØØ5.
```

If the expression has a result of more than 8 bits, it will be truncated to its low-order 8 bits and will be flagged as a T error. If an operand after the .BYTE directive is left void, it will be interpreted as zero. For example,

```
        .=42Ø                   ;ZERO WILL BE STORED IN
        .BYTE , ,               ;BYTES 42Ø, 421 AND 422.
```

3.8.6 .ASCII

The .ASCII directive translates strings of ASCII characters into their 7-bit ASCII codes with the exception of null, rubout, carriage return, line feed, and form feed. The text to be translated is delimited by a character at the beginning and the end of the text. The delimiting character may be any printing ASCII character except colon and equal sign and those used in the text string. The 7-bit ASCII code generated for each character will be stored in successive bytes of the object program. For example,

```
        .=5ØØ                   ;THE ASCII CODE FOR "Y" WILL BE
        .ASCII  /YES/           ;STORED IN 5ØØ, THE CODE FOR "E"
                                ;IN 5Ø1, THE CODE FOR "S" IN 5Ø2.

        .ASCII  /5+3/2/         ;THE DELIMITING CHARACTER OCCURS
                                ;AMONG THE OPERANDS.  THE ASCII
                                ;CODES FOR "5", "+", AND "3" ARE
                                ;STORED IN BYTES 5Ø3, 5Ø4, AND
                                ;5Ø5.  2/ IS NOT ASSEMBLED.
```

The .ASCII directive must be terminated by a space or a tab.

3.9 OPERATING PROCEDURES

3.9.1 Introduction

The Assembler enables you to assemble an ASCII tape containing PAL-11A statements into an absolute binary tape. To do this, two or three passes are necessary. On the first pass the Assembler creates a table of user-defined symbols and their associated values, and a list of undefined symbols is printed on the teleprinter. On the second pass the Assembler assembles the program and punches out an absolute binary tape and/or outputs an assembly listing. During the third pass (this pass is optional) the Assembler punches an absolute binary tape or outputs an assembly listing. The symbol table (and/or a list of errors) may be output on any of these passes. The input and output devices as well as various options are specified during the initial dialogue (see Section 3.9.3). The Assembler initiates the dialogue immediately after being loaded and after the last pass of an assembly.

3.9.2 Loading PAL-11A

PAL-11A is loaded by the Absolute Loader (see Chapter 6 for operating procedures). Note that the start address of the Absolute Loader must be in the Switch Register when loading the Assembler. This is because the Assembler tape has an initial portion which clears all of core up to the address specified in the Switch Register, and jumps to that address to start loading the Assembler.

3.9.3 Initial Dialogue

After being loaded, the Assembler initiates dialogue by printing on the teleprinter:

```
*S
```

meaning "What is the Source symbolic input device?" The response may be:

H	meaning High-speed reader
L	meaning Low-speed reader
T	meaning Teletype keyboard

If the response is T, the source program must be typed at the terminal once for each pass of the assembly and it must be identical each time it is typed.

The device specification is terminated, as is all user response, by typing the RETURN key.

If an error is made in typing at any time, typing the RUBOUT key will erase the immediately preceding character if it is on the current line. Typing CTRL/U will erase the whole line on which it occurs.

After the *S question and response, the Assembler prints:

```
*B
```

meaning "What is the Binary output device?" The responses to *B are similar to those for *S:

H	meaning High-speed punch
L	meaning Low-speed punch
↵	meaning do not output binary tape (↵ denotes typing the RETURN key)

In addition to I/O device specification, various options may be chosen. The binary output will occur on the second pass unless /3 (indicating the third pass) is typed following the H or L. Errors will be listed on the same pass if /E is typed. If /E is typed in response to more than one inquiry, only the last occurrence will be honored. It is strongly suggested that the errors be listed on the same pass as the binary output, since errors may vary from pass to pass. If both /3 and /E are typed, /3 must precede /E. The response is terminated by typing the RETURN key. Examples:

*B L/E — Binary output on the low-speed punch and the errors on the teleprinter, both during the second pass.

*B H/3/E — Binary output on the high-speed punch and the errors on the teleprinter, both during the third pass.

*B↵ — Typing just the RETURN key will cause the Assembler to omit binary output.

After the *B question and response, the Assembler prints:

*L

meaning "What is the assembly Listing output device?" The response to *L may be:

L	meaning Low-speed punch (outputs a tab as a tab-rubout)
H	meaning High-speed punch
T	meaning Teleprinter (outputs a tab as multiple spaces)
P	meaning line Printer (8K version only)
↵	meaning do not output listing (↵ denotes typing the RETURN key)

After the I/O device specification, pass and error list options similar to those for *B may be chosen. The assembly listing will be output on the third pass unless /2 (indicating the second pass) is typed following H, L, T, or P. Errors will be listed on the teleprinter during the same pass if /E is typed. If both /2 and /E are typed, /2 must precede /E. The response is terminated by typing the RETURN key. Examples:

*L L/2/E — Listing on low-speed punch and errors on teleprinter during second pass.

*L H — Listing on high-speed punch during third pass.

*L — The RETURN key alone will cause the Assembler to omit listing output.

After the *L question and response, the final question is printed on the teleprinter:

*T

meaning "What is the symbol Table output device?" The device specification is the same as for the *L question. The symbol table will be output at the end of the first pass unless /2 or /3 is typed in response to *T. The first tape to be assembled should be placed in the reader before typing the RETURN key because assembly will begin upon typing the RETURN key in response to the *T question. The /E option is not a meaningful response to *T. Example:

*T T/3 — Symbol table output on teleprinter at end of third pass.

*T ↵ — Typing just the RETURN key will cause the Assembler to omit symbol table output.

The symbol table is printed alphabetically, four symbols per line. Each symbol printed is followed by its identifying characters and by its value. If the symbol is undefined, six asterisks replace its value. The identifying characters indicate the class of the symbol; that is, whether it is a label, direct-assignment, register symbol, etc. The following examples show the various forms:

```
ABCDEF        001244          (Defined label)
R3       =   %000003          (Register symbol)
DIRASM   =    177777          (Direct assignment)
XYZ      =    ******          (Undefined direct assignment)
R6       =   %******          (Undefined register symbol)
LABEL    =    ******          (Undefined label)
```

Generally, undefined symbols (including labels) will be listed as undefined direct assignments.

Multiply-defined symbols are not flagged in the symbol table printout but they are flagged wherever they are used in the program.

It is possible to output both the binary tape and the assembly listing on the same pass, thereby reducing the assembly process to two passes (see Example 1 below). This will happen automatically unless the binary device and the listing device are conflicting devices or the same device (see Example 2 below). The only conflicting devices are the teleprinter and the low-speed punch. Even though the Assembler deduces that three passes are necessary, the binary and listing can be forced on pass 2 by including /2 in the responses to *B and *L (see Example 3 below).

Example 1. Runs 2 passes:

```
*S  H         High-speed reader
*B  H         High-speed punch
*L  P         Line Printer
*T  T         Teleprinter
```

Example 2. Runs 3 passes:

```
*S  H         High-speed reader
*B  H         High-speed punch
*L  H         High-speed punch
*T  T         Teleprinter
```

Example 3. Runs 2 passes:

*S	H	High-speed reader
*B	H/2	High-speed punch on pass 2
*L	H/2	High-speed punch on pass 2
*T	T	Teleprinter

Note that there are several cases where the binary output can be intermixed with ASCII output:

a.	*B	H/2	Binary and
	*L	H/2	listing to punch on pass 2
b.	*B	L/E	Binary to low-speed punch and error listing to teleprinter (and low-speed punch)
c.	*B	L/2/E	Binary, error listing, and
	*L	T/2	listing to low-speed punch.

The binary so generated is loadable by the Absolute Loader as long as there are no CTRL/A characters in the source program. The start of every block on the binary tape is indicated by a 001 and the Absolute Loader ignores all information until a 001 is detected. Thus, all source and/or error messages will be ignored if they do not contain any CTRL/A characters (octal 001).

If a character other than those mentioned is typed in response to a question, the Assembler will ignore it and print the question again. Example:

*S	H	High-speed reader
*B	Q	Q is not a valid response
*B		The question is repeated

If at any time you wish to restart the Assembler, type CTRL/P.

When no passes are omitted or error options specified, the Assembler performs as follows:

PASS 1: Assembler creates a table of user-defined symbols and their associated values to be used in assembling the source to object program. Undefined symbols are listed on the teleprinter at the end of the pass. The symbol table is also listed at this time. If an illegal location statement of the form .=expression is encountered, the line and error code will be printed out on the teleprinter before the assembly proceeds. An error in a location statement is usually a fatal error in the program and should be corrected.

PASS 2: Assembler punches the object tape, and prints the pass error count and undefined location statements on the teleprinter.

PASS 3: Assembler prints or punches the assembly program listing, undefined location statements, and the pass error count on the teleprinter.

The functions of passes 2 and 3 will occur simultaneously on pass 2 if the binary and listing devices are different, and do not conflict with each other (low-speed punch and Teletype printer conflict).

The following table summarizes the initial dialogue questions:

Printout	Inquiry
*S	What is the input device of the Source symbolic tape?
*B	What is the output device of the Binary object tape?
*L	What is the output device of the assembly Listing?
*T	What is the output device of the symbol Table?

The following table summarizes the legal responses:

Character	Response Indicated
T	Teletype keyboard or printer
L	Low-speed reader or punch
H	High-speed reader or punch
P	Line Printer (8K version only)
/1	Pass 1
/2	Pass 2
/3	Pass 3
/E	Errors listed on same pass (not meaningful in response to *S or *T)
↵	Omit function

Typical examples of complete initial dialogues:

For minimal PDP-11 configuration:

*S	L	Source input on low-speed reader
*B	L/E	Binary output on low-speed punch Errors during same (second) pass
*L	T	Listing on teleprinter during pass 3
*T	T	Symbol table on teleprinter at end of pass 1

For a PDP-11 with high-speed I/O devices:

*S	H	Source input on high-speed reader
*B	H/E	Binary output on high-speed punch, Errors during same (second) pass.
*L		No listing
*T	T/2	Symbol table on teleprinter at end of pass 2

3.9.4 Assembly Dialogue

During assembly, the Assembler will pause to print on the teleprinter various messages to indicate that you must respond in some way before the assembly process can continue. You may also type CTRL/P, at any time, if you wish to stop the assembly process and restart the initial dialogue, as mentioned in the previous section.

When a .EOT assembler directive is read on the tape, the assembler prints:

```
EOF ?
```

and pauses. During this pause, the next tape is placed in the reader, and RETURN is typed to continue the assembly.

If the specified assembly listing output device is the high-speed punch and if it is out of tape, or if the device is the Line Printer and is out of paper, the Assembler prints on the teleprinter:

```
EOM ?
```

and waits for tape or paper to be placed in the device. Type the RETURN key when the tape or paper has been replenished; assembly will continue.

Conditions causing the EOM ? message for an assembly listing device are:

HSP	LPT
No power	No power
No tape	Printer drum gate open
	Too hot
	No paper

There is no EOM if the line printer is switched off-line, although characters may be lost for this condition as well as for an EOM. If the binary output device is the high-speed punch and if it is out of tape, the Assembler prints:

```
EOM ?
*S
```

The assembly process is aborted and the initial dialogue is begun again.

When a .END assembler directive is read on the tape, the Assembler prints:

```
END ?
```

and pauses. During the pause the first tape is placed in the reader, and the RETURN key is typed to begin the next pass. On the last pass, the .END directive causes the Assembler to begin the initial dialogue for the next assembly.

If you are starting the binary pass and the binary is to be punched on the low-speed punch, turn the punch on before typing the RETURN key for starting the pass. The carriage return and line feed characters will be punched onto the binary tape, but the Absolute Loader will ignore them.

If the last tape ends with a .EOT, the Assembler may be told to emulate a .END assembler directive by responding with E followed by the

RETURN key. The Assembler will then print:

```
        END ?
```

and wait for another RETURN before starting the next pass. Example:

```
        EOF ?    E
        END ?
```

NOTE

> When a .END directive is emulated with an E response to the EOF? message, the error counter is incremented.
>
> To avoid incrementing the error counter, place a paper tape containing only the line .END in the reader and press the RETURN key instead of using the E response.

3.9.5 Assembly Listing

PAL-11A produces a side-by-side assembly listing of symbolic source statements, their octal equivalents, assigned absolute addresses, and error codes, as follows:

```
        EELLLLLL OOOOOO SSS......S
                 OOOOOO
                 OOOOOO
```

The E's represent the error field. The L's represent the absolute address. The O's represent the object data in octal. The S's represent the source statement. While the Assembler accepts 72_{10} characters per line on input, the listing is reduced by the 16 characters to the left of the source statement.

The above represents a three-word statement. The second and third words of the statement are listed under the command word. No addresses precede the second and third words since the address order is sequential.

The third line is omitted for a two-word statement; both second and third lines are omitted for a one-word statement.

For a .BYTE directive, the object data field is three octal digits.

For a direct assignment statement, the value of the defining expression is given in the object code field although it is not actually part of the code of the object program.

Each page of the listing is headed by a page number.

3.10 ERROR CODES

The error codes printed beside the octal and symbolic code in the assembly listing have the following meanings:

Error Code	Meaning
A	Addressing error. An address within the instruction is incorrect.
B	Bounding error. Instructions or word data are being assembled at an odd address in memory. The location counter is updated by +1.
D	Doubly-defined symbol referenced. Reference was made to a symbol which is defined more than once.
I	Illegal character detected. Illegal characters which are also non-printing are replaced by a ? on the listing.
L	Line buffer overflow. Extra characters on a line (more than 72_{10}) are ignored.
M	Multiple definition of a label. A label was encountered which was equivalent (in the first six characters) to a previously encountered label.
N	Number containing 8 or 9 has no decimal point.
P	Phase error. A label's definition or value varies from one pass to another.
Q	Questionable syntax. There are missing arguments or the instruction scan was not completed or a carriage return was not immediately followed by a line feed or form feed.
R	Register-type error. An invalid use of or reference to a register has been made.
S	Symbol table overflow. When the quantity of user-defined symbols exceeds the allocated space available in the user's symbol table, the assembler outputs the current source line with the S error code, then returns to the initial dialogue.

T Truncation error. A number generated more than 16 bits of significance or an expression generated more than 8 bits of significance during the use of the .BYTE directive.

U Undefined symbol. An undefined symbol was encountered during the evaluation of an expression. Relative to the expression, the undefined symbol is assigned a value of zero.

3.11 SOFTWARE ERROR HALTS

PAL-11A loads all unused trap vectors with the code

```
        .WORD  .+2,HALT
```

so that if the trap does occur, the processor will halt in the second word of the vector. The address of the halt, displayed in the console address register, therefore indicates the cause of the halt. In addition to the halts which may occur in the vectors, the standard IOX error halt at location 40 may occur (see Chapter 7).

Address of Halt	Meaning
12	Reserved instruction executed
16	Trace trap occurred
26	Power fail trap
32	EMT executed
40	IOX detected error

See Appendix B for summaries of PAL-11A features.

CHAPTER 4

EDITING THE SOURCE PROGRAM

CHAPTER 4

Editing the Source Program, ED-11

The PDP-11 Text Editor program (ED-11) enables you to display your source program (or any text) on the teleprinter, make corrections or additions to it, and punch all or any portion of the program on paper tape. This is accomplished by typing simple one-character commands on the keyboard.

The Editor commands can be grouped according to function:

1. input/output;
2. searching for strings of characters;
3. positioning the current character location pointer;
4. inserting, deleting, and exchanging text portions.

All input/output functions are handled by IOX, the PDP-11 Input/Output Executive (see Chapter 7).

4.1 COMMAND MODE AND TEXT MODE

Whenever ED-11 prints an * on the teleprinter, you may type a command to it. (Only one command per line is acceptable.) The Editor is then said to be in Command Mode. While most commands operate exclusively in this mode, there are five ED-11 commands that require additional information in order for the commands to be carried out. The Editor goes into Text Mode to receive this test.

Should a nonexistent command be typed or a command appear in incorrect format, ED-11 will print a ?. This will be followed by an * at the beginning of a new line indicating that the Editor is in Command Mode.

Editor processing begins in Command Mode. When you type a command, no action occurs until you follow it by typing the RETURN key (sometimes symbolized as ↵). If the command is not a text-type command, typing the RETURN key will initiate the execution of the command and ED-11 will remain in Command Mode. However, if the command is a text-type command (Insert, eXchange, Change, Get, or wHole), typing the RETURN key will cause the Editor to go into Text Mode. At this time you should type the text to be operated on by the command. This can include the non-printing characters discussed below, as well as spaces and tabs (up to eight spaces generated by the CTRL/TAB keys).

Note that typing the RETURN key always causes the physical return of the Teletype ball to the beginning of the line, and automatically generates a line feed thereby advancing the carriage to a new line. In Text Mode, the RETURN key not only serves these mechanical functions, allowing you to continue typing at the beginning of a new line, but at the same time it enters a carriage return and line feed character into the text. (A carriage return not followed by a line feed cannot, therefore, be entered from the keyboard.)

These are both counted as characters and can be edited along with the printing characters (as can the form feed, discussed in Section 4.2.5). When you wish to terminate Text Mode and reenter Command Mode, you must type the LINE FEED key (sometimes symbolized as ↓). A typed LINE FEED is not considered to be part of the text unless it is the first character entered in Text Mode.

4.2 COMMAND DELIMITERS

4.2.1 Arguments

Some ED-11 commands require an argument to specify the particular portion of text to be affected by the command or how many times to perform the command. In other commands this specification is implicit and arguments are not allowed.

The ED-11 command arguments are described as follows:

1. n stands for any number from 1 to 32767_{10} (2^{15}-1) and may, except where noted, be preceded by a + or -.

   If no sign precedes n, it is assumed to be a positive number.

Where an argument is acceptable, its absence implies an argument of 1 (or -1 if a - is present).

The role of n varies according to the command it is associated with.

2. 0 refers to the beginning of the current line.
3. @ refers to a marked (designated) character location (see Section 4.2.3).
4. / refers to the end of text in the Page Buffer.

The roles of all arguments will be explained further with the corresponding commands which qualify them.

4.2.2 The Character Location Pointer (Dot)

Almost all ED-11 commands function with respect to a movable reference point, Dot. This character pointer is normally located between the most recent character operated upon and the next character; and, at any given time, can be thought of as "where the Editor is" in your text. As will be seen shortly, there are commands which move Dot anywhere in the text, thereby redefining the "current location" and allowing greater facility in the use of the other commands.

4.2.3 Mark

In addition to Dot, a secondary character pointer known as Mark also exists in ED-11. This less agile pointer is used with great effect to mark or "remember" a location by moving to Dot and conditionally remaining there while Dot moves on to some other place in the text. Thus, it is possible to think of Dot as "here" and Mark as "there". Positioning of Mark, which is referenced by means of the argument @, is discussed below in several commands.

4.2.4 Line-Oriented Command Properties

ED-11 recognizes a line as a unit by detecting a line-terminator in the text. This means that ends of lines (line feed or form feed characters) are counted in line-oriented commands. This is important to know, particularly if Dot, which is a character location pointer, is not pointing at the first character of a line.

In such a case, an argument n will not affect the same number of lines (forward) as its negative (backward). For example, the argument -1 applies to the character string beginning with the first character following the second previous end-of-line character and ending at Dot; argument +1 applies to the character string beginning at Dot and ending at the first end-of-line character. If Dot is located, say, in the center of a line, notice that this would affect 1-1/2 lines back or 1/2 line forward, respectively:

Example of List Commands -1L and +1L:

```
     Text               Command             Printout

CMPB  ICHAR,#Ø33        *-1L            BEQ $ALT
BEQ   $ALT                              CMPB I
CMPB  ICHAR,#175        *+1L                              Dot remains
BNE   PLACE                             CHAR,#175             here
          Dot is here
```

4.2.5 The Page Buffer

The Page Buffer holds the text being edited. The unit of source data that is read into the Page Buffer from a paper tape, is the page. Normally, a page is terminated, and therefore defined by a form feed (CTRL/FORM) in the source text wherever a page is desired. (A form feed is an acceptable Text Mode character.) Overflow, no-tape, or reader-off conditions can also end a page of input (as described in Section 4.3.1.2). Since more than one page of text can be in the buffer at the same time, it should be noted that the entire contents of the Page Buffer are available for editing.

4.3 COMMANDS

4.3.1 Input and Output Commands

Three commands are available for reading in a page of text. The Read command (Section 4.3.1.2) is a specialized input command; the Next command (Section 4.3.1.4) reads in a page after punching out the previous page; and the wHole command (Section 4.3.3.2) reads in and punches out pages of text as part of a search for a specified character string.

Output commands either list text or punch it on paper tape. The List command causes specified lines of text to be output on the teleprinter so that they may be examined. Paper tape commands (Next and wHole also perform input) provide for the output of specified pages, lines, form feeds (for changing the amount of data that constitutes a given page), and blank tape. Note that the process of outputting text does not cause Dot to move.

4.3.1.1 Open

The Open command (O) should be typed whenever a new tape is put in the reader. This is used when the text file being edited is on more than one paper tape.

Note also, that if the reader is off at the time an input command is given, turning the reader on must be followed by the Open command.

4.3.1.2 Read

One way of getting a page of text into the Page Buffer so that it can be edited is by means of the Read (R) command. The command R causes a page of text to be read from either the low-speed reader or high-speed reader (as specified in the starting dialogue, Section 4.4.2), and appended to the contents (if any) of the Page Buffer.

Text will be read in until either:

1. A form feed character is encountered;
2. The page buffer is 128 characters from being filled, or a line feed is encountered after the buffer has become 500 characters from being filled;
3. The reader is turned off, or runs out of paper tape (see Open command, Section 4.3.1.1).

Following execution of an R command, Dot and Mark will be located at the beginning of the Page Buffer.

A 4K system can accommodate about 4000 characters of text. Each additional 4K of memory will provide space for about 8000 characters.

NOTE

An attempt to overflow the storage area will cause the command (in this case, R) to stop executing. A ? will then be printed, followed by an * on the next line indicating that a command may be typed. No data will be lost.

4.3.1.3 List and Punch

Output commands List (L) and Punch (P) can be described together, as they differ only in that the device addressed by the former is the teleprinter, and the device addressed by the latter is the paper tape punch. Dot is not moved by these commands.

nL nP	Lists Punches	the character string beginning at Dot and ending with the nth end-of-line
-nL -nP	Lists Punches	the character string beginning with the first character following the (n+1)th previous end-of-line and terminating at Dot
0L 0P	Lists Punches	the character string beginning with the first character of the current line and ending at Dot
@L @P	Lists Punches	the character string between Dot and the Marked location
/L /P	Lists Punches	the character string beginning at Dot and ending with the last character in the Page Buffer

In addition to the above List commands, there are three special List commands that accept no arguments. The current line is defined as the line containing Dot, i.e., from the line feed (or form feed) preceding Dot to the line feed (or form feed) following Dot.

V	Lists the entire line containing Dot
<	Same as -1L. If Dot is located at the beginning of a line, this simply lists the line preceding the current line
>	Lists the line following the current line

Examples:

```
          TEXT                   COMMANDS              PRINTOUT

   CMPB ICHAR,#Ø33                  V              CMPB   ICHAR,#175
   BEQ  $ALT                        <              BEQ    $ALT
   CMPB ICHAR,#175                                 CMPB   I
   BNE  PLACE                       >              BNE    PLACE

   Dot is here.                             Dot remains here.
```

4.3.1.4 Next

Typing nN punches out the entire contents of the Page Buffer (followed by a trailer of blank tape if a form feed is the last character in the buffer), deletes the contents of the buffer, and reads the Next page into the buffer. It performs this sequence n times. If there are fewer than the n pages specified, the command will be executed for the number of pages actually available, and a ? will be printed out. Following execution of a Next, Dot and Mark will be located at the beginning of the Page Buffer.

4.3.1.5 Form Feed and Trailer

F Punches out a Form feed character and four inches of blank tape

nT Punches out four inches of Trailer (blank) tape n times

4.3.1.6 Procedure with Low-Speed Punch

If the low speed punch is the specified output device (see Section 4.4.2), the Editor pauses before executing any tape command just typed (Punch, Form feed, Trailer, Next, wHole). The punch must be turned on at this time, after which, typing the SPACE bar initiates the execution of the command. Following completion of the operation, the Editor pauses again to let you turn the punch off. When the punch has been turned off, typing the SPACE bar returns ED-11 to Command Mode.

4.3.2 Commands to Move Dot and Mark

4.3.2.1 Beginning and End

B Moves Dot to the Beginning of the Page Buffer

E Moves Dot to the End of the Page Buffer (see also /J and /A below)

4.3.2.2 Jump and Advance

nJ Jumps Dot forward past n characters

-nJ Moves Dot backward past n characters

nA Advances Dot forward past n ends-of-lines to the beginning of the succeeding line

-nA Moves Dot backwards across n ends-of-lines and positions Dot immediately after n+1 ends of lines, i.e., at the beginning of the -n line.

0J or 0A Moves Dot to the beginning of the current line

@J or @A Moves Dot to the Marked location

/J or /A Moves Dot to the end of the Page Buffer (see also E above)

Notice that while n moves Dot n characters in the Jump command, its role becomes that of a line counter in the Advance command. However, because 0, @, and / are absolute, their use with these commands overrides line/ character distinctions. That is, Jump and Advance perform identical functions if both have either 0, @ or / for an argument.

4.3.2.3 Mark

The M command marks ("remembers") the current position of Dot for later reference in a command using the argument @. Note that only one position at a time can be in a marked state. Mark is also affected by the execution of those commands which alter the contents of the Page Buffer:

C D H I K N R X

4.3.3 Search Commands

4.3.3.1 Get

The basic search command nG starts at Dot and Gets the nth occurrence of the specified text in the Page Buffer. If no argument is present, it is assumed to be 1. When you type the command, followed by the RETURN key, ED-11 will go into Text Mode. The character string to be searched for must now be typed. (ED-11 will accept a search object of up to 42 characters in length.) Typing the LINE FEED key terminates Text Mode and initiates the search.

This command sets Dot to the position immediately following the found character string, and a 0L listing is performed by ED-11. If a carriage return, line feed, or form feed is specified as part of the search object, the automatic 0L will only display a portion of text -- the part defined as the last line. Where any of these characters is the last character of the search object, the 0L will of course yield no printout at all.

If the search is unsuccessful, Dot will be at the end of the Page Buffer and a ? will be printed out. The Editor then returns to Command Mode.

Examples:

```
1.      Text                            Command               Printout

     MOV @RMAX,@R5                       2G↵                   BEQ CK
    ↑ADD #6,(R5)+                        CK↓                         ↑
     CLR $CK3
     TST R2
     BEQ CKCR

    Dot was here.                                           Dot is now here.

2.   CMPB   ICHAR,#RUBOUT                G↵                    BR
     BEQ    SITE                         TE↵                    ↑
    ↑BR     PUT                          BR↓
    Dot                                                        Dot
```

4.3.3.2 wHole

A second search command, H, starts at Dot and looks through the wHole text file for the next occurrence of the character string you have specified in Text Mode. It combines a Get and a Next such that if the search is not successful in the Page Buffer, the contents of the buffer are punched on tape, the buffer contents are deleted, and a new page is read in, where the search is continued. This will proceed until the search object is found or until the complete source text has been searched. In either case, Mark will be at the beginning of the Page Buffer.

If the search object is found, Dot will be located immediately following it, and a 0L will be performed by ED-11. As in the Get command, if the search is not successful Dot will be at the end of the buffer and a ? will appear on the teleprinter. Upon completion of the command, the Editor will be in Command Mode. No argument is allowed. Note that an H command specifying a nonexistent search object can be used to close out an edit, i.e., copy all remaining text from the input tape to the output tape.

4.3.4 Commands to Modify the Text

4.3.4.1 Insert

The Insert command (I) allows text to be inserted at Dot. After I is typed (followed by the typing of the RETURN key), the Editor goes into Text Mode to receive text to be inserted. Up to 80 characters per line are acceptable. Execution of the command occurs when the LINE FEED key (which does not Insert a line feed character unless it is the <u>first</u> key typed in Text Mode) is typed terminating Text Mode. At this point, Dot is located in the position immediately following the last inserted text character. If the Marked location was anywhere <u>after</u> the text to be Inserted, Dot becomes the new Marked location.

During an insert, it sometimes happens that the user accidentally types CTRL/P rather than SHIFT/P (for @), thus deleting the entire insert (see Section 4.4.1). To minimize the effect of such a mistake, the insert may be terminated every few lines and then continued with a new Insert command.

As with the Read command, an attempt to overflow the Page Buffer will cause a ? to be printed out followed by an * on the next line indicating that a command may be typed. All or part of the last line typed may be lost. All previously typed lines will be inserted. Examples:

```
        Text                     Command              Effect

1.  MOV #8.,EKOT                   I↵            MOV #8.,EKOCNT
              ↑                    CN↓                       ↑
             Dot                                            Dot

2.  Inserting a carriage return (and automatic line feed):

    CLR R1CLR R2                   I↵                CLR R1
          ↑                        ↵                 CLR R2
        Dot                        ↓

3.  Inserting a single line feed:
                                   I↵
    LOOK WHAT HAPPENS HERE         ↓                 LOOK WHAT
             ↗                     ↓                          HAPPENS HERE
        Dot                                                   ↑
                                                              Dot
```

4.3.4.2 Delete and Kill

These commands are closely related to each other; they both erase specified text from the Page Buffer. The Delete command (D) differs from the Kill command (K) only in that the former accepts an argument, n, that counts <u>characters</u> to be removed, while the latter accepts an argument, n, that counts <u>lines</u> to be removed. 0, @, and / are also allowed as arguments. After execution of these commands, Dot becomes the Marked location.

nD	Deletes the following n characters	nK	Kills the character string beginning at Dot and ending at the nth end-of-line
-nD	Deletes the previous n characters	-nK	Kills the character string beginning with the first character following the (n+1)th previous end-of-line and ending at Dot

0D or 0K	Removes the current line up to Dot
@D or @K	Removes the character string bounded by Dot and Mark
/D or /K	Removes the character string beginning at Dot and ending with the last character in the Page Buffer

	Text	Command	Effect
1.	;CHECK THE MOZXDE Dot	-2D	;CHECK THE MODE Dot
2.	;IS IT A TAB OR ;IS IT A CR Dot	2K	;IS IT A TAB Dot

4.3.4.3 Change and eXchange

The Change (C) and eXchange (X) commands can be thought of as two-phase commands combining, respectively, an Insert followed by a Delete, and an Insert followed by a Kill. After the Change or eXchange command is typed, ED-11 goes into Text Mode to receive the text to be inserted. If ±n is used as the argument, it is then interpreted as in the Delete (character-oriented) or Kill (line-oriented), and accordingly removes the indicated text. 0, @, and / are also allowed as arguments.

nC xxxx xxxx	Changes the following n characters	nX xxxx xxxx	eXchanges the character string beginning at Dot and ending at the nth end-of-line
-nC xxx	Changes the previous n characters	-nX xxx	eXchanges the character string beginning with the first character following the (n+1)th previous end-of-line and ending at Dot

0C or xxxx xxxx	0X xxxx xxxx	Replaces the current line up to Dot

```
@C    or   @X      Replaces the character string bounded by Dot
xxx        xxx     and the Marked location
xxx        xxx

/C    or   /X      Replaces the character string beginning at Dot
xxx        xxx     and ending with the last character in the Page
                   Buffer.
```

Again, the use of absolute arguments 0, @, and / overrides the line/character distinctions that n and -n produce in these commands.

If the Insert portion of a Change or eXchange is terminated because of attempting to overflow the Page Buffer, data from the latest line may have been lost, and text removal will not occur. Such buffer overflow might be avoided by separately executing a Delete or Kill followed by an Insert, rather than a Change or eXchange, which does an Insert followed by a Delete or Kill. Examples:

```
Text                        Command          Effect

;A LINE FEED IS HERE        -9C↲             ;A TAB IS HERE
                            TAB↓
;THIS                       2X↲              ;THIS
;IS ON     Dot              PAPER↓           ;IS ON
;FOUR                                        ;PAPER
;LINES

Dot                                                 Dot
```

4.4 OPERATING PROCEDURES

4.4.1 Error Corrections

During the course of editing a page of the program, it may become necessary to correct mistakes in the commands themselves. There are four special commands which do this:

a. Typing the RUBOUT key removes the preceding typed character, if it is on the current line. Successive RUBOUTs remove preceding characters on the line (including the SPACE), one character for each RUBOUT typed.

b. The CTRL/U combination (holding down the CTRL key and typing U) removes all the characters in the current line.

c. CTRL/P cancels the current command in its entirety. This includes all the current command text just typed, if ED-11 was in Text Mode. Care should be taken in not using another CTRL/P before typing a line terminator as this will cause an ED-11 restart (see d. below). If CTRL/P is typed while a found search object of a Get or wHole is being printed out, the normal position of Dot (just after the specified search object) is not affected.

CTRL/P should not be used while a punch operation is in progress as it is not possible to know exactly how much data will be output.

d. Two CTRL/P's not interrupted by a typed line terminator will restart ED-11, initiating the dialogue described in Section 4.4.2.

After removing the incorrect command data, the user can, of course, directly type in the desired input.

4.4.2 Starting

The Editor is loaded by the Absolute Loader (see Chapter 6, Section 6.2.2) and starts automatically. Once the Editor has been loaded, the following sequence occurs:

ED-11 Prints	User Types	
*I	L↵	(if the Low-speed Reader is to be used for source input)
	H↵	(if the High-speed Reader is to be used for source input)
*O	L↵	(if the Low-speed Punch is to be used for edited output)
	H↵	(if the High-speed Punch is to be used for edited output)

If all text is to be entered from the keyboard (i.e., via the Insert command), either L or H may be specified for Input.

If the output device is the high-speed punch (HSP), the Editor enters Command Mode to accept input. Otherwise, the sequence continues with:

LSP OFF? ↵ (when Low-speed Punch (LSP) is off)

Upon input of ↵ from the keyboard, the Editor enters Command Mode and is ready to accept input.

4.4.3 Restarting

To restart ED-11, type CTRL/P twice. This will initiate the normal starting dialogue described in Section 4.4.2. If the Low-speed Reader (LSR) is in operation it must first be turned off. The text to be edited should be loaded (or reloaded) at this time.

4.4.4 Creating a Paper Tape

Input commands assume that text will be read in from a paper tape by means of the low-speed reader or high-speed reader. However, the five commands that go into Text Mode enable the user to input from the keyboard. The Insert command, in particular (Section 4.3.4.1) can be useful for entering large quantities of text not on paper tape. The Page Buffer can thus be filled from the keyboard, and a paper tape actually created by then using a command to punch out the buffer contents.

4.4.5 Editing Example

The following example consists of three parts:

a. The marked up source program listing indicating the desired changes.

b. The ED-11 commands to implement those changes (with comments on the editing procedure).

REMINDER

> Typing the RETURN key terminates Command Mode in all cases. In commands which then go into Text Mode, typing the LINE FEED key (symbolized as ↓) produces the terminator.

c. The edited text.

PART I   Original Source for Edit

```
         ;COMMON INPUT ROUTINE FOR USE BY NON FILE DEVICES

$INPUT:  ADD     ICHAR,(R5)+        ;UPDATE CKSUM
         CLR     -(LS)              ;CLEAR DONE
         MOV     (R5)+,RMAX         ;GET ADR MAX
         MOV     (R5)+,MODADR       ;GET ADR MODE
                                    ;R5 NOW POINTS TO POINTER

$CKMODE: BITB    @MODADR,#ASCII     ;IS THIS ASCII
         BNE     CKBIN              ;NO---TRY BINARY

$CKNUL:  TSTB    ICHAR              ;ASCII---IS CHAR A NULL
         BEQ     CK                 ;YES--NO GO

                                    ;LOOK AT MODE TO SEE IF
$CKPAR:  BITB    @MODADR,#PARBIT    ;SUPPOSED TO CHECK PARITY?
         BNE     PAROK              ;NO
         MOVB    ICHAR,OCHAR        ;YES---CK IT
         JSR     R7,PARGEN
         SUB     ICHAR,OCHAR        ;
         BEQ     PAROK              ;OK?
         BIS     #PARERR,@MODADR    ;NO---SET ERR BIT
PAROK:   CLR     OCHAR
         BIC     #177200,ICHAR      ;STRIP PARITY
         CMPB    @10(RADD),#KBD     ;IS THIS KBD INPUT
         BNE     OK0                ;NO
         TSTB    EKOCNT             ;YES---DONE EKO OF LAST?
         BEQ     $OK                ;YES
         CLR     ICHAR              ;NO---DROP NEW CHAR
$JP2CK:  JMP     CK DUN

         ;WHAT IS THE CHAR
$OK:     CMPB    ICHAR,#CTRLC       ;IS IT A ↑C
         BNE     ~~CKUPP~~ OKØ      ;NO
         MOV     #UPC,OCHAR         ;YES--ECHO ↑C
         INC     RDUN
         MOV     #ABRTAD,20(R6)     ;DIDDLE RETURN ADR
         BR      PLUS1

~~CKUPP:  CMPB    ICHAR,#CTRLP       ;IS IT A ↑P~~
~~         BNE     CK1                ;NO~~
~~         TST     RESTAD             ;YES--DID HE SET UP~~
~~         BEQ     OK0                ;A RESTART ADR?~~
~~         MOV     RESTAD,22(R6)      ;YES---XFR THERE~~
~~         CLR     ICHAR~~
~~         INC     RDUN~~
~~         MOV     #UPP,OCHAR~~
~~         BR      PLUS1~~

                                    ;THIS IS NOT KBD INPUT
~~OK0:     BITB    @MODADR,#FORMAT    ;IS THIS ASCII FORMATTED?~~ ;FORMATTED AND
~~         BEQ     CKINP              ;YES...DO CHAR CONV~~     ;ASCII, UNFORMATTED
~~                                    ;NO---IT IS UNFORMATTED~~ ARE HANDLED THE SAME

         CMPB    ICHAR,#RUBOUT      ;IS THIS A RUBOUT
         BEQ     CK                 ;YES---IGNORE IT
         BR      PUT                ;NO---

~~CKINP:  CMPB    ICHAR,#RUBOUT      ;YES---IS CHAR A RUBOUT?~~
~~         BNE     CKUPU              ;NO~~
~~         CLR     ICHAR              ;YES~~
```

```
        TST     2(R5)                   ;BC=Ø?
        BEQ     CK                      ;YES---FORGET IT
        MOVB    #BSLASH,OCHAR           ;ECHO A \
        DEC     (R5)+                   ;POINTER=POINTER-1
        DEC     @R5                     ;BC=BC-1
        BR      EKO                     ;EKO

CKUPU:  CMPB    ICHAR,#CTRLU            ;IS IT A ↑U?
        BNE     CKTAB                   ;NO
        MOV     #UPU,OCHAR              ;YES---ECHO ↑U
        CLR     ICHAR
        MOV     @RMAX,@R5               ;POINTER=BUFADR+6
        ADD     #6,(R5)+
        CLR     @R5                     ;BC=Ø
        BR      EKO                     ;ECHO

CKTAB:  CMPB    ICHAR,#HTAB             ;IS IT A TAB
        BNE     CKCR                    ;NO
        MOV     #BLNKS,OCHAR            ;YES---ECHO BLANKS
        MOV     TABCNT,EKOCNT           ;SET UP COUNTER
        BR      PUT                     ;

CKCR:   CMPB    ICHAR,#CR               ;IS IT A CR?
        BNE     $CK3                    ;NO
        MOV     #CRLF,OCHAR             ;YES---ECHO CRLF
        INC     RDUN
        BR      PLUS1                   ;
                                                ALT
$CK3:   CMPB    ICHAR,#Ø33              ∧————;IS CHAR AN ALTMODE?
        BEQ     $ALT
        CMPB    ICHAR,#175
        BEQ     $ALT
        CMPB    ICHAR,#176
        BNE     CK~~LF~~ ←——— EX
~~$ALT:  MOV     #DOL,OCHAR~~
∧       MOV     #175,ICHAR  ———— $ALT:
~~        INC     RDUN~~
~~        BR      PUT~~
CKLF:   CMPB    ICHAR,#LF
        BNE     CKFF
        INC     RDUN
        BR      PUT

CKFF:   MOV     ICHAR,OCHAR
        CMPB    ICHAR,#FF
        BNE     PUT
        MOV     #8.,EKOCNT
        MOV     #LFLF,OCHAR
        BR      PUT
```

Part II: Editing Session

Assume that ED-11 has been started, is in Command Mode, and the tape is in the reader. Underlined matter indicates ED-11 output.

```
*R                          ;Reads in a page of text

*H                          ;Searches entire program for 2CK: —
2CK:↓                       ;when found ED-11 performs a 0L
$JP2CK:

*G                          ;Searches current page for next CK —
CK↓                         ;when found ED-11 performs a 0L
$JP2CK  JMP    CK

*I                          ;Inserts DUN following CK
DUN↓

*G                          ;Searches for next CKUPP -
CKUPP↓                      ;when found ED-11 performs a 0L
        BNE    CKUPP

*-5C                        ;OK0 replaces last 5 characters (CKUPP)
OKØ↓

*6A                         ;Dot is moved 6 lines ahead (including
                            ;a blank line)

*9K                         ;9 lines are killed starting with CKUPP:

*L                          ;Next line is listed - Dot is not moved
                            ;THIS IS NOT KBD INPUT

*I                          ;Blank line is inserted
↵
↓

*A                          ;Dot is moved 1 line ahead to point to
                            ;character 0 of OK0:

*4X                         ;Following comments replace the next 4
                            ;lines
                            ;FORMATTED AND UNFORMATTED
                            ;ASCII ARE HANDLED THE SAME↓

*G                          ;Searches for next CKINP: —
CKINP:↓                     ;0L printout occurs when found
CKINP:

*ØJ                         ;Dot is moved to the beginning of the
                            ;current line.

*/K                         ;The rest of the page is killed (3 lines)
```

```
*N                              ;Current page is punched out on paper tape -
                                ;a new page is read in

*L                              ;The next line is listed - Dot is not moved
   TST   2(R5)    ;BC=Ø?

*15K                            ;15 lines are killed starting with TST

*2L                             ;1 blank line and 1 line of text
                                ;are listed - Dot is not moved
```

```
CKTAB: CMPB ICHAR,#HTAB ;IS IT A TAB

*2G                             ;Searches for 2nd occurrence of $CK3 -
$CK3↓                           ;0L printout verifies it is found
$CK3

*-C                             ;ALT replaces preceding character
ALT↓

*V                              ;Lists entire current line to verify
$CKALT: CMPB ICHAR,#Ø33 ;the above -C result

*G                              ;Searches for the 033 to position Dot
Ø33↓                            ;for next command -- 0L occurs
$CKALT: CMPB ICHAR,#Ø33

*I                              ;The following text is inserted in the
                                ;comment field
                                     ;IS CHAR AN ALTOMODE?

*G                              ;Searches for next CKLF --  0L occurs
CKLF↓
        BNE   CKLF

*-2C                            ;EX replaces the preceding two characters
EX↓                             ;(LF)

*2J                             ;Jumps Dot past the carriage return and
                                ;line feed characters

*K                              ;Kills next line (starting with $ALT:)

*I                              ;Inserts $ALT: at beginning of the fol-
$ALT:↓                          ;lowing line

*A                              ;Advances Dot past 1 line feed to the
                                ;beginning of the next line

*M                              ;Marks the position of Dot

*B                              ;Moves Dot to the beginning of the cur-
                                ;rent page

*@P                             ;Punches out the lines from Dot to the
                                ;position just marked - Dot not moved
```

```
*@A                             ;Moves Dot from the beginning of the
                                ;page to the marked position

*2K                             ;Kills the next 2 lines
*
```

PART III Edited Source

```
        ;COMMON INPUT ROUTINE FOR USE BY NON FILE DEVICES

$INPUT: ADD     ICHAR,(R5)+         ;UPDATE CKSUM
        CLR     -(L5)               ;CLEAR DONE
        MOV     (R5)+,RMAX          ;GET ADR MAX
        MOV     (R5)+,MODADR        ;GET ADR MODE
                                    ;R5 NOW POINTS TO POINTER

$CKMODE:BITB    @MODADR,#ASCII      ;IS THIS ASCII
        BNE     CKBIN               ;NO---TRY BINARY

$CKNUL: TSTB    ICHAR               ;ASCII---IS CHAR A NULL
        BEQ     CK                  ;YES--NO GO

                                    ;LOOK AT MODE TO SEE IF
$CKPAR: BITB    @MODADR,#PARBIT     ;SUPPOSED TO CHECK PARITY?
        BNE     PAROK               ;NO
        MOVB    ICHAR,OCHAR         ;YES---CK IT
        JSR     R7,PARGEN
        SUB     ICHAR,OCHAR         ;
        BEQ     PAROK               ;OK?
        BIS     #PARERR,@MODADR     ;NO---SET ERR BIT
PAROK:  CLR     OCHAR
        BIC     #177200,ICHAR       ;STRIP PARITY
        CMPB    @10(RADD),#KBD      ;IS THIS KBD INPUT
        BNE     OK0                 ;NO
        TSTB    EKOCNT              ;YES---DONE EKO OF LAST?
        BEQ     $OK                 ;YES
        CLR     ICHAR               ;NO---DROP NEW CHAR
$JP2CK: JMP     CKDUN

        ;WHAT IS THE CHAR
$OK:    CMPB    ICHAR,#CTRLC        ;IS IT A ↑C
        BNE     OK0                 ;NO
        MOV     #UPC,OCHAR          ;YES--ECHO ↑C
        INC     RDUN
        MOV     #ABRTAD,20(R6)      ;DIDDLE RETURN ADR
        BR      PLUS1

                                    ;THIS IS NOT KBD INPUT
                                    ;FORMATTED AND UNFORMATTED
                                    ;ASCII ARE HANDLED THE SAME
        CMPB    ICHAR,#RUBOUT       ;IS THIS A RUBOUT
        BEQ     CK                  ;YES---IGNORE IT
        BR      PUT                 ;NO---
```

```
CKTAB:  CMPB    ICHAR,#HTAB     ;IS IT A TAB
        BNE     CKCR            ;NO
        MOV     #BLNKS,OCHAR    ;YES---ECHO BLANKS
        MOV     TABCNT,EKOCNT   ;SET UP COUNTER
        BR      PUT             ;

CKCR:   CMPB    ICHAR,#CR       ;IS IT A CR?
        BNE     $CK3            ;NO
        MOV     #CRLF,OCHAR     ;YES---ECHO CRLF
        INC     RDUN
        BR      PLUS1           ;

$CKALT: CMPB    ICHAR,#Ø33      ;IS CHAR AN ALTMODE?
        BEQ     $ALT
        CMPB    ICHAR,#175
        BEQ     $ALT
        CMPB    ICHAR,#176
        BNE     CKEX
$ALT:   MOV     #175,ICHAR
CKLF:   CMPB    ICHAR,#LF
        BNE     CKFF
        INC     RDUN
        BR      PUT

CKFF:   MOV     ICHAR,OCHAR
        CMPB    ICHAR,#FF
        BNE     PUT
        MOV     #8.,EKOCNT
        MOV     #LFLF,OCHAR
        BR      PUT
```

4.5 SOFTWARE ERROR HALTS

ED-11 loads all unused trap vectors with the code

```
        .WORD    .+2,HALT
```

so that if the trap does occur, the processor will halt in the second word of the vector. The address of the halt, displayed in the console address register, therefore indicates the cause of the halt. In addition to the halts which may occur in the vectors, the standard IOX error halt at location 40 may occur (see Chapter 7).

Address of HALT	Meaning
12	Reserved instruction executed
16	Trace trap occurred
26	Power fail trap
32	EMT executed
36	TRAP executed
40	IOX detected error

CHAPTER 5

DEBUGGING OBJECT PROGRAMS ON-LINE

CHAPTER 5

DEBUGGING OBJECT PROGRAMS ON-LINE

5.1 INTRODUCTION

ODT-11 (On-line Debugging Technique for the PDP-11) is a system program which aids in debugging assembled object programs. From the Teletype keyboard you interact with ODT and the object program to:

- print the contents of any location for examination or alteration,
- run all or any portion of your object program using the breakpoint feature,
- search the object program for specific bit patterns,
- search the object program for words which reference a specific word,
- calculate offsets for relative addresses.

During a debugging session you should have at the teleprinter the assembly listing of the program to be debugged. Minor corrections to the program may be made on-line during the debugging session. The program may then be run under control of ODT to verify any change made. Major corrections, however, such as a missing subroutine, should be noted on the assembly listing and incorporated in a subsequent updated program assembly.

A binary tape of the debugged program can be obtained by use of the DUMPAB program (see Chapter 6, Section 6.3).

5.1.1 ODT-11 and ODT-11X

There are two versions of ODT included in the PDP-11 Paper Tape Software System: a standard version, ODT-11, and an extended version, ODT-11X. Both versions are independent, self-contained programs. ODT-11X has all the features of ODT-11, plus some additional features. Each version is supplied on two separate paper tapes: a source tape and an absolute binary tape. The purpose of the tapes, and loading and starting procedures are explained in a later section of this chapter.

ODT-11 is completely described in Section 5.2, and the additional features of ODT-11X are covered in Section 5.3. In all sections of this chapter, except where specifically stated, reference to ODT applies to both versions. Concluding sections are concerned with ODT's internal operations -- how breakpoints are effected, how it uses the "trace trap" and the T-bit, and other useful data. Such information is not necessary to efficiently use ODT, but is available for anyone desiring such in-depth information.

The following discussion assumes that the reader is familiar with the PDP-11 instruction formats and the PAL-11A Assembly Language as described in Chapter 3.

5.1.2 ODT's Command Syntax

ODT's commands are composed using the following characters and symbols. They are often used in combination with the address upon which the operation is to occur, and are offered here for familiarization prior to their thorough coverage which follows. Unless indicated otherwise, n below represents an octal address.

n/ open the word at location n

/ reopen last opened location

n\ (SHIFT/L) open the byte at location n (ODT-11X only)

\ reopen the last opened byte (ODT-11X only)

↓ (LINE FEED key) open next sequential location

↑[1] open previous location

RETURN close open location and accept the next command

←[2] take contents of opened location, index by contents of PC, and open that location

@ take contents of opened location as absolute address and open that location (ODT-11X only)

> take contents of opened location as relative branch instruction and open referenced location (ODT-11X only)

< return to sequence prior to last @, >, or ← command and open succeeding location (ODT-11X only)

$n/ open general register n (0-7)

[1] The circumflex, ^, appears on some keyboards and printers in place of the up-arrow.

[2] The underline, _, appears on some keyboards and printers in place of the back-arrow.

;	separates commands from command arguments (used with alphabetic commands below)
;B	remove Breakpoint(s) (see description of each ODT version for particulars)
n;B	set Breakpoint at location n
n;rB	set Breakpoint r at location n (ODT-11X only)
;rB	remove rth Breakpoint (ODT-11X only)
n;E	search for instructions that reference Effective address n
n;W	search for Words with bit patterns which match n
;nS	enable Single-instruction mode (n can have any value and is not significant); disable breakpoints
;S	disable Single-instruction mode
n;G	Go to location n and start program run
;P	Proceed with program execution from breakpoint; stop when next breakpoint is encountered or at end of program In Single-instruction mode only (ODT-11X), Proceed to execute next instruction only
n;P	Proceed with program execution from breakpoint; stop after encountering the breakpoint n times. In Single-instruction mode only (ODT-11X), Proceed to execute next n instructions.
n/(word) m;O	calculate Offset from location n to location m
$B/	ODT-11, open Breakpoint status word ODT-11X, open Breakpoint 0 status word
$M/	open search Mask
$S/	open location containing user program's Status register
$P/	open location containing ODT's Priority level

With ODT-11, location references must be to even numbered 16-bit words. With ODT-11X, location references may be to 16-bit words or 8 bit bytes.

The semicolon in the above commands is ignored by ODT-11, but is used for the sake of consistency, since similar commands to ODT-11X require it.

5.2 COMMANDS AND FUNCTIONS

When ODT is started as explained in Section 5.6, it will indicate its readiness to accept commands by printing an asterisk on the left margin of the teleprinter paper. In response to the asterisk, you can issue most commands; for example, you can examine and, if desired, change a word, run the object program in its entirety or in segments, or even search core for certain words or references to certain words. The discussion below will first explain some elementary features before covering the more sophisticated features.

All commands to ODT are stated using the characters and symbols shown above in Section 5.1.2.

5.2.1 Opening, Changing, and Closing Locations

An open location is one whose contents ODT has printed for examination, and whose contents are available for change. A closed location is one whose contents are no longer available for change. Any even-numbered location may be opened using ODT-11.

The contents of an open location may be changed by typing the new contents followed by a single character command which requires no argument (i.e., ↓, ↑, RETURN, ←, @, >, <). Any command typed to open a location when another location is already open, will first cause the currently open location to be closed.

5.2.1.1 The Slash, /

One way to open a location is to type its address followed by a slash:

```
*1000/012746
```

Location 1000 is open for examination and is available for change. Note that in all examples ODT's printout is underlined; your typed input is not.

Should you not wish to change the contents of an open location, merely type the RETURN key and the location will be closed; ODT will print another asterisk and wait for another command, However, should you wish to change the word, simply type the new contents before giving a command to close the location.

```
*1000/012746  012345
*
```

In the example above, location 1000 now contains 012345 and is closed since the RETURN key was typed after entering the new contents, as indicated by ODT's second asterisk.

Used alone, the slash will reopen the last location opened:

```
*1000/012345  2340
*/002340
```

As shown in the example above, an open location can be closed by typing the RETURN key. In this case, ODT changed the contents of location 1000 to 002340 and then closed the location before printing the *. We then typed a single slash which directed ODT to reopen the last location opened. This allowed us to verify that the word 002340 was correctly stored in location 1000. (ODT supplies the leading zeroes if not given.)

Note again that opening a location while another is currently open will automatically close the currently open location before opening the new location.

5.2.1.2 The LINE FEED Key

If the LINE FEED key is typed when a location is open, ODT closes the open location and opens the next sequential location:

```
*1000/002340  ↓      (↓ denotes typing the LINE FEED key)
001002/012740
```

In this example, the LINE FEED key instructed ODT to print the address of the next location along with its contents and to wait for further instructions. After the above operation, location 1000 is closed and

1002 is open. The open location may be modified by typing the new contents.

5.2.1.3 The Up-Arrow, ↑

The up-arrow (or circumflex) symbol is effected by typing the SHIFT and N key combination. If the up-arrow is typed when a location is open, ODT closes the open location and opens the previous location (as shown by continuing from the example above):

```
001002/012740   ↑  ( ↑ is printed by typing SHIFT and N)
001000/002340
```

Now location 1002 is closed and 1000 is open. The open location may be modified by typing the new contents.

5.2.1.4 The Back-Arrow, ←

The back-arrow (or underline) symbol is effected by typing the SHIFT and O key combination. If the back-arrow is typed to an open location, ODT interprets the contents of the currently open location as an address indexed by the Program Counter (PC) and opens the location so addressed:

```
*1006/000006  ←    ( ← is printed by typing SHIFT and O)
001016/100405
```

Notice in this example that the open location, 1006, was indexed by the PC as if it were the operand of an instruction with address mode 67 as explained in Chapter 3.

A modification to the opened location can be made before a ↓, ↑ , or ← is typed. Also, the new contents of the location will be used for address calculations using the ← command. Example:

```
*100/000222  4↓         (modify to 4 and open next location)
000102/000111  6 ↑      (modify to 6 and open previous location)
000100/000004  100←     (change to 100 and open location indexed
000202/(contents)        by PC)
```

5.2.1.5 Accessing General Registers 0-7

The program's general registers 0-7 can be opened using the following command format:

```
*$n/
```

where n is the integer representing the desired register (in the range 0 through 7). When opened, these registers can be examined or changed by typing in new data as with any addressable location. For example:

```
*$0/000033              (R0 was examined and closed)
*
```

and

```
*$4/000474  464         (R4 was opened, changed, and closed)
*
```

The example above can be verified by typing a slash in response to ODT's asterisk:

```
*/000464
```

The ↓, ↑, ←, or @ commands may be used when a register is open (the @ is an ODT-11X command).

5.2.1.6 Accessing Internal Registers

The program's Status Register contains the condition codes of the most recent operational results and the interrupt priority level of the object program. It is opened using the following command:

```
*$S/000311
```

where $S represents the address of the Status Register. In response to $S/ in the example above, ODT printed the 16-bit word of which only the low-order 8 bits are meaningful: Bits 0-3 indicate whether a carry, overflow, zero, or negative (in that order) has resulted, and bits 5-7 indicate the interrupt priority level (in the range 0-7) of the object program. (See Chapter 1 of this manual or the PDP-11 Handbook for the Status Register format.)

The $ is used to open certain other internal locations:

$B   internal breakpoint status word (see Section 5.2.2.2)

$M   mask location for specifying which bits are to be examined during a bit pattern search (see Section 5.2.4)

$P   location defining the operating priority of ODT (see Section 5.2.6)

$S   location containing the condition codes (bits 0-3) and interrupt priority level (bits 5-7)

5.2.2 Breakpoints

The breakpoint feature facilitates monitoring the progress of program execution. A breakpoint may be set at any instruction which is not referenced by the program for data. When a breakpoint is set, ODT replaces the contents of the breakpoint location with a trap instruction so that when the program is executed and the breakpoint is encountered, program execution is suspended, the original contents of the breakpoint location are restored, and ODT regains control.

5.2.2.1 Setting the Breakpoint, n;B

ODT-11 provides only one breakpoint (ODT-11X provides eight breakpoints). However, the breakpoint may be changed at any time. The breakpoint is set by typing the address of the desired location of the breakpoint followed by ;B. For example:

```
*1020;B
*
```

sets the breakpoint at location 1020. The breakpoint above is changed to location 1120 as shown below.

```
*1020;B
*1120;B
*
```

Breakpoints should not be set at locations which are referenced by the program for data, or on an IOT, EMT, or TRAP instruction. This restriction is explained in Section 5.5.2.

The breakpoint is removed by typing ;B without an argument, as shown below.

```
*1120;B                 (sets breakpoint at location 1120)
*;B                     (removes breakpoint)
*
```

5.2.2.2 Locating the Breakpoint, $B

The command $B/ causes the ODT-11 version to print the address of the breakpoint (see also Section 5.3.3 on $B in ODT-11X):

```
*$B/001120
```

The breakpoint was set at location 1120. $B represents the address containing ODT-11's breakpoint location. Typing the RETURN key in the example above will leave the breakpoint at location 1120 and return control to ODT-11, or the breakpoint could be changed to a different location:

```
*$B/001120  1114
*$B/001114
*
```

The breakpoint was found in location 1120, changed to location 1114, and the change was verified.

If no breakpoint was set, $B contains an address internal to ODT-11.

5.2.3 Running the Program, n;G and n;P

Program execution is under control of ODT. There are two commands for running the program: n;G and n;P. The n;G command is used to start execution (Go) and n;P to continue (Proceed) execution after having halted at a breakpoint. For example:

```
*1000;G
```

starts execution at location 1000. The program will run until encountering a breakpoint or until program completion, unless it gets caught in an infinite loop, where you must either restart or reenter as explained in Section 5.6.2.

When a breakpoint is encountered, execution stops and ODT-11 prints B; followed by the address of the breakpoint. You may then examine desired locations for expected data. For example:

```
*1010;B          (breakpoint is set at location 1010)
*1000;G          (execution started at location 1000)
B;001010         (execution stopped at location 1010)
*
```

To continue program execution from the breakpoint, type ;P in response to ODT-11's last *.

When a breakpoint is set in a loop, it may be desirable to allow the program to execute a certain number of times through the loop before recognizing the breakpoint. This may be done by typing the n;P command and specifying the number of times the breakpoint is to be encountered before program execution is suspended (on the nth encounter). (See Section 5.3.3 for ODT-11X interpretation of this command when more than one breakpoint is set in a loop.)

Example:

```
B;001010         (execution halted at breakpoint)
*1250;B          (set breakpoint at location 1250)
*4;P             (continue execution, loop through
B;001250          breakpoint 3 times and halt on the
*                 4th occurrence of the breakpoint)
```

The breakpoint repeat count can be inspected by typing $B/ and following that with the typing of LINE FEED. The repeat count will then be printed. This also provides an alternative way of specifying the count. The location, being open, can have its contents modified in the usual manner by the typing of new contents and then the RETURN key.

Example:

```
*$B/001114  ↓       (address of breakpoint is 1114)
nnnnnn/000003  6    (repeat count was 3, changed to 6)
*
```

Breakpoints are inserted when performing an n;G or n;P command. Upon execution of the n;G or n;P command, the general registers 0-6 are set to the values in the locations specified as $0-$6 and the processor status register is set to the value in the location specified as $S.

5.2.4 Searches

With ODT you can search all or any specified portion of core memory for any specific bit pattern or for references to a specific location.

The location represented by $M is used to specify the mask of the search. The next two sequential locations contain the lower and upper limits of the search. Bits set to 1 in the mask will be examined during the search; other bits will be ignored. For example,

```
*$M/000000  177400  ↓     (↓  denotes typing LINE FEED)
nnnnnn/000000  1000  ↓    (starting address of search)
nnnnnn/000000  1040       (last address in search)
*
```

where nnnnnn represents some location in ODT. This location varies and is meaningful only for reference purposes. Note that in the first line above, the slash was used to open $M which now contains 177400, and that the LINE FEEDs opened the next two sequential locations which now contain the lower and upper limits of the search.

5.2.4.1 Word Search n;W

Before initiating a word search, the mask and search limits must be specified as explained above. Then the search object and the initiating command are given using the n;W command where n is the search object. When a match is found, the address of the unmasked matching word is printed. For example:

```
*$M/000000  177400  ↓       (test high order eight bits)
nnnnnn/000000  1000  ↓
nnnnnn/000000  1040
*400;W                      (initiating word search)
001010/000770
001034/000404
*
```

In the search process, the word currently being examined and the search object are exclusive ORed (XORed), and the result is ANDed to the mask. If this result is zero, a match has been found, and is reported on the teleprinter. Note that if the mask is zero, all locations within the limits will be printed.

5.2.4.2 Effective Address Search, n;E

ODT enables you to search for words which address a specified location. After specifying the search limits (Section 5.2.4), the command n;E is typed (where n is the effective address), initiating the search.

Words which are either an absolute address (argument n itself), a relative address offset, or a relative branch to the effective address will be printed after their addresses. For example:

```
*$M/177400  ↓
nnnnnn/001000  1010  ↓
nnnnnn/001040  1060
*1034;E                     (initiating search)
001016/001006               (relative branch)
001054/002767               (relative branch)
*1020;E                     (initiating a new search)
001022/177774               (relative address offset)
001030/001020               (absolute address)
*
```

Particular attention should be given to the reported references to the effective address because a word may have the specified bit pattern of an effective address without actually being so used. ODT will report these as well.

5.2.5 Calculating Offsets, n;O

Relative addressing and branching involve the use of an offset - the number of words or bytes forward or backward from the current location to the effective address. During the debugging session it may be necessary to change a relative address or branch reference by replacing one instruction offset with another. ODT calculates the offsets for you in response to its n;O command.

The command n;O causes ODT to print the 16-bit and 8-bit offsets from the currently open location to address n. In ODT-11, the 8-bit offset is printed as a 16-bit word. For example:

```
*346/000034  414;O   000044  000022  22
*/000022
*20/000046   200;O   000156  000067  67
*20/000067
```

In the first example, location 346 is opened and the offsets from that location to location 414 are calculated and printed. The contents of location 346 are then changed to 22 and verified on the next line. The 16-bit offset is printed followed by the 8-bit offset. In the example above, 000156 is the 16-bit offset and 000067 is the 8-bit offset.

The 8-bit offset is printed only if the 16-bit offset is even, as was the case above. With ODT-11 only, the user must determine whether the 8-bit offset is out of the range of 177600 to 000177 (-128_{10} to 127_{10}). The offset of a relative branch is calculated and modified as follows:

```
*1034/103421  1034;O  177776  177777  103777
*
```

Note that the modified low-order byte 377 must be combined with the unmodified high-order byte. Location 1034 was still open after the calculation, thus typing 103777 changed its contents; the location was then closed.

5.2.6 ODT's Priority Level, $P

$P represents a location in ODT that contains the priority level at which ODT operates. If $P contains the value 377, ODT will operate at the priority level of the processor at the time ODT is entered. Otherwise $P may contain a value between 0 and 7 corresponding to the fixed priority at which ODT will operate.

To set ODT to the desired priority level, open $P. ODT will print the present contents, which may then be changed:

```
        *$P/000006    377
        *
```

If $P is not specified, its value will be seven.

Breakpoints may be set in routines at different priority levels. For example, a program running at a low priority level may use a device service routine which operates at a higher priority level. If a breakpoint occurs from a low priority routine, if ODT operates at a low priority, and if an interrupt does occur from a high priority routine, then the breakpoints in the high priority routine will not be executed since they have been removed.

5.3 ODT-11X

ODT-11X has all the commands and features of ODT-11 as explained in Section 5.2, plus the following.

5.3.1 Opening, Changing and Closing Locations

In addition to operating on words, ODT-11X operates on bytes.

One way to open a byte is to type the address of the byte followed by a backslash:

```
        *1001\025          ( \ is printed by typing SHIFT and L)
```

A backslash typed alone will reopen the last open byte. If a word was previously open, the backslash will reopen its even byte.

```
*1002/000004\004
```

The LINE FEED and up-arrow (or circumflex) keys will operate on bytes if a byte is open when the command is given. For example:

```
*1001\025  ↓
001002\004  ↑
001001\025
*
```

5.3.1.1 Open the Addressed Location, @

The symbol @ will optionally modify, close an open word, and use its contents as the address of the location to open next.

```
*1006/001024  @            (open location 1024 next)
001024/000500
*1006/001024  2100 @       (modify to 2100 and open
002100/177774               location 2100)
```

5.3.1.2 Relative Branch Offset, >

The right angle bracket, >, will optionally modify, close an open word, and use its even byte as a relative branch offset to the next word opened.

```
*1032/000407  301 >        (modify to 301 and interpret as
000636/000010               a relative branch)
```

Note that 301 is a negative offset (-77). The offset is doubled before it is added to the PC; therefore, 1034 + -176 = 636.

5.3.1.3 Return to Previous Sequence, <

The left angle bracket, <, will optionally modify, close an open location, and open the next location of the previous sequence interrupted by a ←, @, or > command. Note that ←, @, or > will cause a sequence change to the word opened. If a sequence change has not occurred, < will simply open the next location as a LINE FEED does. The command will operate on both words and bytes.

```
*1032/000407  301  >       (> causes a sequence change)
000636/000010 <            (< causes a return to original
                            sequence)
001034/001040 @            (@ causes a sequence change)
001040/000405\ 005 <       (< now operates on byte)
001035\ 002 <              (< acts like ↓ )
001036\ 004
```

5.3.2 Calculating Offsets, n;O

The command n;O causes ODT to print the 16-bit and 8-bit offsets from the currently open location to address n. The following examples, repeated from the ODT-11 section describing this command (see Section 5.2.5), show only a difference in printout format:

```
*346/000034  414;O  000044  022  22
*/000022


*1034/103421  1034;O  177776  377\ 021  377
*/103777
```

Note that the modified low-order byte 377 must be combined with the unmodified high-order byte.

5.3.3 Breakpoints

With ODT-11X you can, at any one time, have up to eight breakpoints set, numbered 0 through 7. The n;B command used in ODT-11 to set the breakpoint at address n will set the next available breakpoint in ODT-11X. Specific breakpoints may be set or changed by the n;mB command where m is the number of the breakpoint. For example:

```
*1020;B                    (sets breakpoint 0)
*1030;B                    (sets breakpoint 1)
*1040;B                    (sets breakpoint 2)
*1032;1B                   (resets breakpoint 1)
*
```

The ;B command used in ODT-11 to remove the only breakpoint will remove all breakpoints in ODT-11X. To remove only one of the breakpoints, the ;nB command is used, where n is the number of the breakpoint. For example:

```
*;2B                               (removes the second breakpoint)
*
```

The $B/ command will open the location containing the address of breakpoint 0. The next seven locations contain the addresses of the other breakpoints in order, and thus can be opened using the LINE FEED key. (The next location is for Single-instruction mode, explained in the next section.) Example:

```
*$B/001020  ↓
nnnnnn/001032 ↓
nnnnnn/(address internal to ODT)
```

In this example, breakpoint 2 is not set. The contents will be an address internal to ODT. After the table of breakpoints is the table of Proceed command repeat counts for each breakpoint, and for the Single-instruction mode (see Section 5.3.4).

```
.
.
.                  ↓
nnnnnn/001036      ↓          (address of breakpoint 7)
nnnnnn/nnnnnn      ↓          (single-instruction address)
nnnnnn/000000   15 ↓          (count for breakpoint 0)
nnnnnn/000000                 (count for breakpoint 1)
```

It should be noted that a repeat count in a Proceed command refers only to the breakpoint that has most recently occurred. Execution of other breakpoints encountered is determined by their own repeat counts.

5.3.4 Single-Instruction Mode

With this mode you can specify the number of instructions you wish executed before suspension of the program run. The Proceed command, instead of specifying a repeat count for a breakpoint encounter, specifies the number of succeeding instructions to be executed. Note that breakpoints are disabled when single-instruction mode is operative.

Commands for single-instruction mode follow:

;nS Enables Single-instruction mode (n can have any value and serves only to distinguish this form from the form ;S); breakpoints are disabled.

n;P Proceeds with program run for next n instructions before reentering ODT (if n is missing, it is assumed to be 1). (Trap instructions and associated handlers can affect the Proceed repeat count. See Section 5.5.2.)

;S Disables Single-instruction mode

When the repeat count for Single-instruction mode is exhausted and the program suspends execution, ODT prints:

```
B8;n
*
```

where n is the address of the next instruction to be executed. The $B breakpoint table contains this address following that of breakpoint 7. However, unlike the table entries for breakpoints 0-7, the B8 entry is not affected by direct modification.

Similarly, following the repeat count for breakpoint 7, is the repeat count for Single-instruction mode. This table entry, however, may be directly modified, and thus is an alternative way of setting the Single-instruction mode repeat count. In such a case, ;P implies the argument set in the $B repeat count table rather than the argument 1.

5.4 ERROR DETECTION

ODT-11 and ODT-11X inform you of two types of errors: illegal or unrecognizable command and bad breakpoint entry.

Neither ODT-11 nor ODT-11X checks for the legality of an address when commanded to open a location for examination or modification.

Thus, the command

```
177774/
```

will reference nonexistent memory, thereby causing a trap through the vector at location 4. If this vector has not been properly initialized (by IOX, or the user program if IOX is not used), unpredictable results will occur.

Similarly, a command such as

```
$20/
```

which references an address eight times the value represented by $2, may cause an illegal (nonexistent) memory reference.

Typing something other than a legal command will cause ODT to ignore the command, print

```
?
*
```

and wait for another command. Therefore, to cause ODT to ignore a command just typed, type any illegal character (such as 9 or RUBOUT) and the command will be treated as an error, i.e., ignored.

ODT suspends program execution whenever it encounters a breakpoint, i.e., a trap to its breakpoint routine. If the breakpoint routine is entered and no known breakpoint caused the entry, ODT prints:

```
BE001542
*
```

and waits for another command. In the example above, BE001542 denotes Bad Entry from location 001542. A bad entry may be caused by an illegal trace trap instruction, setting the T-bit in the status register, or by a jump to the middle of ODT.

5.5 PROGRAMMING CONSIDERATIONS

Information in this section is not necessary for the efficient use of

ODT. However, its content does provide a better understanding of how ODT performs some of its functions.

5.5.1 Functional Organization

The internal organization of ODT is almost totally modularized into independent subroutines. The internal structure consists of three major functions: command decoding, command execution, and various utility routines.

The command decoder interprets the individual commands, checks for command errors, saves input parameters for use in command execution, and sends control to the appropriate command execution routine.

The command execution routines take parameters saved by the command decoder and use the utility routines to execute the specified command. Command execution routines exit either to the object program or back to the command decoder.

The utility routines are common routines such as SAVE-RESTORE and I/O. They are used by both the command decoder and the command executers.

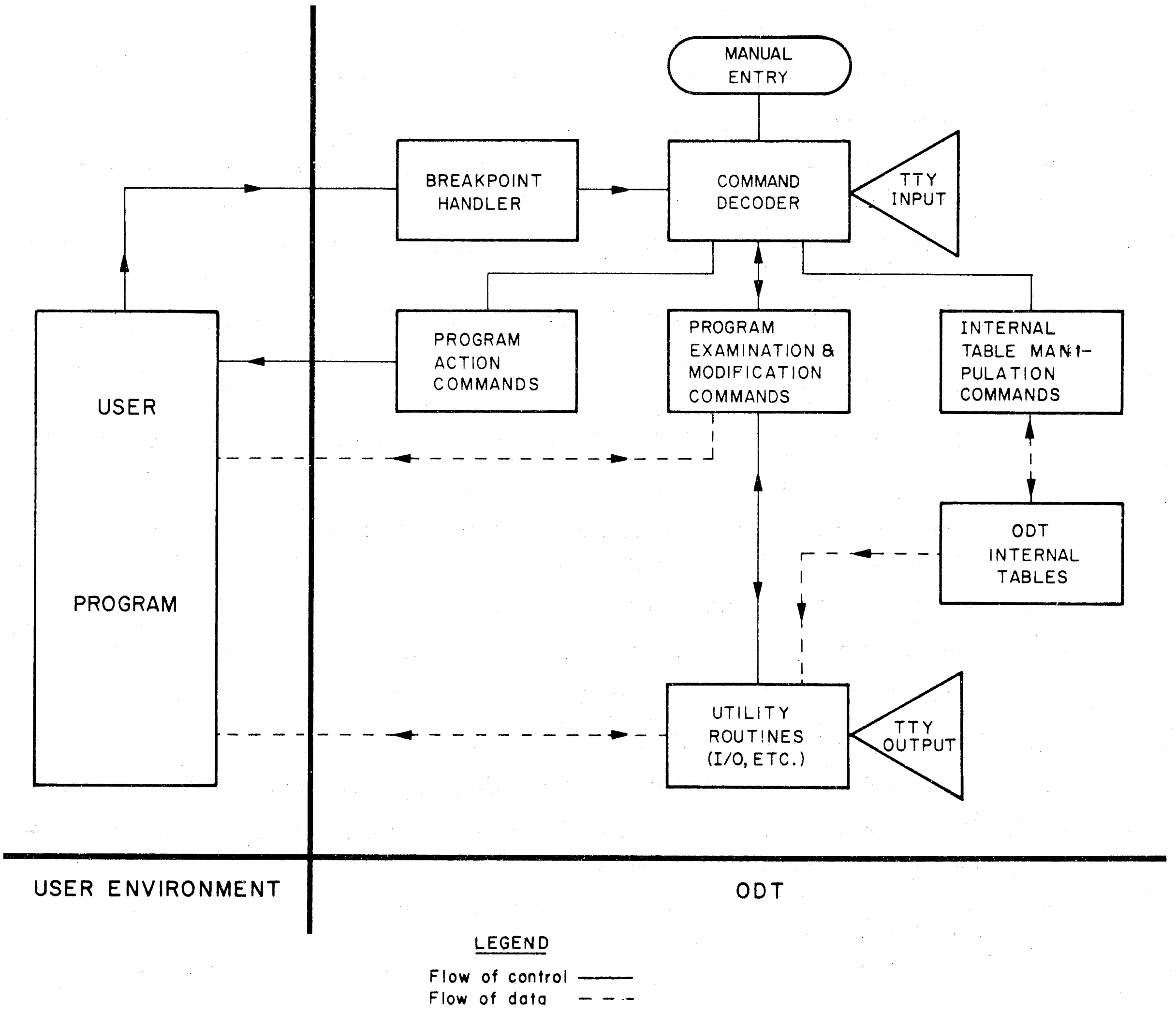
Communication and data flow are illustrated in Figure 5-1.

5.5.2 Breakpoints

The function of a breakpoint is to give control to ODT whenever the user program tries to execute the instruction at the selected address. Upon encountering a breakpoint, the user can utilize all of the ODT commands to examine and modify his program.

When a breakpoint is executed, ODT-11(X) removes (all) the breakpoint instruction(s) from the user's code so that the locations may be examined and/or altered. ODT then types a message to the user of the form Bn(Bm;n for ODT-11X) where n is the breakpoint address (and m is the breakpoint number). The breakpoints are automatically restored when execution is resumed.

A major restriction in the use of breakpoints is that the word



11-0065

Figure 5-1 Communication and Data Flow

where a breakpoint has been set must not be referenced by the program in any way since ODT has altered the word. Also, no breakpoint should be set at the location of any instruction that clears the T-bit. For example:

```
        MOV #240,177776      ;SET PRIORITY TO LEVEL 5.
```

A breakpoint occurs when a trace trap instruction (placed in the user program by ODT) is executed. When a breakpoint occurs, the following steps are taken:

1. Set processor priority to seven (automatically set by trap instruction).
2. Save registers and set up stack.
3. If internal T-bit trap flag is set, go to step 13.
4. Remove breakpoint(s).
5. Reset processor priority to ODT's priority or user's priority.
6. Make sure a breakpoint or Single-instruction mode caused the interrupt.
7. If the breakpoint did not cause the interrupt, go to step 15.
8. Decrement repeat count.
9. Go to step 18 if non-zero, otherwise reset count to one.
10. Save Teletype status.
11. Type message to user about the breakpoint or Single-instruction mode interrupt.
12. Go to command decoder.
13. Clear T-bit in stack and internal T-bit flag.
14. Jump to the "GO" processor.
15. Save Teletype status.
16. Type "BE" (Bad Entry) followed by the address.
17. Clear the T-bit, if set, in the user status and proceed to the command decoder.
18. Go to the "Proceed" processor, bypassing the TTY restore routine.

Note that steps 1-5 inclusive take approximately 100 microseconds during which time interrupts are not permitted to occur (ODT is running at level 7).

When a proceed (;P) command is given, the following occurs:

1. The proceed is checked for legality.
2. The processor priority is set to seven.
3. The T-bit flags (internal and user status) are set.
4. The user registers, status, and Program Counter are restored.
5. Control is returned to the user.
6. When the T-bit trap occurs, steps 1, 2, 3, 13, and 14 of the breakpoint sequence are executed, breakpoints are restored, and program execution resumes normally.

When a breakpoint is placed on an IOT, EMT, TRAP, or any instruction causing a trap, the following occurs:

1. When the breakpoint occurs as described above, ODT is entered.
2. When ;P is typed, the T-bit is set and the IOT, EMT, TRAP, or other trapping instruction is executed.
3. This causes the current PC and status (with the T-bit included) to be pushed on the stack.
4. The new PC and status (no T-bit set) are obtained from the respective trap vector.
5. The whole trap service routine is executed without any breakpoints.
6. When an RTI is executed, the saved PC and PS (including the T-bit) are restored. The instruction following the trap-causing instruction is executed. If this instruction is not another trap-causing instruction, the T-bit trap occurs, causing the breakpoints to be reinserted in the user program, or the Single-instruction mode repeat count to be decremented. If the following instruction is a trap-causing instruction, this sequence is repeated, starting at step 3.

NOTE

> Exit from the trap handler must be via the RTI instruction. Otherwise, the T-bit will be lost. ODT will not gain control again since the breakpoints have not been reinserted yet.

In ODT-11, the ;P command is illegal if a breakpoint has not occurred (ODT will respond with ?). In ODT-11X, ;P is legal after any trace trap entry.

WARNING

> Since ODT-11 ignores all semicolons, typing the ODT-11X form of breakpoint command number to ODT-11, specifying a breakpoint number n, causes the following error:
>
> ```
> 100;B  (sets the breakpoint at location 100)
> 100;0B (sets the breakpoint at location 1000)
> 100;4B (sets the breakpoint at location 1004)
> ```

The internal breakpoint status words for ODT-11 have the following format:

1. The first word contains the breakpoint address. If this location points to a location within ODT, it is assumed no breakpoint is set for the cell(specifically, ODT has set a dummy breakpoint within itself).
2. The next word contains the breakpoint repeat count.

For ODT-11X (with eight breakpoints) the formats are:

1. The first eight words contain the breakpoint addresses for breakpoints 0-7. (The ninth word contains the address of the next instruction to be executed in Single-instruction mode.)
2. The next eight words contain the respective repeat counts. (The following word contains the repeat count for Single-instruction mode.)

These words may be changed at will by the user, either by using the breakpoint commands or by direct manipulation with $B.

When program runaway occurs (that is, when the program is no longer under ODT control, perhaps executing an unexpected part of the program where a breakpoint has not been placed) ODT may be given control by pressing the HALT key to stop the machine, and restarting ODT (see Section 5.6.2). ODT will print *, indicating that it is ready to accept a command.

If the program being debugged uses the Teletype for input or output, the program may interact with ODT to cause an error since ODT uses the Teletype as well. This interactive error will not occur when the program being debugged is run without ODT.

1. If the Teletype printer interrupt is enabled upon entry to the ODT break routine, and no output interrupt is pending when ODT is entered, ODT will generate an unexpected interrupt when returning control to the program.
2. If the interrupt of the Teletype reader (the keyboard) is enabled upon entry to the ODT break routine, and the program is expecting to receive an interrupt to input a character, both the expected interrupt and the character will be lost.
3. If the Teletype reader (keyboard) has just read a character into the reader data buffer when the ODT break routine is entered, the expected character in the reader data buffer will be lost.

5.5.3 Search

The word search allows the user to search for bit patterns in specified sections of memory. Using the $M/ command, the user specifies a mask, a lower search limit ($M+2), and an upper search limit ($M+4). The search object is specified in the search command itself.

The word search compares selected bits (where ones appear in the mask) in the word and search object. If all of the selected bits are equal, the unmasked word is printed.

The search algorithm is:

1. Fetch a word at the current address.
2. XOR (exclusive OR) the word and search object.
3. AND the result of step 2 with the mask.
4. If the result of step 3 is zero, type the address of the unmasked word and its contents. Otherwise, proceed to step 5.
5. Add two to the current address. If the current address is greater than the upper limit, type * and return to the command decoder, otherwise go to step 1.

Note that if the mask is zero, ODT will print every word between the limits, since a match occurs every time (i.e., the result of step 3 is always zero).

In the effective address search, ODT interprets every word in the search range as an instruction which is interrogated for a possible direct relationship to the search object.

The algorithm for the effective address search is (where (X) denotes contents of X, and K denotes the search object):

1. Fetch a word at the current address X.
2. If (X)=K [direct reference],print contents and go to step 5.
3. If (X)+X+2=K [indexed by PC], print contents and go to step 5.
4. If (X) is a relative branch to K, print contents.
5. Add two to the current address. If the current address is greater than the upper limit, perform a carriage return/line feed and return to the command decoder; otherwise, go to step 1.

5.5.4 Teletype Interrupt

Upon entering the TTY SAVE routine, the following occurs:

1. Save the LSR status register (TKS).
2. Clear interrupt enable and maintenance bits in the TKS.
3. Save the TTY status register (TPS).
4. Clear interrupt enable and maintenance bits in the TPS.

To restore the TTY:

1. Wait for completion of any I/O from ODT.
2. Restore the TKS.
3. Restore the TPS.

WARNINGS

If the TTY printer interrupt is enabled upon entry to the ODT break routine, the following may occur:

1. If no output interrupt is pending when ODT is entered, an additional interrupt will always occur when ODT returns control to the user.
2. If an output interrupt is pending upon entry, the expected interrupt will occur when the user regains control.

WARNINGS (cont.)

If the TTY reader (keyboard) is busy or done, the expected character in the reader data buffer will be lost.

If the TTY reader (keyboard) interrupt is enabled upon entry to the ODT break routine, and a character is pending, the interrupt (as well as the character) will be lost.

5.6 OPERATING PROCEDURES

This section describes assembling and loading procedures for ODT, restarting and reentering procedures, error recovery, and setting the priority level of ODT.

5.6.1 Loading Procedures

ODT-11 and ODT-11X are supplied on source and binary tapes. Source tapes are assembled as explained in Section 5.6.3. Binary tapes of either version are loaded into core memory using the Absolute Loader, as explained in Section 6.2.2. When using ODT's binary tapes, the object program should be loaded prior to loading ODT, since ODT is started when loaded.

ODT-11 is loaded into core starting at location 13026, and requires about 533_{10} locations of core. ODT-11X is loaded into core starting at location 12054, and requires about 800 words of core.

5.6.2 Starting and Restarting

After loading ODT into core, it is automatically started by the Absolute Loader. ODT indicates its readiness to accept input by printing an *.

When ODT is started at its start address, the SP register is set to an ODT internal stack, registers R0-R5 are left untouched, and the trace trap vector is initialized. If ODT is started after breakpoints have been set in a program, ODT will forget about the breakpoints and will leave the program modified, i.e., the breakpoint instructions will be left in the program.

There are two ways of restarting ODT:

1. Restart at start address+2
2. Reenter at start address+4

To restart, key in the start address+2 (13030 for ODT-11 or 12056 for ODT-11X), press LOAD ADDRess and then START. A restart will save the general registers, remove all the breakpoint instructions from the user program and then forget all breakpoints, i.e., simulate the ;B command.

To reenter, key in the load address+4 (13032 for ODT-11 or 12060 for ODT-11X), press LOAD ADDRess and then START. A reenter will save the general registers, remove the breakpoint instructions from the user program, and ODT will type the BE (Bad Entry) error message. ODT will remember which breakpoints were set and will reset them on the next ;G command (;P is illegal after a Bad Entry).

5.6.3 Assembling ODT

If the program being debugged requires storage where the version of ODT being used is normally loaded, it is necessary to reassemble ODT after changing the starting location.

The source tape of ODT is in three segments, each separated from the next by blank tape. The first segment contains:

```
.=n                  (standard location setting statement)
.EOT
```

where n=13026 for ODT-11 or n=12054 for ODT-11X. This statement tells the Assembler to start assembling at address n. To relocate ODT to another starting address, substitute for segment one a source tape consisting of:

```
.=n                  (n is the new load address for ODT)
.EOT
```

The .EOT statement tells the Assembler that this is the end of the segment but not the end of the program -- the Assembler will stop and wait for another tape to be placed in the reader.

The second segment of tape contains the ODT source program. This segment is also terminated with .EOT.

The third segment of the tape consists of the statement:

```
.END  O.ODT
```

where .END means "end of program" and O.ODT represents the starting address of the program (see Section 6.2.3).

When relocating ODT, the first segment of the source tape must be changed to reflect the desired load address. The third segment may be changed to .END without a start address. The latter will cause the Loader to halt upon completion of loading.

The segmentation allows the following assembly forms:

1. Assemble alone but at a new address. A new segment one must be generated and assembled with segments two and three.
2. Assemble immediately after the user's program to be debugged. Assemble the tape of the user's program (ending with .EOT) followed by ODT's segment two and either segment three or a new segment three.
3. Assemble inside the program to be debugged. Assemble the first part of the user program (ending with .EOT) followed by ODT's second segment followed by the second part of the user program.

When setting locations before assembling, it must be noted that immediately preceding ODT a minimum internal stack of 40_8 bytes is required for the ODT-11 and 116_8 bytes is required for ODT-11X. Additional room must be allocated for subroutine calls and possible interrupts while ODT is in control. Twelve bytes maximum will be used by ODT proper for subroutine calls and interrupts, giving a minimum safe stack space of 52_8 bytes for ODT-11 or 130_8 bytes for ODT-11X.

Once a new binary tape of ODT has been assembled, load it using the Absolute Loader as explained in Section 6.2.2. Normally, the program to be debugged is loaded <u>before</u> ODT, since ODT will automatically be in control immediately after loading, unless the third segment of ODT's source tape was altered before assembly. As soon as the tape is read in, ODT will print an * on the Teletype to indicate that it is ready for a command.

CHAPTER 6

LOADING AND DUMPING CORE MEMORY

CHAPTER 6

Loading and Dumping Core Memory

When your PDP-11 computer is first received its core memory is completely demagnetized -- it "knows" absolutely nothing, not even how to receive paper tape input. However, the computer can accept data when toggled directly into core using the console switches. Since the Bootstrap Loader program is the very first program to be loaded, it must be toggled into core.

The Bootstrap Loader (see Section 6.1) is a program which instructs the computer to accept and store in core data which is punched on paper tape in bootstrap format. The Bootstrap Loader is used to load very short paper tape programs of 162_8 16-bit words or less -- primarily the Absolute Loader and Memory Dump Programs. Programs longer than 162_8 16-bit words must be assembled into absolute binary format using the PAL-11A Assembler and loaded into core using the Absolute Loader.

The Absolute Loader (see Section 6.2) is a system program which enables you to load into any available core memory bank data punched on paper tape in absolute binary format. It is used primarily to load the paper tape system software (excluding certain subprograms) and object programs assembled with PAL-11A.

The loader programs are loaded into the upper-most area of available core so that they will be available for use with system and user programs. When writing your programs be aware that they should not use the locations used by the loaders without restoring their contents; otherwise, the loaders will have to be reloaded since they would have been altered by your object program.

Core memory dump programs (see Section 6.3) are used to print or punch the contents of specified areas of core. For example, when developing or debugging user programs it is often necessary to get a copy of the program or portions of core. There are two dump programs supplied in the paper tape software system: DUMPTT, which prints or punches the octal representation of all or specified portions of core, and DUMPAB, which punches all or specified portions of core in absolute binary format suitable for loading with the Absolute Loader.

6.1 THE BOOTSTRAP LOADER

The Bootstrap Loader should be loaded (toggled) into the highest core memory bank. The locations and corresponding instructions of the Bootstrap Loader are listed and explained below.

Location	Instruction
xx7744	016701
xx7746	000026
xx7750	012702
xx7752	000352
xx7754	005211
xx7756	105711
xx7760	100376
xx7762	116162
xx7764	000002
xx7766	xx7400
xx7770	005267
xx7772	177756
xx7774	000765
xx7776	yyyyyy

Figure 6-1. Bootstrap Loader Instructions

In Figure 6-1, xx represents the highest available memory bank. For example, the first location of the Loader would be one of the following, depending on memory size, and xx in all subsequent locations would be the same as the first.

Location	Memory Bank	Memory Size
017744	0	4K
037744	1	8K
057744	2	12K
077744	3	16K
117744	4	20K
137744	5	24K
157744	6	28K

Note also in Figure 6-1 that the contents of location xx7766 should reflect the appropriate memory bank in the same manner as the location.

The contents of location xx7776 (yyyyyy in the Instruction column of Figure 6-1) should contain the device status register address of the paper tape reader to be used when loading the bootstrap formatted tapes. Either paper tape reader may be used, and each is specified as follows:

Teletype Paper Tape Reader	--	177560
High-Speed Paper Tape Reader	--	177550

6.1.1 Loading the Loader Into Core

With the computer initialized for use as described in Chapter 2, toggle in the Bootstrap Loader as explained below.

1. Set xx7744 in the Switch Register (SR) and press LOAD ADDRess (xx7744 will be displayed in the ADDRESS REGISTER.

2. Set the first instruction, 016701, in the SR and lift DEPosit (016701 will be displayed in the DATA register).

NOTE

> When DEPositing data into consecutive words, the DEPosit automatically increments the ADDRESS REGISTER to the next word.

3. Set the next instruction, 000026, in the SR and lift DEPosit (000026 will be displayed in the DATA register).

4. Set the next instruction in the SR, press DEPosit, and continue depositing subsequent instructions (ensure that location xx7766 reflects the proper memory bank) until after 000765 has been deposited in location xx7774.

5. Deposit the desired device status register address in location xx7776, the last location of the Bootstrap Loader.

It is good programming practice to verify that all instructions are stored correctly. This is done by proceeding at step 6 below.

6. Set xx7744 in the SR and press LOAD ADDRess.

7. Press EXAMine (the octal instruction in location xx7744 will be displayed in the DATA register so that it can be compared to the correct instruction, 016701. If the instruction is correct, proceed to step 8, otherwise go to step 10.

8. Press EXAMine (the instruction of the location displayed in the ADDRESS REGISTER will be displayed in the DATA register; compare the DATA register contents to the instruction for the displayed location.

9. Repeat step 8 until all instructions have been verified or go to step 10 whenever the correct instruction is not displayed.

Whenever an incorrect instruction is displayed, it can be corrected by performing steps 10 and 11.

10. With the desired location displayed in the ADDRESS REGISTER, set the correct instruction in the SR and lift DEPosit (the contents of the SR will be deposited in the displayed location).
11. Press EXAMine to ensure that the instruction was correctly stored (it will be displayed in the DATA register).
12. Proceed at step 9 until all instructions have been verified.

The Bootstrap Loader is now loaded into core. The procedures above are illustrated in the flowchart of Figure 6-2.

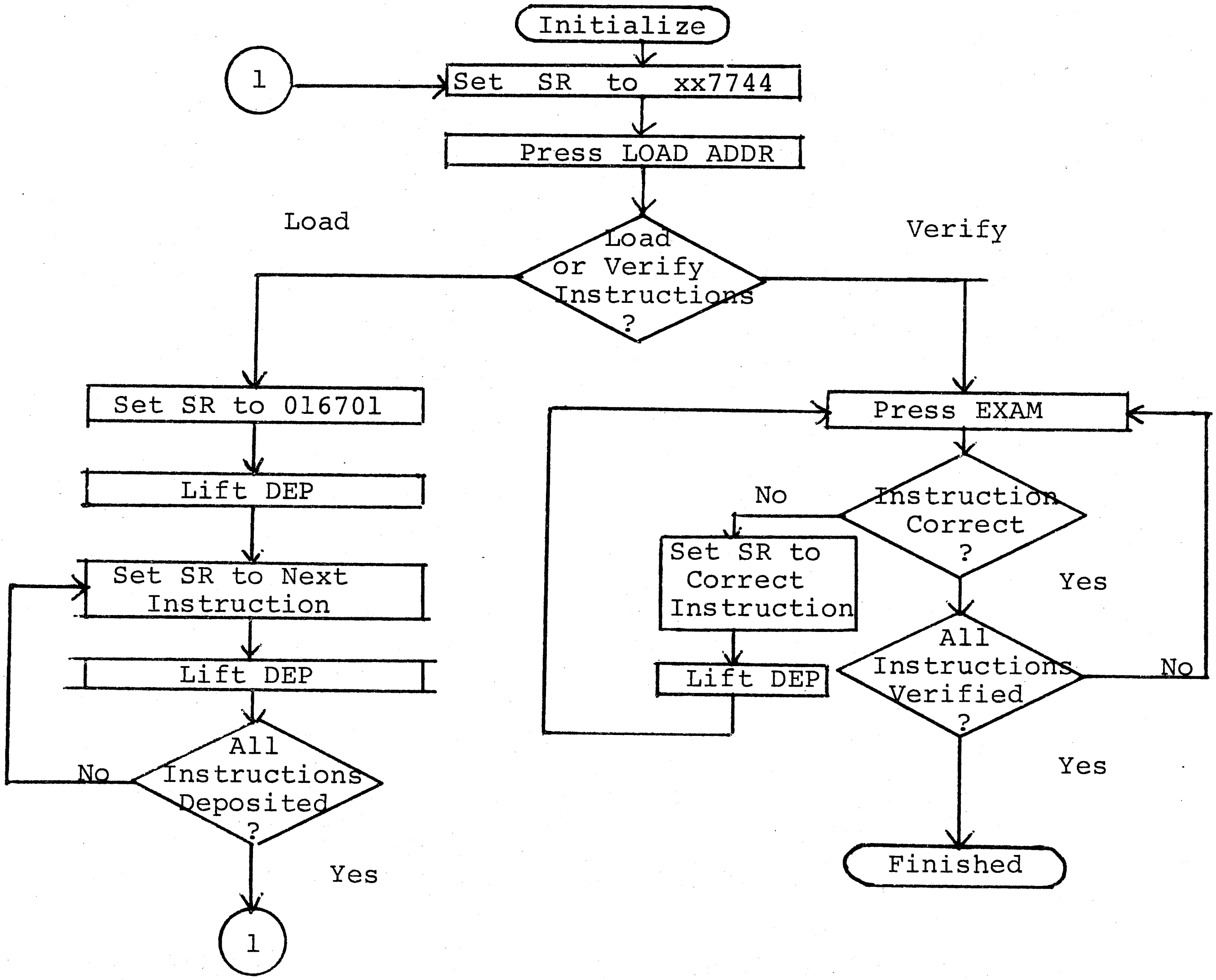


Figure 6-2. Loading and Verifying the Bootstrap Loader

6.1.2 Loading Bootstrap Tapes

Any paper tape punched in bootstrap format is referred to as a bootstrap tape(see Section 6.1.3) and is loaded into core using the Bootstrap Loader. Bootstrap tapes begin with about two feet of special bootstrap leader code (ASCII code 351, not blank leader tape as is required by the Absolute Loader).

With the Bootstrap Loader in core, the bootstrap tape will be loaded into core starting anywhere between location xx7400 and location xx7743, i.e., 162_8 words. The paper tape input device used is that which is specified in location xx7776 (see Section 6.1.1.).

Bootstrap tapes are loaded into core as explained below.

1. Set the ENABLE/HALT switch to HALT.
2. Place the bootstrap tape in the specified reader with the special bootstrap leader code over the reader sensors (under the reader station).
3. Set the SR to xx7744 (the starting address of the Bootstrap Loader) and press LOAD ADDRess.
4. Set the ENABLE/HALT switch to ENABLE.
5. Press START. The bootstrap tape will pass through the reader as data is being loaded into core.
6. The bootstrap tape stops after the last frame of data (see Figure 6-5) has been read into core. The program on the bootstrap is now in core.

The procedures above are illustrated in the flowchart of Figure 6-3.

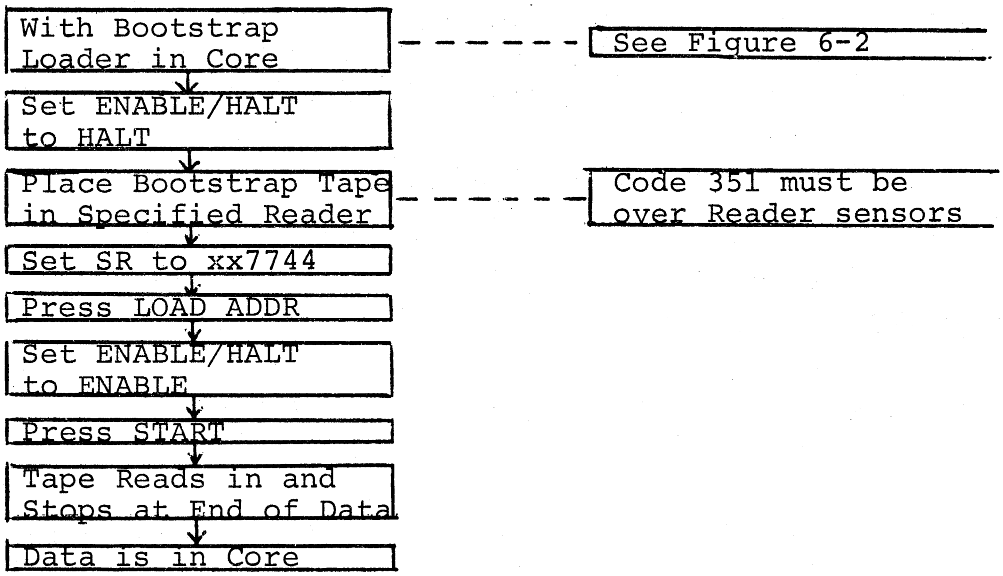

With Bootstrap Loader in Core
See Figure 6-2
Set ENABLE/HALT to HALT
Place Bootstrap Tape in Specified Reader
Code 351 must be over Reader sensors
Set SR to xx7744
Press LOAD ADDR
Set ENABLE/HALT to ENABLE
Press START
Tape Reads in and Stops at End of Data
Data is in Core

Figure 6-3. Loading Bootstrap Tapes Into Core

Should the bootstrap tape not read in immediately after depressing the START switch, it would be due to any one of the following:

1. Bootstrap Loader not correctly loaded.
2. Using the wrong input device.
3. Code 351 not directly over the reader sensors.
4. Bootstrap tape not properly positioned in reader.

6.1.3 Bootstrap Loader Operation

The Bootstrap Loader source program is shown below. The starting address in the example denotes that the Loader is to be loaded into memory bank zero (a 4K system).

```
         000001             R1=%1      ;USED FOR THE DEVICE ADDRESS
         000002             R2=%2      ;USED FOR THE LOAD ADDRESS DISPLACEMENT
         017400             LOAD=17400          ;DATA MAY BE LOADED NO LOWER
                                                ;THAN THIS
         017744             .=17744    ;START ADDRESS OF THE BOOTSTRAP LOADER
017744   016701   START:    MOV DEVICE,R1       ;PICK UP DEVICE ADDRESS,
         000026                                 ;PLACE IN R1
017750   012702   LOOP:     MOV #.-LOAD+2,R2    ;PICK UP ADDRESS
         000352                                 ;DISPLACEMENT
017754   005211   ENABLE:   INC @R1             ;ENABLE THE PAPER TAPE
017756   105711   WAIT:     TSTB @R1            ;READER
                                                ;WAIT UNTIL FRAME
017760   100376             BPL WAIT            ;IS AVAILABLE
017762   116162             MOVB 2(R1),LOAD(R2)        ;STORE FRAME READ
         000002                        ;FROM TAPE IN MEMORY
         017400
017770   005267             INC LOOP+2          ;INCREMENT LOAD ADDRESS
         177756                        ;DISPLACEMENT
017774   000765   BRNCH:    BR LOOP             ;GO BACK AND READ MORE DATA
017776   000000   DEVICE:   0          ;ADDRESS OF INPUT DEVICE
```

Figure 6-4. The Bootstrap Loader Program

The program above is a brief example of the PAL-11A Assembly Language which is explained in Chapter 3.

Bootstrap tapes are coded in the following format.

```
351
 .      Special bootstrap leader code (at least two feet
 .      in length)
351
xxx     Load offset (see text below)
AAA
```

BBB	
CCC	Program to be loaded (up to 162_8 words or 344_8 frames)
.	
.	
.	
ZZZ	
301	
035	
026	
000	
302	Boot overlay code, as shown.
025	
373	
yyy	Jump offset (see text below)

Figure 6-5. Bootstrap Tape Format

The Bootstrap Loader starts by loading the device status register address into R1 and 352_8 into R2. The next instruction indicates a read operation in the device and the next two instructions form a loop to wait for the read operation to be completed. When data is encountered it is transferred to a location determined by the sum of the index word (xx7400) and the contents of R2.

Because R2 is initially 352_8, the first word is moved to location xx7752, and it becomes the immediate data to set R2 in the next execution of the loop. This immediate data is then incremented by one and the program branches to the beginning of the loop.

The leader code, plus the increment, is equal in value to the data placed in R2 during the initialization; therefore, leader code has no effect on the loader program. Each time leader code is read the processor executes the same loop and the program remains unmodified. The first code other than leader code, however, replaces the data to be loaded into R2 with some other value which acts as a pointer to the program starting location (loading address). Subsequent bytes are read not into the location of the immediate data but into consecutive core locations. The program will thus be read in byte by byte. The INC instruction which operates on the data for R2 puts data bytes in sequential locations, and requires that the value of the leader code and the offset be one less than the value desired in R2.

The boot overlay code will overlay the first two instructions of the Loader, because the last data byte is placed in the core location immediately preceding the Loader. The first instruction is unchanged by the overlay, but the second instruction is changed to place the next byte read, jump offset, into the lower byte of the branch instruction. By changing the offset in this branch instruction, the Loader can branch to the start of the loaded program or to any point within the program.

The Bootstrap Loader is self-modifying, and the program loaded by the Loader restores the Loader to its original condition by restoring the contents of locations xx7752 and xx7774 to 000352 and 000765 respectively.

6.2 THE ABSOLUTE LOADER

The Absolute Loader is a system program which, when in core, enables you to load into any core memory bank data punched on paper tape in absolute binary format. It is used primarily to load the paper tape system software (excluding certain subprograms) and your object programs assembled with PAL-11A. The major features of the Absolute Loader include:

1. Testing of the checksum on the input tape to assure complete, accurate loads.
2. Starting the loaded program upon completion of loading without additional user action, as specified by the .END in the program just loaded.
3. Specifying the load bias of position independent programs at load-time rather than at assembly time, by using the desired Loader switch register option.

6.2.1 Loading the Loader Into Core

The Absolute Loader is supplied on punched paper tape in bootstrap format. Therefore, the Bootstrap Loader is used to load the Absolute Loader into core. It occupies locations xx7474 through xx7743, and its starting address is xx7500. The Absolute Loader program is 72_{10} words long, and is loaded adjacent to the Bootstrap Loader as explained in Section 6.1.2.

6.2.2 Loading Absolute Tapes

Any paper tape punched in absolute binary format is referred to as an absolute tape, and is loaded into core using the Absolute Loader. When using the Absolute Loader, there are two types of load available: normal and relocated.

A normal load occurs when the data is loaded and placed in core according to the load addresses on the object tape. It is specified by setting bit 0 of the Switch Register to zero immediately before starting the load.

There are two types of relocated loads.

a. Loading to continue from where the loader left off after the previous load -

This is used, for example, when the object program being loaded is contained on more than one tape. It is specified by setting the Switch Register to 000001 immediately before starting the load.

b. Loading into a specific area of core -

This is normally used when loading position independent programs. A position independent program is one which may be loaded and run anywhere in available core. The program is written using the position independent instruction format (see Chapter 9). This type of load is specified by setting the Switch Register to the load bias and adding 1 to it (i.e., setting bit 0 to 1).

Optional switch register settings for the three types of loads are listed below.

Type of Load	Switch Register Bits 1-14	 Bit 0
Normal	(ignored)	0
Relocated - continue loading where left off	0	1
Relocated - load in specified area of core	nnnnn (specified address)	1

The absolute tape may be loaded using either of the paper tape readers. The desired reader is specified in the last word of available core memory (xx7776), the input device status word, as explained in Section 6.1. The input device status word may be changed at any time prior to loading the absolute tape.

With the Absolute Loader in core as explained in Section 6.1.2, absolute tapes are loaded as explained below.

1. Set the ENABLE/HALT switch to HALT.

   To use an input device different from that used when loading the Absolute Loader, change the address of the device status word (in location xx7776) to reflect the desired device, i.e., 177560 for the Teletype reader or 177550 for the high-speed reader.

2. Set the SR to xx7500 and press LOAD ADDR.

3. Set the SR to reflect the desired type of load (Figure E-3 in Appendix E).

4. Place the absolute tape in the proper reader with blank leader tape directly over the reader sensors.

5. Set ENABLE/HALT to ENABLE.

6. Press START. The absolute tape will begin passing through the reader station as data is being loaded into core.

If the absolute tape does not begin passing through the reader station, the Absolute Loader is not in core correctly. Therefore, reload the Loader and start over at step 1 above. If it halts in the middle of the tape, a checksum error occurred in the last block of data read in.

Normally, the absolute tape will stop passing through the reader station when it encounters the transfer address as generated by the statement, .END, denoting the end of a program. If the system halts after loading, check that the low byte of the DATA register is zero. If so, the tape is correctly loaded. If not zero, a checksum error (explained later) has occurred in the block of data just loaded, indicating that some data was not correctly loaded. Thus, the tape should be reloaded starting at step 1 above.

When loading a continuous relocated load, subsequent blocks of data are loaded by placing the next tape in the appropriate reader and pressing the CONTinue switch.

The Absolute Loader may be restarted at any time by starting at step 1 above.

6.2.3 Absolute Loader Operation

The Loader uses the eight general registers (R0-R7) and does not preserve or restore their previous contents. Therefore, caution should be taken to restore or load these registers when necessary after using the Loader.

A block of data punched on paper tape in absolute binary format has the following format.

FRAME 1	001	start frame
2	000	null frame
3	xxx	byte count (low 8 bits)
4	xxx	byte count (high 8 bits)
5	yyy	load address (low 8 bits)
6	yyy	load address (high 8 bits)
	.	data is
	.	placed
	.	here
	zzz	last frame contains a block checksum

A program on paper tape may consist of one or more blocks of data. Each block having a byte count (frames 3 and 4) greater than six will cause subsequent data to be loaded into core (starting at the address specified in frames 5 and 6 under a normal load). The byte count is a positive integer containing the total number of bytes in the block, excluding the checksum. When the byte count of a block is equal to six the specified load address is checked to see whether the address is to an even or to an odd location. If even, the Loader will transfer control to the address specified. Thus the loaded program will be run upon completion of loading. If odd, the loader halts.

The transfer address (TRA) may be explicitly specified in the source program by placing the desired address in the operand field following the .END statement. For example,

```
.END ALPHA
```

specifies the symbolic location ALPHA as the TRA, and

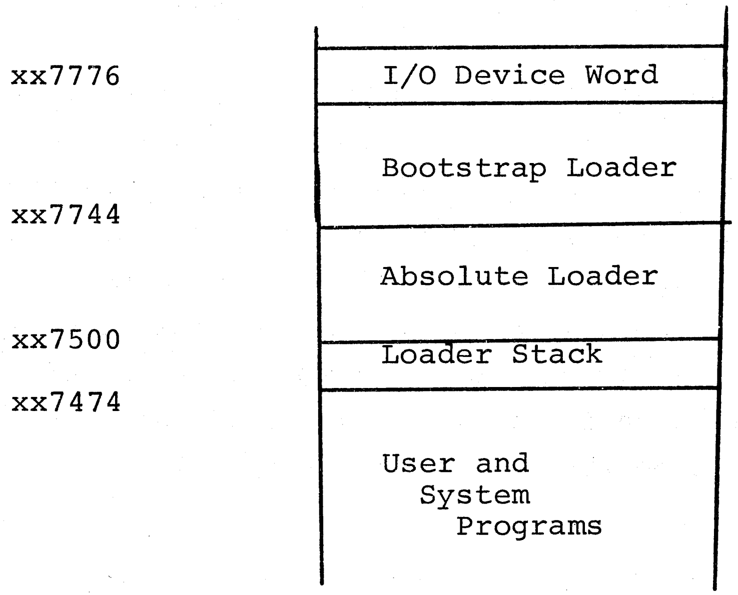
```
.END
```

causes the Loader to halt. With

```
.END nnnnnn
```

the Loader will also halt if the address (nnnnnn) is odd.

The checksum is displayed in the low byte of the DATA register of the computer console. Upon completion of a load, the low byte of the DATA register should be all zeros (unlit). Otherwise, a checksum error has occurred, indicating that the load was not correct. The checksum is the low-order byte of the negation of the sum of all the previous bytes in the block. When all bytes of a block, including the checksum, are added together the low-order byte of the result should be zero. If not, some data was lost during the load or erroneous data was picked up; the load was incorrect. When a checksum error is displayed, the entire program should be reloaded, as explained in the previous section. The loaders occupy core memory as illustrated below.



6.3 CORE MEMORY DUMPS

A core memory dump program is a system program which enables you to dump (print or punch) the contents of all or any specified portion of core memory onto the Teletype printer and/or punch, line printer or high-speed punch. There are two dump programs available in the Paper Tape Software System:

1. DUMPTT, which dumps the octal representation of the contents of specified portions of core onto the teleprinter, low-speed punch, high-speed punch, or line printer.

2. DUMPAB, which dumps the absolute binary code of the contents of specified portions of core onto the low-speed punch or high-speed punch.

Both dump programs are supplied on punched paper tape in bootstrap and absolute binary formats. The bootstrap tapes are loaded over the Absolute

Loader as explained in Section 6.1.3, and are used when it would be undesirable to alter the contents of user storage (below the Absolute Loader). The absolute binary tapes are position independent and may be loaded and run anywhere in core as explained in Section 6.2.2.

DUMPTT and DUMPAB are very similar in function, and differ primarily in the type of output they produce.

6.3.1 Operating Procedures

Neither dump program will punch leader or trailer tape, but DUMPAB will always punch ten blank frames of tape at the start of each block of data dumped.

Operating procedures for both dump programs follow:

1. Select the dump program desired and place it in the reader specified by location xx7776 (see Section 6.1).

2. If a bootstrap tape is selected, load it using the Bootstrap Loader, Section 6.1.2. When the computer halts go to Step 4.

3. If an absolute binary tape is selected, load it using the Absolute Loader (Section 6.2.2), relocating as desired.

   Place the proper start address in the Switch Register, press LOAD ADDRess and START. (The start addresses are shown in Section 6.3.3).

4. When the computer halts, enter the address of the desired output device status register in the Switch Register and press CONTinue (low-speed punch and teleprinter=177564; high-speed punch = 177554; line printer = 177514).

5. When the computer halts, enter in the Switch Register the address of the first byte to be dumped and press CONTinue. This address must be even when using DUMPTT.

6. When the computer halts again enter in the Switch Register the address of the last byte to be dumped and press CONTinue. When using the low-speed punch, set the punch to ON before pressing CONTinue.

7. Dumping will now proceed on the selected output device.

8. When dumping is complete, the computer will halt.

If further dumping is desired, proceed to step 5. It is not necessary to respecify the output device address except when changing to another output device. In such a case, proceed to the second paragraph of step 3 to restart.

If DUMPAB is being used, a transfer block must be generated as described below. If a tape read by the Absolute Loader does not have a transfer block, the loader will wait in an input loop. In such a case, the program may be manually initiated. However, this practice is not recommended, as there is no guarantee that load errors will not occur when the end of the tape is read.

The transfer block is generated by performing step 5 with the transfer address in the Switch Register, and step 6 with the transfer address minus 1 in the Switch Register. If the tape is not to be self-starting, an odd-numbered address must be specified in step 5 (000001, for example).

The dump programs use all eight general registers and do not restore their original contents. Therefore, after a dump the general registers should be loaded as necessary prior to their use by subsequent programs.

6.3.2 Output Formats

The output from DUMPTT is in octal in the following format:

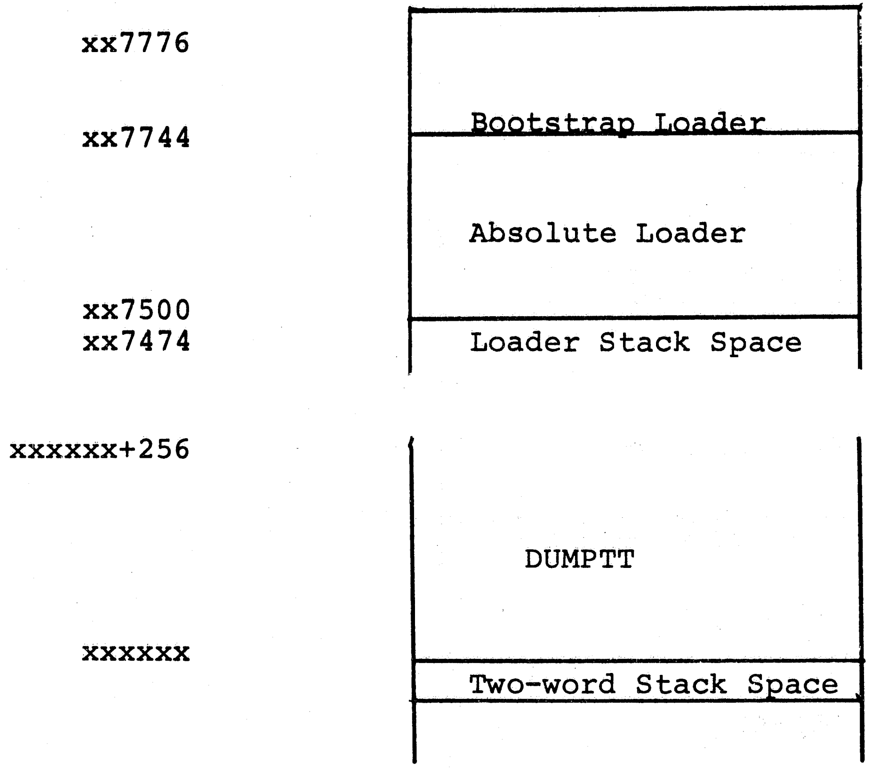
```
    xxxxxx>yyyyyy yyyyyy yyyyyy yyyyyy yyyyyy yyyyyy yyyyyy yyyyyy
```

where xxxxxx is the address of the first location printed or punched, and yyyyyy are words of data, the first of which starts at location xxxxxx. This is the format for every line of output. There will be no more than eight words of data per line, but there will be as many lines as are needed to complete the dump.

The output from DUMPAB is in absolute binary, as explained in Section 6.2.3.

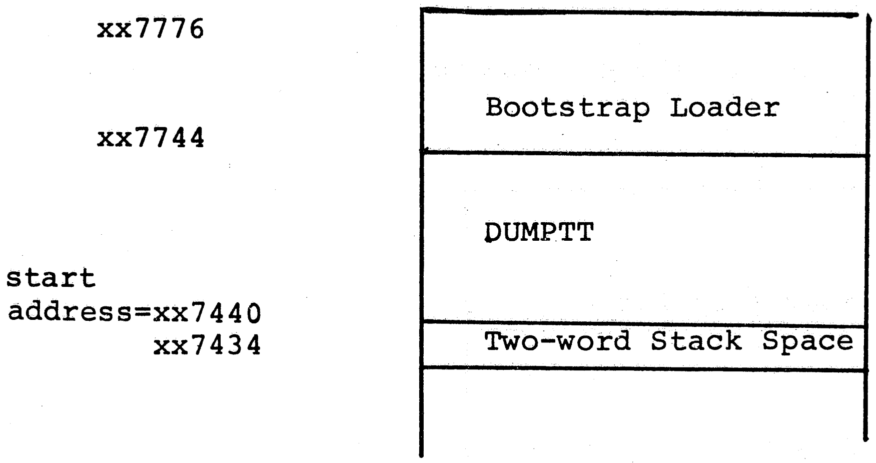
6.3.3 Storage Maps

The DUMPTT program is 87 words long. When used in absolute format the storage map is:

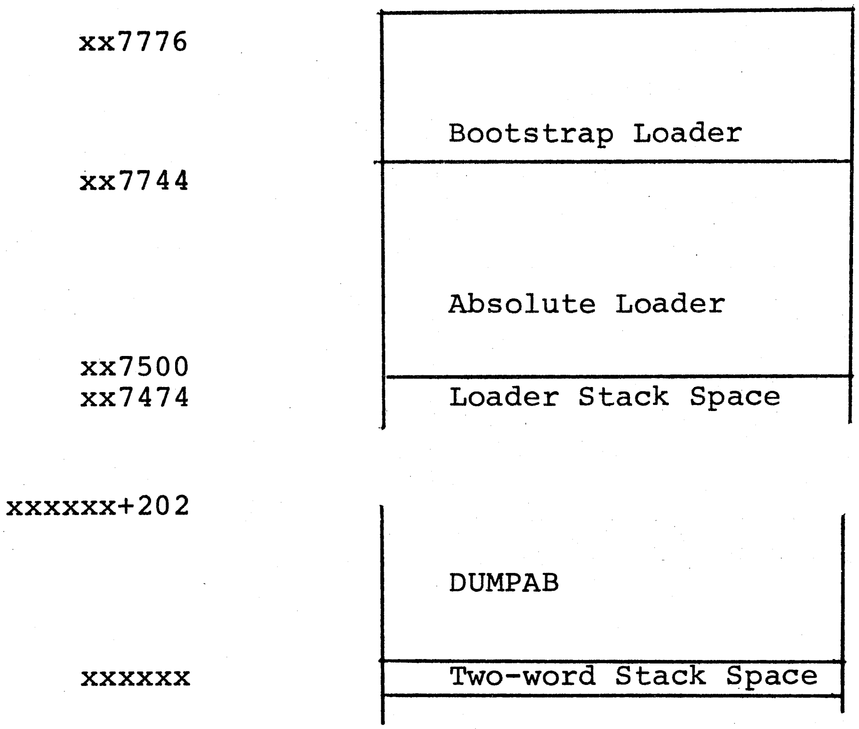


xxxxxx = desired load address = start address

When used in bootstrap format the storage map is:

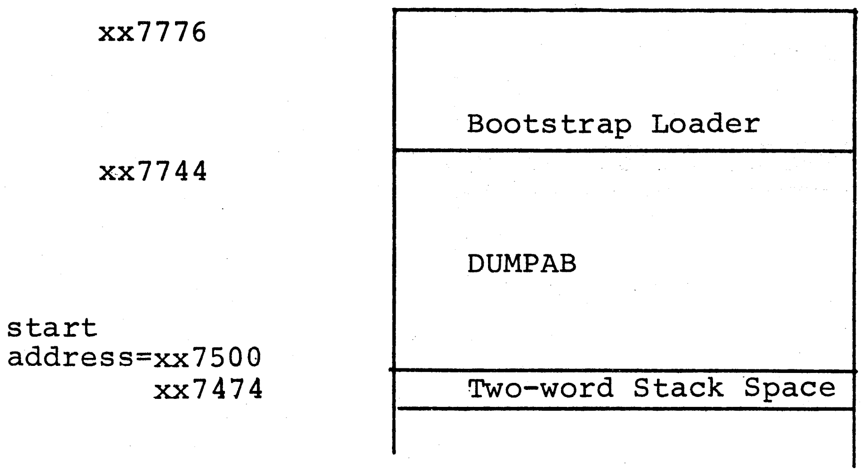


The DUMPAB program is 65_{10} words long. When used in absolute format the storage map is:



xxxxxx = desired load address = start address

When used in bootstrap format the storage map is:



CHAPTER 7

INPUT/OUTPUT PROGRAMMING

CHAPTER 7
INPUT/OUTPUT PROGRAMMING

7.1 INTRODUCTION

IOX, the PDP-11 Input/Output eXecutive, frees you from the details of dealing directly with the I/O devices. It also provides certain programming formats so that programs written for the paper tape software system may be used in a monitor environment later with only minor coding changes.

IOX provides asynchronous I/O service for the following non-file-oriented external devices:

1. Teletype keyboard, printer, and tape reader and punch
2. High-speed paper tape reader and punch

For Line Printer handling, in addition to <u>all</u> IOX facilities, IOXLPT is available.

Simple I/O requests can be made, specifying devices and data forms for interrupt-controlled data transfers, which can be occurring concurrently with the execution of a running user program. Multiple I/O devices may be running single or double buffered I/O processing simultaneously.

Real-time capability is provided by allowing user programs to be executed at device priority levels upon completion of a device action or data transfer.

Communication with IOX is accomplished by IOT (Input/Output Trap) instructions in the user's program. Each IOT is followed by two or three words consisting of one of the IOX commands and its operands. The IOX commands can be divided into two categories:

1. those concerned with establishing necessary conditions for performing input and output (mainly initializations), and
2. those concerned directly with the transfer of data.

When transfer of data is occurring, IOX is operating at the priority level of the device. The calling program runs at <u>its</u> priority level, either concurrent with the data transfer, or sequentially.

Programming format for commands is:

```
IOT
.WORD (an address)
.BYTE (a command code),(a slot number)
```

Before using the data transfer commands, two preparatory tasks must be performed:

1. Since device specifications are made by referencing "slots" in IOX's Device Assignment Table (DAT) rather than devices themselves, the slots specified in your code must have devices assigned to them.

2. The buffer, whose address is specified in your code, must be set up with information about the data.

In those non-data-transfer commands where an address or slot number does not apply, a 0 must be used. Addresses or codes indicated can, of course, be specified symbolically.

NOTES:

1. At load time IOX loads the following interrupt and trap vectors: Teletype keyboard, Teletype printer, high-speed reader, high-speed punch, illegal memory reference, and IOT. An error HALT is placed in location 40.

2. The number of words required by IOX is 634_{10}; for IOXLPT, about 725_{10} words.

3. IOX is not position-independent, but may be reassembled anywhere in core. As supplied, its load address is 15100; IOXLPT's load address is 34600.

The following program segment illustrates a simple input-process-output sequence. It includes:

a. The setting up of a single buffer

b. All necessary initializations

c. A formatted ASCII read into the buffer

d. A wait for completion of the read

e. Processing of data just read

f. A write command from the buffer.

```
          RESET=2                     ;ASSIGN IOX COMMAND CODES
          READ=11
          WAITR=4
          WRITE=12

          IOT                         ;IOX RESET TO DO NECESSARY
          .WORD Ø                     ;INITIALIZATIONS INCLUDING
          .BYTE RESET,Ø               ;INITING SLOT 0 FOR KBD, AND 1 FOR TTY

          IOT                         ;TRAP TO IOX
          .WORD BUFFER                ;SPECIFY BUFFER
          .BYTE READ,Ø                ;READ FROM KBD (SLOT 0) TILL
                                      ;LINE FEED OR FORM FEED

   WAIT:  IOT                         ;TRAP TO IOX
          .WORD WAIT                  ;BUSY RETURN ADDRESS WHILE WAITING
                                      ;FOR KBD TO FINISH
          .BYTE WAITR,Ø               ;WAIT FOR KBD (SLOT 0) TO FINISH
          (process BUFFER)

          IOT                         ;TRAP TO IOX
          .WORD BUFFER                ;SPECIFY BUFFER
          .BYTE WRITE,1               ;WRITE TO TELEPRINTER (SLOT 1)

 BUFFER:  1ØØ                         ;BUFFER SIZE IN BYTES
          Ø                           ;CODE FOR FORMATTED ASCII MODE
          Ø                           ;IOX WILL SET HERE THE NUMBER OF BYTES READ
          .=.+1ØØ                     ;STORAGE RESERVED FOR 100 BYTES
```

In more complex programming it is likely that more than one buffer will be set up for the transfer of data, so that data processing can occur concurrently rather than sequentially, as here. Note too, that there are five IOX commands not used in this example that will help meet the requirements of I/O problems not as straightforward as this.

7.1.1 Loading IOX

IOX (IOXLPT) is supplied on source and binary tapes. Source tapes are assembled as described in Section 7.1.2. The binary tape of IOX (IOXLPT) is loaded with the Absolute Loader and must be in core before the user program to which it applies.

When IOX is loading, the paper tape passes through the reader and there is no response at the terminal to indicate that loading is completed.

IOXLPT is used instead of IOX if a line printer is part of the system.

7.1.2 Assembling IOX

If there is more than 4K of core available and it is desired to load IOX (or IOXLPT) in other than the normal location, IOX must be reassembled.

The code

```
        .=15100
        .EOT
```

appears at the beginning of the first IOX tape (PA1) and contains the starting address. Create a new tape containing the new starting address desired; be sure to allow enough room for 634_{10} words for IOX, 725_{10} for IOXLPT. For example,

```
        .=25100
        .EOT
```

Use PAL-11A as described in Chapter 3 to assemble IOX and substitute the new section of tape for the first part of the old tape (PA1). After the new section is read, insert the IOX tape in the reader so the read head is past the old starting address and .EOT and type the RETURN key to read in the rest of the tape.

Now read in the second tape (PA2). An EOF? message is output at the end of the second tape. Type the RETURN key and the END? message is printed. Put the tapes through for the second pass of the assembler. The resulting binary tape can be used as described in paragraph 7.1.1.

IOX (IOXLPT) can also be assembled with a user program if desired. The .=15100 and .EOT lines must be deleted before IOX is assembled with a user program.

IOX can be assembled into the program wherever desired but if it is the first tape read by the assembler, remove it from the reader before typing the RETURN key (after the EOF? message of the second tape. (IOX and IOXLPT have a .END code which would cause the assembly pass to end when read). Assembling a user program and IOX together eliminates the need to read in IOX each time the program is run.

7.2 THE DEVICE ASSIGNMENT TABLE

Use of the Device Assignment Table (DAT) serves to make your program device-independent by allowing you to reference a slot to which a device has been assigned, rather than a specific device itself. Thus, changing the input or output device becomes a simple matter of reassigning a different device to the slot indicated in your program.

The DAT is set up by means of the Reset and/or Init commands. The IOX codes for devices (listed in the description of the Init command below) are assigned to the slots.

7.2.1 Reset

```
IOT
.WORD 0
.BYTE 2,0
```

This command must be the first IOX command issued by a user program. It clears the DAT, initializes IOX, resets all devices to their state at power-up, enables keyboard interrupts, and initializes (Inits) DAT slots 0 and 1 for the keyboard and teleprinter respectively.

7.2.2 Init

```
          IOT
          .WORD (address of device code)
          .BYTE 1,(slot number)
```

The device whose code (stored as a byte) is found at the specified address is associated with the specified slot (numbered in the range 0-7). The device interrupt is turned off when necessary. (The keyboard interrupt always remains enabled.) There is no restriction on the number of slots that can be Inited to the same device.

DEVICE		DEVICE CODE
Teletype Keyboard	(KBD)	1
Teletype printer	(TTY)	2
Low-Speed Reader	(LSR)	3
Low-Speed Punch	(LSP)	4
High-Speed Reader	(HSR)	5
High-Speed Punch	(HSP)	6
Line Printer (IOXLPT only)	(LPT)	10

Note that a device code is used only in the Init command. All other commands which reference a device, do so by means of a slot. Example:

```
          INIT=1
          IOT                   ;TRAP TO IOX
          .WORD HSRCOD          ;INIT SLOT 3
          .BYTE INIT,3          ;FOR HSR
           .
           .
           .
HSRCOD:   .BYTE 5               ;HSR CODE
```

7.3 BUFFER ARRANGEMENT IN DATA TRANSFER COMMANDS

Use of data-transfer commands (Read, Write, Real-time Read, Real-time Write) requires the setting up of at least one buffer. This buffer is used not only to store data for processing, but to hold information regarding the quantity, form, and status of the data. The non-data portion of the buffer is called the buffer header, and precedes the data portion. In data transfer commands, it is the address of the first word of the buffer header that is specified in the word following the IOT of the command.

NOTE

> IOX uses the buffer header while transferring data. The user's program must not change or reference it.

The buffer format is:

	Location	Contents
BUFFER HEADER	Buffer	Maximum number of data bytes (unsigned integer)
	Buffer+2	Mode of data (byte)
	Buffer+3	Status of data (byte)
	Buffer+4	Number of data bytes involved in transfer (unsigned integer)
	Buffer+6	Actual data begins here

<table>
<tr><td colspan="2">BUFFER SIZE (in Bytes)</td></tr>
<tr><td>STATUS</td><td>MODE</td></tr>
<tr><td colspan="2">BYTE COUNT</td></tr>
<tr><td colspan="2">DATA
.
.
.</td></tr>
</table>

7.3.1 Buffer Size

The first word of the buffer contains the size (in bytes) of the data portion of the buffer as specified by the user. IOX will not store more than this many data bytes on input. Buffer size has no meaning on output.

7.3.2 Mode Byte

The low-order byte of the second word holds information concerning the mode of transfer. A choice of four modes exists:

		Coded as	
a.	Formatted ASCII	0	(or 200 to suppress echo)
b.	Formatted Binary	1	
c.	Unformatted ASCII	2	(or 202 to suppress echo)
d.	Unformatted Binary	3	

The term echo applies only to the KBD. Data transfers from other devices never involve an echo.

MODE BYTE

Bits	7	6	5	4	3	2	1	0	Bits
1=	No echo						Unformatted	Binary	=1
0=	Echo						Formatted	ASCII	=0

7.3.3 Status Byte

The high-order byte of the second word of the buffer header contains information set by IOX on the status of the data transfer:

Bits 0-4	contain the non-fatal error codes (coded octally)
Bit 5	1 = End-Of-File has occurred (attempt at reading data after an End-Of-Medium)
Bit 6	1 = End-of-Medium has occurred (see Section 7.3.3.3)
Bit 7	1 = Done (Data Transfer complete)

STATUS BYTE

7	6	5	4	3	2	1	0
1 = DONE	1 = EOM	1 = EOF	SEE CODES				
			NON-FATAL ERRORS				

7.3.3.1 Non-Fatal Error Codes

2_8 = checksum error

3_8 = truncation of a long line

4_8 = an improper mode

a. A checksum error can occur only on a Formatted Binary read (see Section 7.4.3).

b. Truncation of a long line can occur on either a Formatted Binary or Formatted ASCII read (Section 7.4.1). This error occurs when the binary block or ASCII line is bigger than the buffer size specified in the buffer header. In both cases, IOX continues reading characters into the last byte in the buffer until the end of the binary block or ASCII line is encountered.

c. An improper mode can occur only on a Formatted Binary read. Such occurrence means that the first non-null character encountered was not the proper starting character for a Formatted Binary block (see Section 7.4.3)

7.3.3.2 Done Bit

When the data transfer to or from the buffer is complete, the Done Bit is set by IOX.

7.3.3.3 End-Of-Medium Bit

The following conditions cause the EOM bit to be set in the buffer Status byte associated with a data transfer command. An EOM occurrence also sets the Done Bit.

HSR	HSP	LSR	LPT
No tape	No tape	Timeout detected	No paper
Off line	No power		No power
No power			Printer drum gate open
			Overtemperature condition

An End-Of-Medium condition on an output device is cleared by a manual operation such as putting a tape in the high-speed punch. IOX does not retain any record of an EOM on an output device. However, an EOM on an input device is recorded by IOX so that succeeding attempts to read from that device will cause an End-Of-File (see Section 7.3.3.4). To reenable input the device must be manually readied and a Seek command (Section 7.6) executed on the proper slot. The Init and Reset commands will also clear the EOM condition for the device.

See Section 7.5.3 for information on detection of conditions causing LSR timeouts.

When an End-Of-Medium has occurred on a Read, there may be data in the buffer. If an EOM has occurred on a Write, there is no way of knowing how much of the buffer was written.

7.3.3.4 End-Of-File Bit

An EOF condition appears in the Status byte if an attempt to read is made after an EOM has occurred. EOF cannot occur on output. When an EOF has occurred, no data is available in the buffer.

7.3.4 Byte Count

The third word contains the Byte Count:

Input: In unformatted data modes, IOX reads as many data bytes as the user has specified. In formatted modes, IOX inserts here the number of data bytes available in the buffer. In all modes, if an EOM occurs, IOX will set the Byte Count equal to the number of bytes actually read. If an EOF occurs, Byte Count will be set to 0.

Output: Byte Count determines the number of bytes output, for all modes. An HSP end-of-tape or LPT out-of-paper condition will also terminate output, and EOM will be set in the Status byte. IOX does not modify the Byte Count on output.

7.4 MODES

7.4.1 Formatted ASCII

A Formatted ASCII read transfers 7-bit characters (bit 8 will be zero) until a line feed or form feed is read. IOX sets the Byte Count word in the buffer header to indicate the number of characters in the buffer. If the line is too long, characters are read and overlaid into the last byte of the buffer until an end-of-line (a line feed or form feed) or EOM is detected. Thus, if there is no error, the buffer will always contain a line feed or form feed.

A Formatted ASCII write transfers the number of 7-bit characters specified by the buffer Byte Count. Bit 8 will always be output as zero.

Device-Dependent Functions

Keyboard

Seven-bit characters read from the keyboard are entered in the buffer and are echoed on the teleprinter except as follows:

Null - Ignored. This character is not echoed or transferred to the buffer.

Tab (CTRL/TAB keys) - Echoes as spaces up to the next tab stop. "Stops" are located at every 8th carriage position.

RUBOUT - Deletes the previous character on the current line and echoes as a backslash (\). If there are no characters to delete, RUBOUT is ignored.

CTRL/U - Deletes the current line and echoes as ↑U.

Carriage Return (RETURN key) - Echoes as a carriage return followed by a line feed. Both characters enter the buffer.

CTRL/P - Echoes as ↑P and causes a jump to the restart address, if non-zero (see 7.6.2).

The echo may be suppressed by setting bit 7 of the buffer header Mode byte.

If the buffer overflows, only the characters which fit into the buffer are echoed. Of course, characters which are deleted by RUBOUT or CTRL/U do not read into the buffer even though they are echoed. If a carriage return causes an overflow, or is typed after an overflow has occurred, a carriage return and line feed will be echoed but only the line feed will enter the buffer.

In the following Formatted ASCII examples:

a. assume there is room for five characters

b. ↲ indicates:
in left column, the RETURN key
in center column, the execution of a carriage return
in right column, the ASCII code for carriage return

c. ↓ indicates:
in center column, the execution of a line feed
in right column, the ASCII code for line feed

d. RUB OUT indicates the RUBOUT key

e. CTRL U indicates the CTRL and U keys.

Typed	Echoed	Entered Buffer
ABC ↵	ABC↵ ↓	ABC↵ ↓
ABCD↵	ABCD ↵↓	ABCD↓
ABCDEF↵	ABCD ↵↓	ABCD↓
ABCDEF RUB OUT ↵	ABCD\ ↵↓	ABC ↵↓
CTRL U RUB OUT ↵	↑U↵↓	↵ ↓
ABCDEF RUB OUT RUB OUT ↵	ABCD \\ ↵↓	AB ↵↓
ABCDEF RUB OUT RUB OUT RUB OUT X ↵	ABCD \\\X↵↓	AX ↵↓

Low-Speed Reader and High-Speed Reader

All characters are transferred to the buffer except that nulls and rubouts are ignored.

Teleprinter

Characters are printed from the buffer as they appear except that nulls are ignored and tabs are output as spaces up to the next tab stop.

Low-Speed Punch and High-Speed Punch

Characters are punched from the buffer as they appear except that nulls are ignored and tabs are followed by a rubout.

Line Printer (IOXLPT only)

Characters are printed from the buffer as they appear except as follows:

Nulls	-	Ignored
Tab	-	Output as spaces up to the next tab stop.
Carriage Return	-	Ignored. It is assumed that a line feed or form feed follows. These characters cause the line printer "carriage" to advance.

All characters beyond the 80th are ignored except a line feed or form feed.

7.4.2 Unformatted ASCII

Unformatted ASCII transfers the number of 7-bit characters specified by the header Byte Count.

Device-Dependent Functions

Keyboard

Characters are read and echoed except as follows:

Tab - Echoes as spaces up to the next tab stop.

CTRL/P - Echoes as ↑P and causes a jump to the restart address, if non-zero (see 7.6.2).

7.4.3 Formatted Binary

Formatted Binary is used to transfer checksummed binary data (8-bit characters) in blocks. A Formatted Binary block appears as follows:

Byte (Octal)		Meaning
ØØ1	-	Start of block
ØØØ	-	Always null
XXX XXX	-	Block Byte Count (low-order followed by high-order). Count includes data and preceding four bytes.
DDD DDD ⋮ DDD DDD	-	Data bytes
CCC	-	Checksum. Negation of the sum of all preceding bytes in the block.

IOX creates the block on output, from the buffer and buffer header. The Byte Count word in the buffer header specifies the number of data bytes following, which are to be output. Note that the Byte Count output is four larger than the header Byte Count. As the block is output, IOX calculates the checksum which is output following the last data byte.

On Formatted Binary reads, IOX ignores null characters until the first non-null character is read. If this character is a 001, a Formatted Binary block is assumed to follow and is read from the device under control of the Byte Count value. If the first non-null character is not 001, the read is immediately terminated and error code 4 is set in the Status byte. As the block is read a checksum is calculated and compared to the checksum following the block. If the checksum is incorrect, error code 2 is set in the Status byte of the buffer header. If the binary block is too large (Byte Count less 4, larger than the Buffer Size specified in the header), the last byte of the buffer is overlaid until the last data byte has been read; error code 3 is set in the Status byte.

Device-Dependent Functions

None. Eight-bit data characters are transferred to and from the device and buffer exactly as they appear.

7.4.4 Unformatted Binary

This mode transfers 8-bit characters with no formatting or character conversions of any kind. For both input and output, the buffer header Byte Count determines the number of characters transferred.

Device-Dependent Functions

None.

7.5 DATA TRANSFERS

7.5.1 Read

```
IOT
.WORD (address of first word of the buffer header)
.BYTE 11,(slot number)
```

This command causes IOX to read from the device associated with the specified slot according to the information found in the buffer header. IOX initiates the transfer of data, clears the Status byte, and returns control to the calling program. If the device on the selected slot is busy, or a conflicting device (see Section 7.5.3) is busy, IOX retains control until the data transfer can be initiated. Upon completion of the Read, the appropriate bits in the Status byte are set by IOX and the Byte Count word indicates the number of bytes in the data buffer. Note that use of the KBD while an LSR Read is in progress will intersperse KBD characters into the buffer unpredictably.

7.5.2 Write

```
IOT
.WORD (address of first word of the buffer header)
.BYTE 12,(slot number)
```

IOX writes on the device associated with the specified slot according to the information found in the buffer header. Transfer of data occurs in the amount specified by Byte Count (Buffer+4). IOX returns control to the calling program as soon as the transfer has been initiated. If the device on the selected slot is busy, or a conflicting device is busy, IOX retains control until the transfer can be initiated. Upon completion of the Write, IOX will set the Status byte to the latest conditions. If a Write causes an EOM condition, the user has no way of determining how much of his buffer has been written (the Byte Count remains the same).

7.5.3 Device Conflicts in Data Transfer Commands

Because there is a physical association between the devices on the ASR Teletype, certain devices cannot be in use at the same time. When a data transfer command is given, IOX simultaneously checks for two conditions before executing the command:

a. Is the device requested already in use? and,

b. Is there some other device in use that would result in an operational conflict?

IOX resolves both conflict situations by waiting until the first device is no longer busy, before allowing the requested device to start functioning. (This is an automatic Waitr command. See next section.) For example, if the LSR is in use, and either a KBD request or a second request for the LSR itself is made, IOX will wait until the current LSR read has been completed before returning control to the calling program. In the particular case of the LSR, IOX also performs a timeout check while waiting for it to become available.

When a Read command has been issued for the LSR, IOX waits about 100 milliseconds for each character to be read. If no character is detected by this time (presumably because the LSR is turned off, or out of tape), a timeout is declared and IOX sets EOM in the appropriate buffer Status byte.

The following is a table listing the devices. Corresponding to each device on the left is a list of devices (or the echo operation) which would conflict with it in operation.

Device	All Possible Conflicting Devices or Operations
KBD	Echo, KBD, TTY, LSR, LSP
TTY	Echo, KBD, TTY, LSP
LSR	KBD, LSR
LSP	Echo, KBD, TTY, LSP
HSR	HSR
HSP	HSP
LPT (IOXLPT only)	LPT

7.5.4 Waitr (Wait, Return)

```
IOT
.WORD (busy return address)
.BYTE 4,(slot number)
```

Waitr, like device conflict resolution, causes IOX to test the status of the device associated with the specified slot. If the device (or any possible conflicting device) is not transferring data, control is passed to the instruction following the Waitr. Otherwise, IOX transfers program control to the busy return address. If it is desired to continuously test for completion of data transfer on the device, the busy return address of the immediately preceding IOT instruction can be specified, effecting a Wait loop.

If a slot is inited to any device other than the LSR, control is returned to the calling program about 150 microseconds after execution of a Waitr. For the LSR, however, the time is about 100 milliseconds.

Note that a not-busy return from Waitr normally means the device is available. However, in the case of a Write, this only means that the last character has been output to the device. The device is still in the process of printing or punching the character. Thus, care must be exercised when performing an IOX Reset, hardware RESET, or HALT after a Write-Waitr sequence, since these may prevent the last character from being physically output.

7.5.5 Waitr vs. Testing the Buffer Done Bit

Since IOX permits you to have device-independent code, it may not be known, from run to run, what devices will be assigned to the slots in your program. Waitr tests the status, not only of the device it specifies, but also of all possible conflicting devices.

This means that when Waitr indicates that the device is not busy, the data transfer on the device of interest may have been done for some time. Depending on the program and what devices are assigned to the slots for a given run, the Waitr could have been waiting an additional amount of time for a conflicting device to become free.

Where this possibility exists and buffer availability is what is of interest, testing the Done bit of the Status byte (set when buffer transfer is complete) would be preferable to Waitr; whereas Waitr would be preferable if device availability is what is of interest.

This distinction is made in order to write device-independent code. In the example below:

a. If the devices at slots 2 and 3 could be guaranteed always to be conflicting, neither Waitr nor testing the Done bit would be necessary, because IOX would automatically wait for the busy device to finish before allowing the other device to begin.

b. If these devices could be guaranteed never to be conflicting, it wouldn't matter which of these methods was used, because Waitr couldn't be waiting extra time for a conflicting device (of no interest) to become free.

```
Example:              PROGRAM A                PROGRAM B

                   IOT                      IOT
                   .WORD BUF2               .WORD BUF2
                   .BYTE READ, SLOT2        .BYTE READ, SLOT2

                   IOT                      IOT
                   .WORD BUF1               .WORD BUF1
                   .BYTE READ, SLOT2        .BYTE READ, SLOT2

                   IOT                      IOT
                   .WORD BUF2               .WORD BUF2
                   .BYTE WRITE, SLOT3       .BYTE WRITE, SLOT3
```

(cont.)

```
                    PROGRAM A            PROGRAM B

          DUNTST:   TSTB BUF1+3     DEVTST:  IOT
                    BPL DUNTST               .WORD DEVTST
                                             .BYTE WAITR,SLOT2

                                             IOT
                                             .WORD SLOT2DEV
                                             .BYTE INIT, SLOT4
```

Programs A and B do two successive reads from the same device into two different buffers. Since the devices are the same, IOX waits for the first read to finish before allowing the second to begin.

In Program A, we wish to process buffer 1. To have issued a Waitr for the device associated with slot 2 could have meant waiting also for the device at slot 3 if that device were in conflict. Hence, testing the Done bit in the buffer header is the proper choice.

In program B, we wish control of the device at slot 2, so that it can be assigned to another slot and so we must know its availability. Therefore, Waitr is appropriate.

7.5.6 Single Buffer Transfer on One Device

```
    A:    IOT                       ;TRAP TO IOX
          .WORD BUF1                ;SPECIFY BUFFER
          .BYTE READ,SLOT3          ;READ FROM DEVICE AT
                                    ;SLOT 3 INTO BUFFER

  BUSY:  IOT                        ;TRAP TO IOX
         .WORD BUSY                 ;SPECIFY BUSY RETURN ADDRESS
         .BYTE WAITR,SLOT3          ;WAIT FOR DEVICE AT SLOT
         (process buffer 1)         ;3 TO FINISH READING
          JMP A
```

The program segment above includes a Waitr which goes to a Busy Return address that is its own IOT -- continuously testing the device at slot 3 for availability. In this instance, involving only a single device and a single buffer, a Done condition in the Buffer 1 Status byte can be inferred from the availability of the device at slot 3. This knowledge assures us that all data requested for Buffer 1 is available for processing.

Testing the Done Bit of Buffer 1 might have been used instead, but was not necessary with only one device operating. Moreover, a Waitr, unlike a

Done Bit test, would detect a timeout on the LSR if that device happened to be associated with slot 3.

7.5.7 Double Buffering

```
        IOT                      ;TRAP TO IOX
        .WORD BUF1               ;SPECIFY BUFFER 1
        .BYTE READ,SLOT3         ;READ FROM DEVICE AT
                                 ;SLOT 3 INTO BUFFER 1
A:      IOT                      ;TRAP TO IOX
        .WORD BUF2               ;SPECIFY BUFFER 2
        .BYTE READ,SLOT3         ;READ FROM DEVICE AT SLOT
                                 ;3 INTO BUFFER 2
        (process BUF1 concurrent with Read into BUF2)
B:      IOT                      ;TRAP TO IOX
        .WORD BUF1               ;SPECIFY BUFFER 1
        .BYTE READ,SLOT3         ;READ FROM DEVICE AT
                                 ;SLOT 3 INTO BUFFER 1
        (process BUF2 concurrent with Read into BUF1)
        JMP A
```

The example above illustrates a time-saving double-buffer scheme whereby data is processed in Buffer 1 at the same time as new data is being read into Buffer 2; and, sequentially, data is processed in Buffer 2 at the same time as new data is being read into Buffer 1.

Because IOX ensures that the requested device is free before initiating the command, the subsequent return of control from the IOT at A implies that the read prior to A is complete; that is, that buffer 1 is available for processing. Similarly, the return of control from the IOT at B implies that buffer 2 is available. Waitr's are not required because IOX has automatically ensured the device's availability before initiating each Read.

7.5.8 Readr (Real-time Read)

```
        IOT
        .WORD (address of first word of the buffer header)
        .BYTE 13,(slot number)
        .WORD (done-address)
```

The Readr command functions as the Read except that upon completion of the data transfer, program control goes to the specified Done-address at the priority level of the device. Readr is used when you wish to execute a segment of your program immediately upon completing the data transfer. IOX goes to the Done address by executing a JSR R7, Done-address.

The general registers, which were saved when the last character interrupt occurred, are on the SP stack in the order indicated below:

```
(SP)→       Return address to IOX
            R5
            R4
            R3
            R2
            R1
            R0
```

Return to IOX is accomplished by an RTS R7 instruction. IOX will then restore all registers and return to the interrupted program. Care should be taken in initiating another data transfer if the specified device can conflict with device requests at other priority levels. Waitr cannot be used to resolve conflict situations between priority levels.

7.5.9 Writr (Real-time Write)

```
IOT
.WORD (address of first word of the buffer header)
.BYTE 14,(slot number of device)
.WORD (done address)
```

The Writr command functions as the Write except that, upon completion of the data transfer, program control goes to the specified Done-address at the priority level of the device. IOX goes to the Done-address by executing a JSR R7,Done-address. The condition of the general registers and the return to IOX are the same as for Readr. Writr is used when you wish to execute a segment of your program immediately upon completing the data transfer.

As in the Readr, care should be taken in initiating another data transfer if the specified device can conflict with device requests at the priority level of the calling program.

7.6 REENABLING THE READER AND RESTARTING

7.6.1 Seek

```
IOT
.WORD Ø
.BYTE 5,(slot number of LSR or HSR)
```

The Seek command clears IOX's internal End-Of-Medium (EOM) indicator on the LSR or HSR, making possible a subsequent read on those devices. With no EOM, an EOF cannot occur. The device associated with the specified slot remains Inited.

7.6.2 Restart

```
IOT
.WORD (address to restart)
.BYTE 3,0
```

This command designates an address at which to restart your program. After this command has been issued, typing CTRL/P on the KBD will transfer program control to the restart address, providing there is no LSR read in progress. In such a case, the LSR must be turned off (causing a timeout) before typing a CTRL/P. If the Restart address is designated as 0, the CTRL/P Restart capability is disabled.

The Restart command does not cancel any I/O in progress. It is the program's responsibility in its restart routine to clean up any I/O by executing a RESET command and ensuring that the stack pointer is reset.

7.7 FATAL ERRORS

Fatal errors result in program termination and a jump to location 40_8 (loaded with a HALT by IOX), with R0 set to the error code and R1 set as follows:

> If the fatal error was due to an illegal memory reference (code 0), R1 will contain the PC at the time of the error.
>
> If the fatal error was due to an error coded in the range 1-5, R1 will point to some element in the IOT argument list or to the instruction following the argument list, depending on whether IOX has finished decoding the arguments when it detects the error.

Fatal Error Code	Reason
0	Illegal Memory Reference, SP overflow, illegal instruction
1	Illegal IOX command
2	Slot out of range
3	Device out of range
4	Slot not inited
5	Illegal data mode

Note that the SP stack contains the value of the registers at the time of the error, namely

```
(SP)→ R5
      R4
      R3
      R2
      R1
      R0
      PC
      Processor Status (PS)
```

(See Section 7.3.3.1 for a discussion of non-fatal errors.)

7.8 EXAMPLE OF PROGRAM USING IOX

This program is used to duplicate paper tape. Note that it could be altered by changing the device code at RDEV or PDEV. For instance, the program could easily be made to list a tape.

```
R0=%0
R1=%1
R2=%2
R3=%3
R4=%4
R6=%6
KSLOT=0
TSLOT=1
RSLOT=3
PSLOT=4
RESET=2
RESTRT=3
INIT=1
WAITR=4
READ=11
WRITE=12
EOF=20000
CR=15                              ;CR ASSIGNED ASCII CODE FOR CARRIAGE RETURN
LF=12                              ;LF ASSIGNED ASCII CODE FOR LINE FEED

        .=1000
MSG1:   0                          ;CANNED MESSAGE
        0                          ;FORMATTED ASCII
MSG1BC: END1-MSG1BC-2              ;BYTE COUNT
        .BYTE   CR,LF
        .ASCII  / PLACE TAPE IN READER/
        .BYTE   CR,LF
        .ASCII  / STRIKE CR WHEN READY/
END1:   .EVEN
```

```
BUF3:   2                       ;BUFFER SIZE
        0                       ;FORMATTED ASCII MODE
        0                       ;BC
        0                       ;CR LF

RDEV:   5                       ;DEVICE CODE FOR HSR
PDEV:   6                       ;DEVICE CODE FOR HSP

BUF1:   100                     ;BUFFER SIZE
        3                       ;CODE FOR UNFORMATTED BINARY
        100                     ;SPECIFIES NUMBER OF BYTES FOR TRANSFER
        .=.+100                 ;RESERVES STORAGE FOR DATA
BUF2:   100                     ;BUFFER SIZE
        3                       ;CODE FOR UNFORMATTED BINARY
        100                     ;SPECIFIES NUMBER OF BYTES FOR TRANSFER
        .=.+100                 ;RESERVES STORAGE FOR DATA
BEGIN:  MOV     #500,R6         ;SPECIFY ADDRESS FOR BOTTOM OF STACK

        IOT
        0
        .BYTE   RESET,0         ;INITIALIZATION

        IOT
        BEGIN                   ;"BEGIN" SPECIFIED AS RESTART
        .BYTE   RESTRT,0        ;ADDRESS FOR CTRL P
        MOV     #100,BUF1+4     ;SET UP INITIAL BC ON BUF1
        MOV     #100,BUF2+4     ;SET UP INITIAL BC ON BUF2

        IOT                     ;TYPE OUT DIRECTIONS
        MSG1
        .BYTE   WRITE,TSLOT

        IOT                     ;READ A CR,LF
        BUF3
        .BYTE   READ,KSLOT

A:      IOT                     ;WAIT FOR HIM TO TYPE A CARRIAGE RETURN,
                                ;LINE FEED
        A
        .BYTE   WAITR,KSLOT

        IOT                     ;INIT READER
        RDEV
        .BYTE   INIT,RSLOT

        IOT                     ;INIT PUNCH
        PDEV
        .BYTE   INIT,PSLOT

        IOT                     ;START FIRST READ
        BUF1
        .BYTE   READ,RSLOT

LOOP:   IOT                     ;READ INTO 2ND BUFFER
        BUF2
        .BYTE   READ,RSLOT
```

```
          BIT     #EOF BUF1+2       ;END OF FILE?
          BNE     BEGIN             ;YES
                                    ;NO

          IOT                       ;WRITE OUT THIS BUFFER
          BUF1
          .BYTE   WRITE,PSLOT

C:        IOT                       ;WAIT TILL DEVICE HAS FINISHED
          C
          .BYTE   WAITR,PSLOT

          IOT                       ;READ INTO 1ST BUFFER
          BUF1
          .BYTE   READ,RSLOT

          BIT      #EOF,BUF2+2      ;END OF FILE?
          BNE     BEGIN

          IOT                       ;WRITE OUT BUFFER 2
          BUF2
          .BYTE   WRITE,PSLOT

B:        IOT                       ;WAIT TILL DEVICE HAS FINISHED
          B
          .BYTE   WAITR,PSLOT
          BR      LOOP
          .END    BEGIN
```

7.9 IOX INTERNAL INFORMATION

7.9.1 Conflict Byte/Word

The IOX Conflict byte (in IOXLPT, Conflict Word) contains the status (busy or free) of all devices as well as whether or not an echo is in progress. Bit 0 is the echo bit, bits 1-6 (and 8 in IOXLPT) refer to the corresponding codes for devices:

			If Bit is Set
Bit	0	=	Echo in progress
Bit Device	1	=	KBD busy
Bit Device	2	=	TTY busy
Bit Device	3	=	LSR busy
Bit Device	4	=	LSP busy
Bit Device	5	=	HSR busy

If Bit is Set

Bit Device	6	=	HSP busy
Bit Device	8 10_8	=	LPT busy

In IOXLPT, the Conflict Byte is expanded to a word in order to accommodate the line printer, there being no bit 8 to correspond with that device's code of 10_8 (the lowest available code for an output device - see Section 7.9.5.1).

Device	All Possible Conflicting Devices	Conflict Number
KBD	Echo, KBD, TTY, LSR, LSP	37
TTY	Echo, KBD, TTY, LSP	27
LSR	KBD, LSR	12
LSP	Echo, KBD, TTY, LSP	27
HSR	HSR	40
HSP	HSP	100
LPT	LPT	400

For each of the devices in the left hand column, all the possible conflicts are listed along with their respective conflict numbers. These numbers, representing bit patterns of the devices listed in column two above, are used to resolve any conflicting requests for devices. The appropriate number is masked with the conflict byte. If the result is zero, there are no conflicts and the device being tested has its bit set allowing data transfer to begin.

7.9.2 Device Interrupt Table (DIT)

Each device interrupt handler has associated with it a Device Interrupt Table (DIT) containing information that the handler needs:

DIT	Checksum
DIT+2	Byte size from buffer header
DIT+4	Address of Mode byte in buffer header
DIT+6	Byte Location Pointer
DIT+10	Byte Count

DIT+12	Device code
DIT+14	Real time done-address
DIT+16	Address of device's data buffer register

The device interrupt routines gain access to the proper data by means of the DIT entry. When a transfer is complete, they set the appropriate bits in the buffer header pointed to by the DIT contents.

7.9.3 Device Status Table (DST)

The Device Status Table (DST) is used by IOX to check for EOF conditions. This table contains a word for each device indicating an EOM condition with a 1. When an EOM condition is recognized on input, IOX not only sets the appropriate bit in the buffer status byte associated with the data transfer, it also records this occurrence in the DST. When a data transfer command is given, IOX checks the DST for the EOM condition. If the appropriate word has a value of 1, IOX sets EOF in the Status byte of the current-command buffer. Since EOF is only possible for the LSR (code 3), and HSR (code 5), the words corresponding to those devices are the only ones that can ever be set to 1.

7.9.4 Teletype Hardware Tab Facility

If the Teletype model has a hardware tab facility, teleprinter output can be speeded up by:

1. For IOX, deleting the code from I.TTYCK+6 through I.TAB3+3.
2. For IOXLPT, skipping the code from I.IOLF through I.TAB3+3 (for the teleprinter only - not the line printer).

7.9.5 Adding Devices to IOX

In order to add a device to IOX the following tasks must be done:

a. Assign a legal code to the device
b. Modify the IOX tables
c. Provide an interrupt routine to handle data for the device.

The line printer (in IOXLPT) will be used as an example throughout this discussion.

7.9.5.1 Device Codes

The numbers from 7 to 17_8 are available for new-device codes, with the exception of 10_8 in the IOXLPT version. This code has been assigned to the line printer. The device code must be odd for an input device and even for an output device. This is so a check can be made for command/device correspondence; i.e., for a Read from an input device or a Write to an output device.

If the newest device was assigned a number that is higher than the codes of all the other devices, I.MAXDEV must be redefined to that value. This is so an out-of-range device specification in an Init command can be detected. In IOXLPT, I.MAXDEV=10.

Since each device code functions as an index in several word tables, the entries relating to a given device must be placed at the same relative position in each appropriate table. That is, the code number must indicate how many words into the table the entry for that device will be found. This, of course, means accounting for any unused space preceding the entry, if the codes are not assigned in strict sequence. Table entries for the line printer are found at the 10_8th word past the table tag, i.e., at Table+20.

7.9.5.2 Table Modification

a. I.FUNC - Each entry is the octal value of the bit pattern in the device Control/Status Register that enables the corresponding device and/or any interrupt facility it has. Bit setting this number into the device's Control/Status register turns the device on; bit clearing turns it off. Determine this value for the device to be added, and place the entry in the appropriate device position in the table. For example, the line printer Control/Status Register has an Interrupt Enable facility in bit 6. This pattern of 100 is the LPT entry, and is located at I.FUNC+20.

b. I.SCRTAB - This table contains the addresses of the device Control/Status registers. The line printer entry I.LPTSCR has the value 177514, and is located at I.SCRTAB+20.

c. I.DST - (Refer to Section 7.9.3.) Create an entry of 0 for the device in the proper table location. Inserting a word of 0 at I.DST+20 created a device status entry for the line printer.

d. I.CONSIT - An entry in this table is used to set or clear a device's busy/free bit in the Conflict Byte (Conflict Word in IOXLPT). (See Section 7.9.1, and e. below.) Each value is obtained by setting one bit only - the bit number corresponding to the device number. The line printer, being device 10_8, has a value of 400_8 (bit 10_8 set) and is located at I.CONSIT+20.

In the IOX version without the line printer, entries to this table are found in the high-order bytes of Table I.CONFLC. One more input device entry can be added to it. In IOXLPT, however, I.CONSIT is a separate word table, allowing eight more devices (four input and four output) to be added. Byte operations in the IOX I.CONSIT became word operations in IOXLPT to adapt to this expansion.

e. I.CONFLC - (Refer to Section 7.9.1 on Conflict Byte/Word.) Entries are bit patterns of conflicting devices. Since the line printer can only conflict with itself, the I.CONFLC entry is equal to the I.CONSIT entry. As in the I.CONSIT table, byte operations were changed to word operations for I.CONFLC in IOXLPT.

f. Create a DIT for the device (refer to Section 7.9.2) by assigning a DIT label and seven words of 0. If it is an output device, the address of the Device Buffer Register must be added as an eighth word.

g. I.INTAB - This is a table of DIT addresses. Place the label of the DIT (mentioned in f. above) in the correct position in the table. I.INTAB+20 contains the line printer entry I.LPTDIT.

7.9.5.3 Interrupt Routines

Write (and assign a label to) an interrupt routine for the device to:

1. Get a character
2. Check for errors by means of the device Control/Status register
3. Do character interpretation according to the device and mode
4. Get a character in or out of the buffer
5. Update IOX's Byte Count
6. Compare IOX's Byte Count to User's Byte Count and Buffer size specification
7. Return for next character

Place the label of the interrupt routine at the address of the device vector, and follow it with the value of the interrupt priority in bits 7, 6, and 5. I.LPTIR, the address of the line printer interrupt routine, is at location 200. Location 202 contains the value 200 (indicating priority level 4).

If the device to be added is similar to the other single-character devices, steps 3-7 above can be performed by IOX as indicated below:

There are two routines, I.INPUT and I.OUTPUT, that are called from the interrupt routines. These routines mainly perform common functions for input and output devices. They are called as follows:

```
        JSR  R5,I.INPUT     and     JSR  R5,I.OUTPUT
```

At the location following one of these calls is the DIT for the proper device. The routine is thus able to use R5 to reference the DIT entries.

I.INPUT and I.OUTPUT also contain device-dependent code to perform functions such as tab counters for the teleprinter and line printer, and deletion of carriage returns in Formatted ASCII mode for the line printer. The device index value is used to identify the device. For the line printer, a symbol I.LPT, has been assigned the value 20 for convenient reference to the device index.

CHAPTER 8

FLOATING-POINT MATH PACKAGE OVERVIEW

CHAPTER 8

FLOATING POINT MATH PACKAGE OVERVIEW

The new Floating-Point Math Package, FPMP-11, is designed to bring the 2/4 word floating point format of the FORTRAN environment to the paper tape software system of the PDP-11. The numerical routines in FPMP-11 are the same as those of the DOS-11 FORTRAN Operating Time System (OTS). TRAP and error handlers have been included to aid in interfacing with the FORTRAN routines.

FPMP-11 provides an easy means of performing basic arithmetic operations such as add, subtract, multiply, divide, and compare. It also provides transcendental functions (SIN, COS, etc.), type conversions (integer to floating-point, 2-word to 4-word, etc.), and ASCII conversions (ASCII to 2-word floating-point, etc.).

Floating-point notation is particularly useful for computations involving numerous multiply and divide operations where operand magnitudes may vary widely. FPMP-11 stores very large and very small numbers by saving only the significant digits and computing an exponent to account for leading and trailing zeros.

To conserve core space in a small system, FPMP-11 can be tailored to include only those routines needed to run a particular user program.

For more information on FPMP-11, refer to the FPMP-11 User's Manual (DEC-11-NFPMA-A-D and to Appendix G of this manual.

CHAPTER 9

PROGRAMMING TECHNIQUES

CHAPTER 9

PROGRAMMING TECHNIQUES

This chapter presents various programming techniques. They can be used to enhance your programming and to make optimum use of the PDP-11 processor. The reader is expected to be familiar with the PAL-11A language (Chapter 3).

We consider this chapter to be open-ended, i.e., we plan to add more programming techniques at every subsequent printing of the handbook. Should you discover different techniques or can improve on those already included, please submit your suggestions for consideration using the Reader's Comments card appended to this handbook or by mailing them to:

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146 Main Street
Maynard, Massachusetts 01754

9.1 WRITING POSITION INDEPENDENT CODE

When a standard program is available for different users, it often becomes useful to be able to load the program into different areas of core and to run it there. There are several ways to do this:

1. Reassemble the program at the desired location.

2. Use a relocating loader which accepts specially coded binary from the assembler.

3. Have the program relocate itself after it is loaded.

4. Write code which is position independent.

On small machines, reassembly is often performed. When the required core is available, a relocating loader (usually called a linking loader) is preferable. It generally is not economical to have a program relocate itself since hundreds or thousands of addresses may need adjustment. Writing position independent code is usually not possible because of the structure of the addressing of the object machine. However, on the PDP-11, position independent code (PIC) is possible.

PIC is achieved on the PDP-11 by using addressing modes which form an effective memory address relative to the Program Counter (PC). Thus, if an instruction and its object(s) are moved in such a way that the relative distance between them is not altered, the same offset relative to the PC can be used in all positions in memory. Thus, PIC usually references locations relative to the current location. PIC may make absolute references as long as the locations referenced stay in the same place while the PIC is relocated. For example, references to interrupt and trap vectors are absolute, as are references to device registers in the external page and direct references to the general registers.

9.1.1 Position Independent Modes

There are three position independent modes or forms of instructions. They are:

1. Branches -- the conditional branches, as well as the unconditional branch, BR, are position independent since the branch address is computed as an offset to the PC.

2. Relative Memory References -- any relative memory reference of the form

```
CLR   X
MOV   X,Y
JMP   X
```

is position independent because the assembler assembles it as an offset indexed by the PC. The offset is the difference between the referenced location and the PC. For example, assume the instruction CLR 200 is at address 100:

```
100/  005067         ;FIRST WORD OF CLR 200
102/  000074         ;OFFSET = 200-104
```

The offset is added to the PC. The PC contains 104, i.e., the address of the word following the offset.

Although the form CLR X is position independent, the form CLR @X is not. Consider the following:

```
S:  CLR @X         ;CLEAR LOCATION A
     .
     .
     .
X:  .WORD A        ;POINTER TO A
     .
     .
     .
A:  .WORD 0
```

The contents of location X are used as the address of the operand in the location labeled A. Thus, if all of the code is relocated, the contents of location X must be altered to reflect the new address of A. If A, however, was the name associated with some fixed location (e.g., trap vector, device register), then statements S and X would be relocated and A would remain fixed. Thus, the following code is position independent.

```
    A = 36         ;ADDRESS OF SECOND WORD OF
                   ; TRAP VECTOR
S:  CLR @X         ;CLEAR LOCATION A
     .
     .
     .
X:  .WORD A        ;POINTER TO A
```

3. Immediate Operands -- The assembler addressing form #X specifies immediate data, that is, the operand is in the instruction. Immediate data is position independent since it is a part of the instruction and is moved with the instruction. Immediate data is fetched using the PC in the autoincrement mode.

   As with direct memory references, the addressing form @#X is not position independent. As before, the final effective address is absolute and points to a fixed location not relative to the PC.

9.1.2 Absolute Modes

Any time a memory location or register is used as a pointer to data, the reference is absolute. If the referenced data is fixed in memory, independent of the position of the PIC (e.g., trap-interrupt vectors, device registers), the absolute modes must be used.[1] If the data is relative to the PIC, the absolute modes must not be used unless the pointers involved are modified. The absolute modes are:

@X	Location X is a pointer
@#X	The immediate word is a pointer
(R)	The register is a pointer
(R)+ and -(R)	The register is a pointer
@(R)+ and @-(R)	The register points to a pointer
X(R) R≠6 or 7	The base, X, modified by (R) is the address of the operand
@X(R)	The base, modified by (R), is a pointer

The non-deferred index modes and stack operations require a little clarification. As described in Sections 3.6.10 and 9.1.1, the form X(7) is the normal mode to reference memory and is a relative mode. Index mode, using a stack pointer (SP or other register) is also a relative mode and may be used conveniently in PIC. Basically, the stack pointer points to a dynamic storage area and index mode is used to access data relative to the pointer. The stack pointer may be initially set up by a position independent program as shown in Section 9.1.4.1. In any case, once the pointer is set up, all data on the stack is referenced relative to the pointer. It should also be noted that since the form 0(SP) is considered a relative mode so is its equivalent @SP. In addition, the forms (SP)+ and -(SP) are required for stack pops and pushes.

9.1.3 Writing Automatic PIC

Automatic PIC is code which requires no alteration of addresses or pointers. Thus, memory references are limited to relative modes unless the location referenced is fixed (trap-interrupt vectors, etc.). In addition to the above rules, the following must be observed:

1. Start the program with .=0 to allow easy relocation using the Absolute Loader (see Chapter 6).

2. All location setting statements must be of the form .=.±X or .= function of tags within the PIC. For example, .=A+10 where A is a local label.

[1] When PIC is not being written, references to fixed locations may be performed with either the absolute or relative forms.

3. There must not be any absolute location setting statements. This means that a block of PIC cannot set up trap and/or interrupt vectors at load time with statements such as:

```
.=34
.WORD  TRAPH,340    ;TRAP VECTOR
```

The Absolute Loader, when it is relocating PIC, relocates all data by the load bias (see Chapter 6). Thus, the data for the vector would be relocated to some other place. Vectors may be set at execution time (see Section 9.1.4).

9.1.4 Writing Non-Automatic PIC

Often it is not possible or economical to write totally automated PIC. In these cases, some relocation may be easily performed at execution time. Some of the required methods of solution are presented below. Basically, the methods operate by examining the PC to determine where the PIC is actually located. Then a relocation factor can be easily computed. In all examples, it is assumed that the code is assembled at zero and has been relocated somewhere else by the Absolute Loader.

9.1.4.1 Setting Up the Stack Pointer -- Often the first task of a program is to set the stack pointer (SP). This may be done as follows:

```
        .=0           ;BEG IS THE FIRST INSTRUCTION OF
                      ;THE PROGRAM.
BEG:    MOV  PC,SP    ;SP=ADR BEG+2
        TST  -(SP)    ;DECREMENT SP BY 2.
                      ;A PUSH ONTO THE STACK WILL STORE
                      ;THE DATA AT BEG-2.
```

9.1.4.2 Setting Up a Trap or Interrupt Vector -- Assume the first word of the vector is to point to location INT which is in PIC.

```
X:    MOV PC,R0           ;R0 = ADR X+2
      ADD #INT-X-2,R0     ;ADD OFFSET
      MOV R0,@#VECT       ;MOVE POINTER TO VECTOR
```

The offset INT-X-2 is equivalent to INT-(X+2) and X+2 is the value of the PC moved by statement X. If PC_0 is the PC that was assumed for the program when loaded at 0, and if PC_n is the current real PC, then the calculation is:

$$INT-PC_0+PC_n=INT+(PC_n-PC_0)$$

Thus, the relocation factor, PC_n-PC_0, is added to the assembled value of INT to produce the relocated value of INT.

9.1.4.3 Relocating Pointers -- If pointers must be used, they may be relocated as shown above. For example, assume a list of data is to be accessed with the instruction

```
                ADD (R0)+,R1
```

The pointer to the list, list L, may be calculated at execution time as follows:

```
M:      MOV  PC,R0        ;GET CURRENT PC
        ADD  #L-M-2,R0    ;ADD OFFSET
```

Another variation is to gather all pointers into a table. The relocation factor may be calculated once and then applied to all pointers in the table in a loop.

```
X:      MOV  PC,R0        ;RELOCATE ALL ENTRIES IN PTRTBL
        SUB  #X+2,R0      ;CALCULATE RELOCATION FACTOR
        MOV  #PTRTBL,R1   ;GET AND RELOCATE A POINTER
        ADD  R0,R1        ;  TO PTRTBL
        MOV  #TBLLEN,R2   ;GET LENGTH OF TABLE
LOOP:   ADD  R0,(R1)+     ;RELOCATE AN ENTRY
        DEC  R2           ;COUNT
        BGE  LOOP         ;BRANCH IF NOT DONE
```

Care must be exercised when restarting a program which relocates a table of pointers. The restart procedure must not include the relocating again, i.e., the table must be relocated exactly once after each load.

9.2 LOADING UNUSED TRAP VECTORS

One of the features of the PDP-11 is the ability to trap on various conditions such as illegal instructions, reserved instructions, power failure, etc. However, if the trap vectors are not loaded with meaningful information, the occurrence of any of these traps will cause unpredictable results. By loading the vectors as indicated below, it is possible to avoid these problems as well as gain meaningful information about any unexpected traps that occur. This technique, which makes it easy to identify the source of a trap, is to load each unused trap vector with:

```
        .=trap address
        .WORD  .+2,HALT
```

This will load the first word of the vector with the address of the second word of the vector (which contains a HALT). Thus, for example, a halt at location 6 means that a trap through the vector at location 4 has occurred. The old PC and status may be examined by looking at the stack pointed to by register 6.

The trap vectors of interest are:

Vector Location	Halt At Location	Meaning
4	6	Bus Error; Illegal Instruction; Stack Overflow; Nonexistent Memory; Nonexistent Device; Word Referenced at Odd Address
10	12	Reserved Instruction
14	16	Trace Trap Instruction (000003) or T-bit Set in Status Word (used by ODT)
20	22	IOT Executed (used by IOX)
24	26	Power Failure or Restoration
30	32	EMT Executed (used by FPP-11)
34	36	TRAP Executed

9.3 CODING TECHNIQUES

Because of the great flexibility in PDP-11 coding, time- and space-saving ways of performing operations may not be immediately apparent. Some comparisons follow.

9.3.1 Altering Register Contents

The techniques described in this section take advantage of the automatic stepping feature of autoincrement and autodecrement modes when used especially in TST and CMP instructions. These instructions do not alter operands. However, it is important to make note of the following:

- These alternative ways of altering register contents affect the condition codes differently.
- Register contents must be even when stepping by 2.

1. Adding 2 to a register might be accomplished by ADD #2,R0. However, this takes two words, whereas TST (R0)+ which also adds 2 to a register, takes only one word.
2. Subtracting 2 from a register can be done by the complementary instructions SUB #2,R0 or TST -(R0) with the same conditions as in adding 2.

3. This can be extended to adding or subtracting 2 from two different registers, or 4 from the same register, in one single-word instruction:

```
        CMP (R0)+,(R0)+       ;ADD 4 TO R0
        CMP -(R1),-(R1)       ;SUBTRACT 4 FROM R1
        CMP (R0)+,-(R1)       ;ADD 2 TO R0, SUBTRACT 2 FROM R1
        CMP -(R3),-(R1)       ;SUBTRACT 2 FROM BOTH R3 AND R1
        CMP (R3)+,(R0)+       ;ADD 2 TO BOTH R3 AND R0
```

4. Variations of the examples above can be employed if the instructions operate on bytes and one of the registers is the Stack Pointer. These examples depend on the fact that the Stack Pointer (as well as the PC) is always autoincremented or autodecremented by 2, whereas registers R0-R5 step by 1 in byte instructions.

```
        CMPB (SP)+,(R3)+      ;ADD 2 TO SP AND 1 TO R3
        CMPB -(R3),-(SP)      ;SUBTRACT 1 FROM R3 AND 2 FROM SP
        CMPB (R3)+,-(SP)      ;ADD 1 TO R3, SUBTRACT 2 FROM SP
```

5. Popping an unwanted word off the processor stack (adding 2 to register 6) and testing another value can be two separate instructions or one combined instruction:

```
        TST (SP)+             ;POP WORD
        TST COUNT             ;SET CONDITION CODES FOR COUNT
or
        MOV COUNT,(SP)+       ;POP WORD & SET CODES FOR COUNT
```

The differences are that the TST instructions take three words and clear the Carry bit, and the MOV instruction takes two words and doesn't affect the Carry bit.

9.3.2 Subroutines

1. Condition codes set within a subroutine can be used to conditionally branch upon return to the calling program, since the RTS instruction does not affect condition codes.

```
             JSR PC,X         ;CALL SUBROUTINE X
             BNE ABC          ;BRANCH ON CONDITION SET
                :             ;IN SUBROUTINE X
        X:                    ;SUBROUTINE ENTRY
                :
             CMP R2,DEF       ;TEST CONDITION
             RTS PC           ;RETURN TO CALLING PROGRAM
```

2. When a JSR first operand register is not the PC, data stored following a subroutine call can be accessed within the subroutine by referencing the register. (The register contains the return address.)

```
                JSR R5,Y
                .WORD HIGH
                .WORD LOW
                    .           ;LATEST R5 VALUE WILL POINT HERE
                    .
                    .
         Y:     MOV (R5)+,R2    ;VALUE OF HIGH ACCESSED
                MOV (R5)+,R4    ;VALUE OF LOW ACCESSED
                    .
                    .
                    .
                RTS R5          ;RETURN TO LOCATION
                                ;CONTAINED IN R5
```

Another possibility is:

```
                JSR R5,SUB
                BR PSTARG         ;LOW-ORDER BYTE IS OFFSET TO RETURN
                                  ;ADDRESS, WHICH EQUALS NO. OF ARGS.
                .WORD A           ;ADDRESS OF ARG A
                .WORD B           ;ADDRESS OF ARG B
                .WORD C           ;ADDRESS OF ARG C
                    .
                    .
                    .
     PSTARG:                      ;RETURN ADDRESS
                    .
                    .
                    .
        SUB:    MOVB@R5,COUNT     ;GET NO. OF ARGS FROM LOW BYTE
                                  ;OF BR (IF DESIRED).
                MOV @14(R5),R2    ;E.G., GET 6TH ARGUMENT
                MOV @6(R5),R1     ;GET 3RD ARGUMENT
                    .
                    .
                    .
                RTS R5            ;RETURNS TO BRANCH WHICH JUMPS PAST
                                  ;ARG LIST TO REAL RETURN ADDRESS.
```

In the example above, the branch instruction contributes two main advantages:

1. If R5 is unaltered when the RTS is executed, return will always be to the branch instruction. This ensures a return to the proper location even if the length of the argument list is shorter or longer than expected.

2. The operand of the branch, being an offset past the argument list, provides the number of arguments in the list.

Arguments can be made sharable by separating the data from the main code. This is easily accomplished by treating the JSR and its return as a subroutine itself:

```
       CALL:        .                ARGLST:    JSR R5,SUB
                    .                           BR PSTARG
                JSR PC,ARGLST                   .WORD A
                    .                              .
                    .                              .
                    .                              .
```

3. The examples above all demonstrate the calling of subroutines from a non-reentrant program. The called subroutine can be either reentrant or non-reentrant in each case. The following example illustrates a method of also allowing calling programs to be reentrant. The arguments and linkage are first placed on the stack, simulating a JSR R5, SUB, so that arguments are accessed from the subroutine via X(R5). Return to the calling program is executed from the stack.

```
    CALL:      .
               .
               .
           MOV R5,-(SP)      ;SAVE R5 ON STACK.
           MOV JSBR,-(SP)    ;PUSH INSTRUCTION JSR R6,@R5 ON
                             ;STACK. PUSH ADDRESSES OF ARGU-
               .             ;MENTS ON STACK IN REVERSE ORDER
               .             ;(SEE BELOW).
           MOV BRN,-(SP)     ;PUSH BRANCH INSTRUCTION ON STACK
       X:  MOV SP,R5         ;MOVE ADDRESS OF BRANCH TO R5.
           JSR PC,SUB        ;CALL SUB AND SAVE RETURN ON STACK.
     RET:  MOV (SP)+,R5      ;RESTORE OLD R5 UPON RETURN.
               .
               .             ;DATA AREA OF PROGRAM.
               .
    JSBR:  JSR R6,@R5
     BRN:  BR .+N+N+2        ;BRANCH PAST N WORD ARGUMENTS
```

The address of an argument can be pushed on the stack in several ways. Three are shown below.

a. The arguments A, B, and C are read-only constants which are in memory (not on the stack):

```
           MOV #C,-(SP)      ;PUSH ADDRESS OF C
           MOV #B,-(SP)      ;PUSH ADDRESS OF B
           MOV #A,-(SP)      ;PUSH ADDRESS OF A
```

b. Arguments A, B, and C have their addresses on the stack at the Lth, Mth, and Nth bytes from the top of the stack.

```
           MOV N(SP),-(SP)     ;PUSH ADDRESS OF C
           MOV M+2(SP),-(SP)   ;PUSH ADDRESS OF B
           MOV L+4(SP),-(SP)   ;PUSH ADDRESS OF A
```

Note that the displacements from the top of the stack are adjusted by two for each previous push because the top of the stack is being moved on each push.

c. Arguments A, B, and C are on the stack at the Lth, Mth, and Nth bytes from the top but their addresses are not.

```
           MOV #N+2,-(SP)    ;PUSH DISPLACEMENT TO ARGUMENT
           ADD SP,@SP        ;CALCULATE ACTUAL ADDRESS OF C
           MOV #M+4,-(SP)
           ADD SP,@SP        ;ADDRESS OF B
           MOV #L+6,-(SP)
           ADD SP,@SP        ;ADDRESS OF A
```

When subroutine SUB is entered, the stack appears as follows:

```
|    RET      |
| BR .+N+N+2  |
|     A       |
|     B       |
|     :       |
| JSR R6,@R5  |     ;BRANCH IS TO HERE
|   old R5    |
```

Subroutine SUB returns by means of an RTS R5, which places R5 into the PC and pops the return address from the stack into R5. This causes the execution of the branch because R5 has been loaded (at location X) with the address of the branch. The JSR branched to then returns control to the calling program, and in so doing, moves the current PC value into the SP, thereby removing everything above the old R5 from the stack. Upon return at RET, this too is popped, restoring the original R5 and SP values.

4. The next example is a recursive subroutine (one that calls itself). Its function is to look for a matching right parenthesis for every left parenthesis encountered. The subroutine is called by JSR PC,A whenever a left parenthesis is encountered (R2 points to the character following it). When a right parenthesis is found, an RTS PC is executed, and if the right parenthesis is not the last legal one, another is searched for. When the final matching parenthesis is found, the RTS returns control to the main program.

```
A:     MOVB (R2)+,R0      ;GET SUCCESSIVE CHARACTERS.
       CMPB #'(,R0        ;LOOK FOR LEFT PARENTHESIS.
       BNE B              ;FOUND?
       JSR PC,A           ;LEFT PAREN FOUND, CALL SELF.
       BR A               ;GO LOOK AT NEXT CHARACTER
B:     CMPB #'),R0        ;LEFT PAREN NOT FOUND, LOOK FOR
                          ;RIGHT PAREN.
       BNE A              ;FOUND? IF NOT, GO TO A.
       RTS PC             ;RETURN PAREN FOUND. IF NOT LAST,
                          ;GO TO B. IF LAST, GO TO MAIN PROGRAM.
```

5. The example below illustrates the use of co-routines, called by JSR PC,@(SP)+. The program uses double buffering on both input and output, performing as follows:

```
Write O1   }                    Write O2   }
Read I1    }  concurrently      Read I2    }  concurrently
Process I2 }                    Process I1 }
```

JSR PC,@(SP)+ always performs a jump to the address specified on top of the stack and replaces that address with the new return address. Each time the JSR at B is executed, it jumps to a different location; initially to A and thereafter to the location following the JSR executed prior to the one at B. All other JSR's jump to B+2.

```
               PC=%7
      BEGIN:   (do I/O resets, inits, etc.)
                 .
                 .
                 .
               IOT             ;READ INTO I1 TO START PROCESS
               .WORD I1
               .BYTE READ,INSLOT
               MOV #A,-(6)     ;INITIALIZE STACK FOR FIRST JSR
          B:   JSR PC,@(6)+    ;DO I/O FOR O1 AND I1 OR O2 AND I2
                 .
                 .     perform processing
                 .
               BR B            ;MORE I/O
;END OF MAIN LOOP
;I/O CO-ROUTINES
          A:   IOT             ;READ INTO I2
               .WORD I2
               .BYTE READ,INSLOT
                 .
                 .     set parameters to process I1, O1
                 .
               JSR PC,@(6)+    ;RETURN TO PROCESS AT B+2
               IOT             ;WRITE FROM O1
               .WORD O1
               .BYTE WRITE,OUTSLOT
               IOT             ;READ INTO I1
               .WORD I1
               .BYTE READ,INSLOT
                 .
                 .     set parameters to process I2, O2
                 .
               JSR PC,@(6)+    ;RETURN TO PROCESS AT B+2
               IOT             ;WRITE FROM O2
               .WORD O2
               .BYTE WRITE,OUTSLOT
               BR A            ;READ INTO I2
```

6. The trap handler, below, simulates a two-word JSR instruction with a one-word TRAP instruction. In this example, all TRAP instructions in the program take an operand, and trap to the handler address at location 34. The table of subroutine addresses (e.g., A, B, ...) can be constructed as follows:

```
      TABLE:
               CALA=.-TABLE
               .WORD A         ;CALLED BY:  TRAP CALA

               CALB=.-TABLE
               .WORD B         ;CALLED BY:  TRAP CALB
                 .
                 .
                 .
```

Another way to construct the table:

```
          TABLE:
                   CALA=.-TABLE+TRAP
                   .WORD A        ;CALLED BY:  CALA
                     .
                     .
                     .
```

The TRAP handler for either of the above methods follows:

```
          TRAP34:  MOV @SP,2(SP)   ;REPLACE STACKED PS WITH PC[1].
                   SUB #2,@SP      ;GET POINTER TO TRAP INSTRUCTION.
                   MOV @(SP)+,-(SP);REPLACE ADDRESS OF TRAP WITH
                                   ;  TRAP INSTRUCTION ITSELF.
                   ADD #TABLE-TRAP,@SP   ;CALCULATE SUBROUTINE ADDR.
                   MOV @(SP)+,PC   ;JUMP TO SUBROUTINE.
```

In the example above, if the third instruction had been written MOV @(SP),(SP) it would have taken an extra word since @(SP) is in Index Mode and assembles as @0(SP). In the final instruction, a jump was executed by a MOV @(SP)+,PC because no equivalent JMP instruction exists.

Following are some JMP and MOV equivalences (note that JMP does not affect condition codes).

JMP (R4)	=	MOV R4,PC
JMP @(R4) (2 words)	=	MOV (R4),PC (1 word)
none	=	MOV @(R4),PC
JMP -(R4)	=	none
JMP @(R4)+	=	MOV (R4)+,PC
JMP @-(R4)	=	MOV -(R4),PC
none	=	MOV @(R4)+,PC
none	=	MOV @-(R4),PC
JMP X	=	MOV #X,PC
JMP @X	=	MOV X,PC
none	=	MOV @X,PC

[1] Replacing the saved PS loses the T-bit status. If a breakpoint has been set on the TRAP instruction, ODT will not gain control again to reinsert the breakpoints because the T-bit trap will not occur.

The TRAP handler can be useful, also, as a patching technique. Jumping out to a patch area is often difficult because a two-word jump must be performed. However, the one-word TRAP instruction may be used to dispatch to patch areas. A sufficient number of slots for patching should first be reserved in the dispatch table of the TRAP handler. The jump can then be accomplished by placing the address of the patch area into the table and inserting the proper TRAP instruction where the patch is to be made.

APPENDICES

APPENDIX A

ASCII CHARACTER SET

NOTE

The PTS systems punch ASCII with Ø in the parity bit. When ASCII is read, the parity bit is ignored.

EVEN PARITY BIT	7-BIT OCTAL CODE	CHARACTER	REMARKS
Ø	ØØØ	NUL	NULL, TAPE FEED, CONTROL SHIFT P.
1	ØØ1	SOH	START OF HEADING; ALSO SOM, START OF MESSAGE, CONTROL A.
1	ØØ2	STX	START OF TEXT; ALSO EOA, END OF ADDRESS, CONTROL B.
Ø	ØØ3	ETX	END OF TEXT; ALSO EOM, END OF MESSAGE, CONTROL C.
1	ØØ4	EOT	END OF TRANSMISSION (END); SHUTS OFF TWX MACHINES, CONTROL D.
Ø	ØØ5	ENQ	ENQUIRY (ENQRY); ALSO WRU, CONTROL E.
Ø	ØØ6	ACK	ACKNOWLEDGE; ALSO RU, CONTROL F.
1	ØØ7	BEL	RINGS THE BELL. CONTROL G.
1	Ø1Ø	BS	BACKSPACE; ALSO FEO, FORMAT EFFECTOR. BACKSPACES SOME MACHINES, CONTROL H.
Ø	Ø11	HT	HORIZONTAL TAB. CONTROL I.
Ø	Ø12	LF	LINE FEED OR LINE SPACE (NEW LINE); ADVANCES PAPER TO NEXT LINE, DUPLICATED BY CONTROL J.
1	Ø13	VT	VERTICAL TAB (VTAB). CONTROL K.
Ø	Ø14	FF	FORM FEED TO TOP OF NEXT PAGE (PAGE). CONTROL L.
1	Ø15	CR	CARRIAGE RETURN TO BEGINNING OF LINE. DUPLICATED BY CONTROL M.
1	Ø16	SO	SHIFT OUT; CHANGES RIBBON COLOR TO RED. CONTROL N.
Ø	Ø17	SI	SHIFT IN; CHANGES RIBBON COLOR TO BLACK. CONTROL O.
1	Ø2Ø	DLE	DATA LINK ESCAPE. CONTROL P (DCØ).
Ø	Ø21	DC1	DEVICE CONTROL 1, TURNS TRANSMITTER (READER) ON, CONTROL Q (X ON).
Ø	Ø22	DC2	DEVICE CONTROL 2, TURNS PUNCH OR AUXILIARY ON. CONTROL R (TAPE, AUX ON).
1	Ø23	DC3	DEVICE CONTROL 3, TURNS TRANSMITTER (READER) OFF, CONTROL S (X OFF).
Ø	Ø24	DC4	DEVICE CONTROL 4, TURNS PUNCH OR AUXILIARY OFF. CONTROL T (~~TAPE~~, AUX OFF).
1	Ø25	NAK	NEGATIVE ACKNOWLEDGE; ALSO ERR, ERROR. CONTROL U.
1	Ø26	SYN	SYNCHRONOUS IDLE (SYNC). CONTROL V.
Ø	Ø27	ETB	END OF TRANSMISSION BLOCK; ALSO LEM, LOGICAL END OF MEDIUM. CONTROL W.
Ø	Ø3Ø	CAN	CANCEL (CANCL). CONTROL X.
1	Ø31	EM	END OF MEDIUM. CONTROL Y.
1	Ø32	SUB	SUBSTITUTE. CONTROL Z.
Ø	Ø33	ESC	ESCAPE. PREFIX. CONTROL SHIFT K.
1	Ø34	FS	FILE SEPARATOR. CONTROL SHIFT L.

EVEN PARITY BIT	7-BIT OCTAL CODE	CHARACTER	REMARKS
Ø	Ø35	GS	GROUP SEPARATOR. CONTROL SHIFT M.
Ø	Ø36	RS	RECORD SEPARATOR. CONTROL SHIFT N.
1	Ø37	US	UNIT SEPARATOR. CONTROL SHIFT O.
1	Ø4Ø	SP	SPACE.
Ø	Ø41	!	
Ø	Ø42	"	
1	Ø43	#	
Ø	Ø44	$	
1	Ø45	%	
1	Ø46	&	
Ø	Ø47	'	ACCENT ACUTE OR APOSTROPHE.
Ø	Ø5Ø	(	
1	Ø51	)	
1	Ø52	*	
Ø	Ø53	+	
1	Ø54	,	
Ø	Ø55	-	
Ø	Ø56	.	
1	Ø57	/	
Ø	Ø6Ø	Ø	
1	Ø61	1	
1	Ø62	2	
Ø	Ø63	3	
1	Ø64	4	
Ø	Ø65	5	
Ø	Ø66	6	
1	Ø67	7	
1	Ø7Ø	8	
Ø	Ø71	9	
Ø	Ø72	:	
1	Ø73	;	
Ø	Ø74	<	
1	Ø75	=	
1	Ø76	>	
Ø	Ø77	?	
1	1ØØ	@	
Ø	1Ø1	A	
Ø	1Ø2	B	
1	1Ø3	C	
Ø	1Ø4	D	
1	1Ø5	E	
1	1Ø6	F	
Ø	1Ø7	G	
Ø	11Ø	H	
1	111	I	
1	112	J	
Ø	113	K	
1	114	L	
Ø	115	M	
Ø	116	N	
1	117	O	
Ø	12Ø	P	
1	121	Q	
1	122	R	
Ø	123	S	
1	124	T	

EVEN PARITY BIT	7-BIT OCTAL CODE	CHARACTER	REMARKS
Ø	125	U	
Ø	126	V	
1	127	W	
1	13Ø	X	
Ø	131	Y	
Ø	132	Z	
1	133	[	SHIFT K.
Ø	134	\	SHIFT L.
1	135	]	SHIFT M.
1	136	↑	
Ø	137	←	
Ø	14Ø	`	ACCENT GRAVE.
Ø	175	}	THIS CODE GENERATED BY ALT MODE.
Ø	176	~	THIS CODE GENERATED BY ESC KEY (IF PRESENT).
1	177	DEL	DELETE, RUB OUT.
			LOWER CASE ALPHABET FOLLOWS (TELETYPE MODEL 37 ONLY).
1	141	a	
1	142	b	
Ø	143	c	
1	144	d	
Ø	145	e	
Ø	146	f	
1	147	g	
1	15Ø	h	
Ø	151	i	
Ø	152	j	
1	153	k	
Ø	154	l	
1	155	m	
1	156	n	
Ø	157	o	
1	16Ø	p	
Ø	161	q	
Ø	162	r	
1	163	s	
Ø	164	t	
1	165	u	
1	166	v	
Ø	167	w	
Ø	17Ø	x	
1	171	y	
1	172	z	
Ø	173	{	
1	174	|	

APPENDIX B

PAL-11A ASSEMBLY LANGUAGE AND ASSEMBLER

B.1 SPECIAL CHARACTERS

Character	Function
form feed	Source line terminator
line feed	Source line terminator
carriage return	Source statement terminator
:	Label terminator
=	Direct assignment indicator
%	Register term indicator
tab	Item terminator Field terminator
space	Item terminator Field terminator
#	Immediate expression indicator
@	Deferred addressing indicator
(	Initial register indicator
)	Terminal register indicator
,	Operand field separator
;	Comment field indicator
+	Arithmetic addition operator
-	Arithmetic subtraction operator
&	Logical AND operator
!	Logical OR operator
"	Double ASCII character indicator
'	Single ASCII character indicator
.	Assembly location counter

B.2 ADDRESS MODE SYNTAX

n is an integer between 0 and 7 representing a register. R is a register expression, E is an expression, ER is either a register expression or an expression in the range 0 to 7.

Format	Address Mode Name	Address Mode Number	Meaning
R	Register	0n	Register R contains the operand. R is a register expression.
@R or (ER)	Deferred Register	1n	Register R contains the operand address.
(ER)+	Autoincrement	2n	The contents of the register specified by ER are incremented after being used as the address of the operand.
@(ER)+	Deferred Autoincrement	3n	ER contains the pointer to the address of the operand. ER is incremented after use.
-(ER)	Autodecrement	4n	The contents of register ER are decremented before being used as the address of the operand.
@-(ER)	Deferred Autodecrement	5n	The contents of register ER are decremented before being used as the pointer to the address of the operand.
E(ER)	Index	6n	E plus the contents of the register specified, ER, is the address of the operand.
@E(ER)	Deferred Index	7n	E added to ER gives the pointer to the address of the operand.
#E	Immediate	27	E is the operand.
@#E	Absolute	37	E is the address of the operand.
E	Relative	67	E is the address of the operand.
@E	Deferred Relative	77	E is the pointer to the address of the operand.

B.3 INSTRUCTIONS

The instructions which follow are grouped according to the operands they take and the bit patterns of their op-codes.

In the representation of op-codes, the following symbols are used:

SS	Source operand specified by a 6-bit address mode.
DD	Destination operand specified by a 6-bit address mode.
XX	8-bit offset to a location (branch instructions)
R	Integer between 0 and 7 representing a general register.

Symbols used in the description of instruction operations are:

SE	Source Effective address
DE	Destination Effective address
( )	Contents of
→	Is transferred to

The condition codes in the processor status word (PS) are affected by the instructions. These condition codes are represented as follows:

N	Negative bit:	set if the result is negative
Z	Zero bit:	set if the result is zero
V	oVerflow bit:	set if the operation caused an overflow
C	Carry bit:	set if the operation caused a carry

In the representation of the instruction's effect on the condition codes, the following symbols are used:

*	Conditionally set
-	Not affected
0	Cleared
1	Set

To set conditionally means to use the instruction's result to determine the state of the code (see the PDP-11 Processor Handbook.

Logical operations are represented by the following symbols:

!	Inclusive OR
(!)	Exclusive OR
&	AND
—	(used over a symbol) NOT (i.e., 1's complement)

B.3.1 Double-Operand Instructions Op A,A

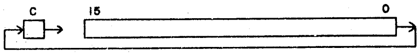
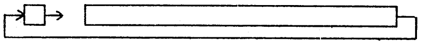
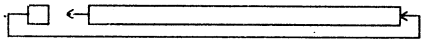
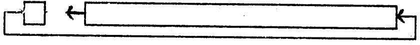
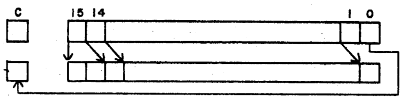
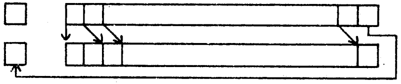
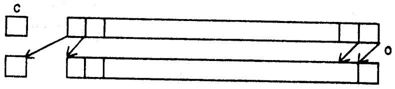
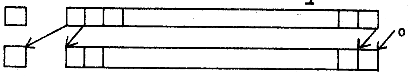
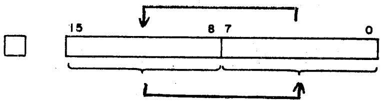
Op-Code	MNEMONIC	Stands for	Operation	Status Word Condition Codes			
				N	Z	V	C
01SSDD	MOV	MOVe	(SE)→ DE	*	*	0	-
11SSDD	MOVB	MOVe Byte					
02SSDD	CMP	CoMPare	(SE)-(DE)	*	*	*	*
12SSDD	CMPB	CoMPare Byte					
03SSDD	BIT	BIt Test	(SE)&(DE)	*	*	0	-
13SSDD	BITB	BIt Test Byte					
04SSDD	BIC	BIt Clear	$(\overline{SE})\&(DE)\rightarrow DE$	*	*	0	-
14SSDD	BICB	BIt Clear Byte					
05SSDD	BIS	BIt Set	(SE)!(DE)→ DE	*	*	0	-
15SSDD	BISB	BIt Set Byte					
06SSDD	ADD	ADD	(SE)+(DE)→ DE	*	*	*	*
16SSDD	SUB	SUBtract	(DE)-(SE)→ DE	*	*	*	*

B.3.2 Single-Operand Instructions Op A

Op-Code	MNEMONIC	Stands for	Operation	Status Word Condition Codes			
				N	Z	V	C
0050DD	CLR	CLeaR	Ø→ DE	0	1	0	0
1050DD	CLRB	CLeaR Byte					
0051DD	COM	COMplement	$(\overline{DE})\rightarrow DE$	*	*	0	1
1051DD	COMB	COMplement Byte					
0052DD	INC	INCrement	(DE)+1→ DE	*	*	*	-
1052DD	INCB	INCrement Byte					
0053DD	DEC	DECrement	(DE)-1→ DE	*	*	*	-
1053DD	DECB	DECrement Byte					
0054DD	NEG	NEGate	$(\overline{DE})+1\rightarrow DE$	*	*	*	*
1054DD	NEGB	NEGate Byte					

Op-Code	MNEMONIC	Stands for	Operation	Status Word Condition Codes			
				N	Z	V	C
0055DD 1055DD	ADC ADCB	ADd Carry ADd Carry Byte	(DE)+(C)→ DE	*	*	*	*
0056DD 1056DD	SBC SBCB	SuBtract Carry SuBtract Carry Byte	(DE)-(C)→ DE	*	*	*	*
0057DD 1057DD	TST TSTB	TeST TeST Byte	(DE)-Ø→ DE	*	*	0	0

B.3.3 Rotate/Shift Instructions Op A

Op-Code	MNEMONIC	Stands for	Operation	Status Word Condition Codes			
				N	Z	V	C
0060DD	ROR	ROtate Right		*	*	*	*
1060DD	RORB	ROtate Right Byte	even or odd byte 	*	*	*	*
0061DD	ROL	ROtate Left		*	*	*	*
1061DD	ROLB	ROtate Left Byte	even or odd byte 	*	*	*	*
0062DD	ASR	Arithmetic Shift Right		*	*	*	*
1062DD	ASRB	Arithmetic Shift Right Byte	even or odd byte 	*	*	*	*
0063DD	ASL	Arithmetic Shift Left		*	*	*	*
1063DD	ASLB	Arithmetic Shift Left Byte	even or odd byte 	*	*	*	*
0001DD	JMP	JuMP	DE→ PC	-	-	-	-
0003DD	SWAB	SWAp Bytes		*	*	0	0

B.3.4 Operate Instructions Op

Op-Code	MNEMONIC	Stands for	Operation	Status Word Condition Codes N	Z	V	C
000000	HALT	HALT	The computer stops all functions.	-	-	-	-
000001	WAIT	WAIT	The computer stops and and waits for an interrupt.	-	-	-	-
000002	RTI	ReTurn from Interrupt	The PC and PS are popped off the SP stack: ((SP))→ PC (SP)+2→ SP ((SP))→ PS (SP)+2→ SP RTI is also used to return from a trap.	*	*	*	*
000005	RESET	RESET	Returns all I/O devices to power-on state.	-	-	-	-

B.3.5 Trap Instructions Op or Op E where $0 \leq E \leq 377_8$

*OP (only)

Op-Code	MNEMONIC	Stands for	Operation	Status Word Condition Codes N	Z	V	C
*000003	(none)	(breakpoint trap)	Trap to location 14. This is used to call ODT.	*	*	*	*
*000004	IOT	Input/Output Trap	Trap to location 20. This is used to call IOX.	*	*	*	*
104000- 104377	EMT	EMulator Trap	Trap to location 30. This is used to call system programs.	*	*	*	*
104400 104777	TRAP	TRAP	Trap to location 34. This is used to call any routine desired by the programmer.	*	*	*	*

CONDITION CODE OPERATES

Op-Code	MNEMONIC	Stands for
000241	CLC	CLear Carry bit in PS.
000261	SEC	SEt Carry bit.
000242	CLV	CLear oVerflow bit.
000262	SEV	SEt oVerflow bit.

Op-Code	MNEMONIC	Stands for
000244	CLZ	CLear Zero bit.
000264	SEZ	SEt Zero bit.
000250	CLN	CLear Negative bit.
000270	SEN	SEt Negative bit.
000254	CNZ	CLear Negative and Zero bits.
000257	CCC	Clear all Condition Codes
000277	SCC	Set all Condition Codes.

B.3.6 Branch Instructions Op E where$-128_{10} \leq (E-\cdot-2)/2 \leq 127_{10}$

Op-Code	MNEMONIC	Stands for	Condition to be met if branch is to occur
0004XX	BR	BRanch always	
0010XX	BNE	Branch if Not Equal (to zero)	Z=0
0014XX	BEQ	Branch if EQual (to zero)	Z=1
0020XX	BGE	Branch if Greater than or Equal (to zero)	$N \text{\textcircled{!}} V=0$
0024XX	BLT	Branch if Less Than (zero)	$N \text{\textcircled{!}} V=1$
0030XX	BGT	Branch if Greater Than (zero)	$Z!(N \text{\textcircled{!}} V)=0$
0034XX	BLE	Branch if Less than or Equal (to zero)	$Z!(N \text{\textcircled{!}} V)=1$
1000XX	BPL	Branch if PLus	N=0
1004XX	BMI	Branch if MInus	N=1
1010XX	BHI	Branch if HIgher	C ! Z = 0
1014XX	BLOS	Branch if LOwer or Same	C ! Z = 1
1020XX	BVC	Branch if oVerflow Clear	V=0
1024XX	BVS	Branch if oVerflow Set	V=1
1030XX	BCC (or BHIS)	Branch if Carry Clear (or Branch if HIgher or Same)	C=0
1034XX	BCS (or BLO)	Branch if Carry Set (or Branch if LOwer)	C=1

B.3.7 Subroutine Call Op ER, A

Op-Code	MNEMONIC	Stands for	Operation
004RDD	JSR	Jump to SubRoutine	Push register on the SP stack, put the PC in the register: DE→(TEMP) - a temporary storage register internal to processor. (SP)-2→ SP (REG)→ (SP) (PC)→ REG (TEMP)→ PC

B.3.8 Subroutine Return Op ER

Op-Code	MNEMONIC	Stands for	Operation
00020R	RTS	ReTurn from Subroutine	Put register contents into PC and pop old contents from SP stack into register.

B.4 ASSEMBLER DIRECTIVES

Op-Code	MNEMONIC	Stands for	Operation
	.EOT	End Of Tape	Indicates the physical end of the source input medium
	.EVEN	EVEN	Ensures that the assembly location counter is even by adding 1 if it is odd
	.END m (m optional)	END	Indicates the physical and logical end of the program and optionally specifies the entry point (m)
	.WORD E,E,.. .	WORD	Generates words of data
	E,E,...	(the void operator)	Generates words of data
	.BYTE E,E,...	BYTE	Generates bytes of data
	.ASCII /xxx...x/	ASCII	Generates 7-bit ASCII characters for the text enclosed by delimiters

B.5 ERROR CODES

Error Code	Meaning
A	Addressing error. An address within the instruction is incorrect.
B	Bounding error. Instructions or word data are being assembled at an odd address in memory.

Error Code	Meaning
D	Doubly-defined symbol referenced. Reference was made to a symbol which is defined more than once.
I	Illegal character detected. Illegal characters which are also non-printing are replaced by a ? on the listing.
L	Line buffer overflow. Extra characters (more than 72_{10}) are ignored.
M	Multiple definition of a label. A label was encountered which was equivalent (in the first six characters) to a previously encountered label.
N	Number containing an 8 or 9 has a decimal point missing.
P	Phase error. A label's definition or value varies from one pass to another.
Q	Questionable syntax. There are missing arguments or the instruction scan was not completed, or a carriage return was not followed by a line feed or form feed.
R	Register-type error. An invalid use of or reference to a register has been made.
S	Symbol-table overflow. When the quantity of user-defined symbols exceeds the allocated space available in the user's symbol table, the assembler outputs the current source line with the S error code, then returns to the command string interpreter to await the next command string to be typed.
T	Truncation error. A number was too big for the allotted number of bits; the leftmost bits were truncated. T error does not occur for the result of an expression.
U	Undefined symbol. An undefined symbol was encountered during the evaluation of an expression. Relative to the expression, the undefined symbol is assigned a value of zero.

B.6 INITIAL OPERATING PROCEDURES

Loading: Use Absolute Loader (see Chapter 6). Make sure that the start address of the absolute loader is in the switches when the assembler is loaded.

Storage Requirements: PAL-11A exists in 4K and 8K versions.

Starting: Immediately upon loading, PAL-11A will be in control and initiate dialogue.

Initial Dialogue:

Printout	Inquiry
*S	What is the input device of the Source symbolic tape?

Printout	Inquiry
*B	What is the output device of the Binary object tape?
*L	What is the output device of the assembly Listing?
*T	What is the output device of the symbol Table?

Each of these questions may be answered by one of the following characters:

Character	Answer Indicated
T	Teletype keyboard
L	Low-speed reader or punch
H	High-speed reader or punch
P	line Printer (8K version only)

Each of these answers may be followed by other characters indicating options:

Option Typed	Function to be Performed
/1	on pass 1
/2	on pass 2
/3	on pass 3
/E	errors to be listed on the Teletype on the same pass (meaningful for *B or *L only)

Each answer is terminated by typing the RETURN key. A RETURN alone as answer will delete the function.

Dialogue during assembly:

Printout	Response
EOF ?	Place next tape in reader and type RETURN. A .END statement may be forced by typing E followed by RETURN.
END ?	Start next pass by placing first tape in reader and typing RETURN.
EOM ?	If listing on HSP or LPT, replenish tape or paper and type RETURN. If binary on HSP, start assembly again.
Restarting:	Type CTRL/P. The initial dialogue will be started again.

APPENDIX C

TEXT EDITOR, ED-11

C.1 INPUT/OUTPUT COMMANDS

R Reads a page of text from input device, and appends it to the contents (if any) of the page buffer. Dot is moved to the beginning of the page and Marked. (See B and M below.)

O Opens the input device when the user wishes to continue input with a new tape in the reader.

n
-n
0
@
/ } L Lists the character string

n
-n
0
@
/ } P Punches the character string

ARGUMENTS

(n) beginning at Dot and ending with nth line feed character.

(-n) beginning with 1st character following the (n+1)th previous line feed and terminating at Dot.

(0) beginning with 1st character of current line and ending at Dot.

(@) bounded by Dot and the Marked location (see M).

(/) beginning at Dot and ending with the last character in the page.

F Outputs a Form Feed character and four inches of blank tape.

nT Punches four inches of Trailer (blank tape) n times.

nN Punches contents of the page buffer (followed by a trailer if a form feed is present), deletes the contents of the buffer, and reads the next page into the page buffer. It does this n times. At completion, Dot and Mark are located at the beginning of the page buffer.

V Lists the entire line containing Dot (i.e., from previous line feed to next line feed or form feed.

< Same as -1L. If Dot is located at the beginning of a line, this simply lists the line preceding the current line.

> Lists the line following the current line.

C.2 POINTER-POSITIONING COMMANDS

B Moves Dot to the beginning of the page.

E Moves Dot to the end of the page.

M Marks the current position of Dot for later reference in a command using the argument @. Certain commands implicitly move Mark.

n			(n)	forward past n characters
-n			(-n)	backward past n characters
0	J	Moves Dot:	(0)	to the beginning of the current line
@			(@)	to the Marked location
/			(/)	to the end of the page

n			(n)	forward past n ends-of-lines
-n			(-n)	to first character following the (n+1)th previous end-of-line
0	A	Moves Dot:	(0)	to the beginning of current line
@			(@)	to the Marked location
/			(/)	to the end of the page

C.3 SEARCH COMMANDS

nG XXXX — Gets (searches for) the nth occurrence of the specified character string on the current page. Dot is set immediately after the last character in the found text, and the characters from the beginning of the line to Dot are listed on the teleprinter. If the search is unsuccessful, Dot will be at the end of the buffer and a ? will be printed out.

H XXXX — Searches the wHole file for the next occurrence of the specified character string. Combines G and N commands. If search is not successful on current page, it continues on Next page. Dot is set immediately after the last character in the found text and the characters from the beginning of the line to Dot are listed on the teleprinter. If the Search object is not found, Dot will be at the end of the buffer and a ? will be printed out. In such a case, all text scanned is copied to the output tape.

C.4 COMMANDS TO MODIFY THE TEXT

	Character-Oriented			Line-Oriented	
nD nC XXXX	Deletes Changes	the following n characters	nK nX XXXX	Kills eXchanges	the character string beginnning at Dot and ending at the nth end-of-line.
-nD -nC XXXX	Deletes Changes	the previous n characters	-nK -nX XXXX	Kills eXchanges	the character string beginning with the first character following the (n+1)th previous end-of-line and ending at Dot.
0D 0C XXXX	Deletes Changes	the current line up to Dot	0K 0X XXXX	Kills eXchanges	the current line up to Dot.
@D @C XXXX	Deletes Changes	The character string beginning at Dot and ending at a previously Marked location.	@K @X XXXX	Kills eXchanges	the character string beginning at Dot and ending at a previously Marked location.

Character-Oriented			Line-Oriented		
/D	Deletes	the character string beginning at Dot and ending with the last character of the page.	/K	Kills	the character string beginning at Dot and ending with the last character of the page.
/C	Changes		/X	eXchanges	
XXXX			XXXX		

I XXXX Inserts the specified text. LINE FEED terminates Text Mode and causes execution of the command. Dot is set to the location immediately following the last character inserted. If text was inserted before the position of Mark, ED-11 performs an M command.

C.5 SYMBOLS

Dot — Location following the most recent character operated upon.

↑ — Holding down the CTRL key (not the ↑ key) in combination with another keyboard character.

RETURN — If in command mode, it executes the current command; goes into Text Mode if required. If in Text Mode, it terminates the current line, enters a carriage return and line feed into the buffer and stays in text mode. At all times causes the carriage to move to the beginning of a new line. (RETURN is often symbolized as ↵).

↓ — (Typing the LINE FEED key) Terminates Text Mode unless the first character typed in Text Mode; executes the current command.

CTRL/FORM — A Form feed which terminates, and thus defines, a page of the user's text.

C.6 GROUPING OF COMMANDS

No Arguments		Argument n only		All Arguments (n,-n,0,@,/)	
V	(Verify: Lists current line)	G	(Get)	A	(Advance)
<	(Lists previous line)	N	(Next)	C	(Change)
>	(Lists next line)	T	(Trailer)	D	(Delete)
B	(Begin)			J	(Jump)
E	(End)			K	(Kill)
F	(Form feed)			L	(List)
H	(wHole)			P	(Punch)
I	(Insert)			X	(eXchange)
M	(Mark)				
O	(Open)				
R	(Read)				

Requiring Text Mode	Line Oriented	Character Oriented
C (Change)	A (Advance)	J (Jump)
G (Get)	K (Kill)	D (Delete)
H (wHole)	L (List)	
I (Insert)	P (Punch)	
X (eXchange)	X (eXchange)	C (Change)

C.7 OPERATING PROCEDURES

C.7.1 Loading: Use Absolute Binary Loader (see Chapter 5).

C.7.2 Storage Requirements: ED-11 uses all of core.

C.7.3 Starting: Immediately upon loading, ED-11 will be in control.

C.7.4 Initial Dialogue:

Program Types	User Response	
*I	L ↵	(if LSR is to be used for source input)
	H ↵	(if HSR is to be used for source input)
*O	L ↵	(if LSP is to be used for edited output)
	H ↵	(if HSP is to be used for edited output)

If the output device is the high-speed punch (HSP), Editor enters command mode to accept input. Otherwise the sequence continues with:

LSP OFF? ↵ (when LSP is off)

Upon input of ↵ from the keyboard, Editor enters command mode and is ready to accept input.

C.7.5 Restarting: Type CTRL/P twice, initiating the normal initial dialogue. The text to be edited should be loaded (or reloaded) at this time.

APPENDIX D

DEBUGGING OBJECT PROGRAMS ON-LINE, ODT-11 AND ODT-11X

D.1 SUMMARY OF CONTENTS

ODT indicates readiness to accept commands by typing * or by opening a location by printing its contents.

1. ODT-11

n/	opens word n
\	reopens last word opened
RETURN key	closes open location
↓	opens next location
↑	opens previous location
←	opens relatively addressed word
$n/	opens general register n (0-7)
n;G	goes to word n and starts execution
n;B	sets breakpoint at word n
;B	removes breakpoint
$B/	opens breakpoint status word
;P	proceeds from breakpoint, stops again on next encounter
n;P	proceeds from breakpoint, stops again on nth encounter
$M/	opens mask for word search
n;W	searches for words which match n in bits specified in $M
n;E	searches for words which address word n
n/ (contents) m;O	calculates offsets from n to m
$S/	opens location containing user program's status register
$P/	opens location containing ODT's priority level

NOTE

If a word is currently open, new contents for the word may be typed followed by any of the commands RETURN, ↓ , ↑ , or ← . The open word will be modified and closed before the new command is executed.

2. ODT-11X

In addition to the commands of the regular version, the extended version has the following:

n\	opens byte
\	reopens last byte opened
@	opens the absolutely addressed word
>	opens the word to which the branch refers
<	opens next location of previous sequence
n;rB	(r between 0 and 7) sets breakpoint r at word n
;rB	removes breakpoint r
;B	removes all breakpoints
$B/	opens breakpoint 0 status word. Successive LINE FEEDs open words for other breakpoints and single-instruction mode.
;nS	enables Single-instruction mode (n can have any value and is not significant)
n;P	in single-instruction mode, Proceeds with program run for next n instructions before reentering ODT (if is missing, it is assummed to be 1)
;S	disables Single-instruction mode

D.2 OPERATING PROCEDURES

For assembling and loading the source tapes of both ODT versions, see Section 5.6.3 The following describes use of the supplied binary tapes.

1. Loading

Both ODT versions are loaded by using the Absolute Loader (see Section 6.2.2). ODT-11 is loaded into core starting at location 13060, and requires about 500 locations of core. ODT-11X is loaded into core starting at location 12150 and requires about 800 locations of core.

2. Starting

Each ODT version is automatically started by the Absolute Loader at its start address immediately after loading.

3. Restarting

There are two ways of restarting ODT:

1. Restart at start address +2
2. Reenter at start address +4

To restart, key in the start address +2 (13062 for ODT-11 or 12152 for ODT-11X) and press the START switch. All previously set breakpoints will be removed, registers R0-R6 will be saved, and ODT will assume that the trace trap vector has been initialized.

To reenter, key in the start address +4 (13064 for ODT-11 or 12154 for ODT-11X) and press START. All previously set breakpoints and internal registers will be saved.

APPENDIX E

LOADING AND DUMPING CORE MEMORY

E.1 The BOOTSTRAP Loader

1.1. Loading the Bootstrap Loader

The Bootstrap Loader should be toggled into the highest core memory bank.

```
xx7744        016701
xx7746        000026
xx7750        012702
xx7752        000352
xx7754        005211
xx7756        105711
xx7760        100376
xx7762        116162
xx7764        000002
xx7766        xx7400
xx7770        005267
xx7772        177756
xx7774        000765
xx7776        yyyyyy
```

xx represents the highest available memory bank. For example, the first location of the loader would be one of the following, depending on memory size, and xx in all subsequent locations would be the same as the first.

Location	Memory Bank	Memory Size
017744	0	4K
037744	1	8K
057744	2	12K
077744	3	16K
117744	4	20K
137744	5	24K
157744	6	28K

The contents of location xx7776 (yyyyyy) in the Instruction column above should contain the device status register address of the paper tape reader to be used when loading the bootstrap formatted tapes specified as follows:

Teletype Paper Tape Reader -- 177560
High-speed Paper Tape Reader -- 177550

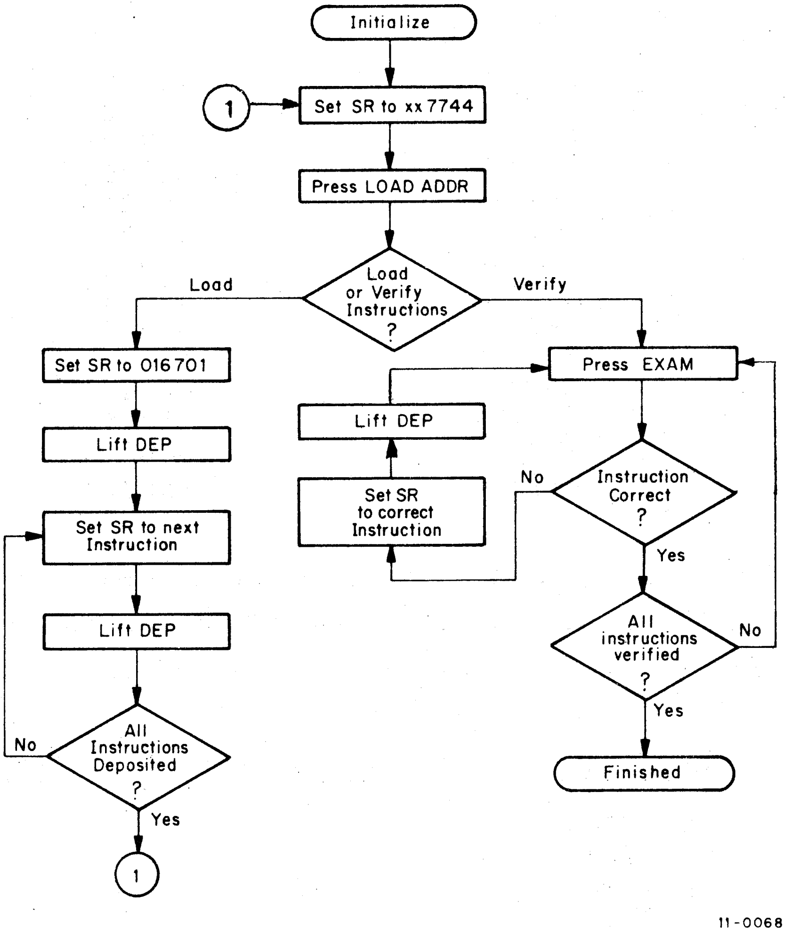


Figure E-1 Loading and Verifying the Bootstrap Loader

2. Loading with the Bootstrap Loader

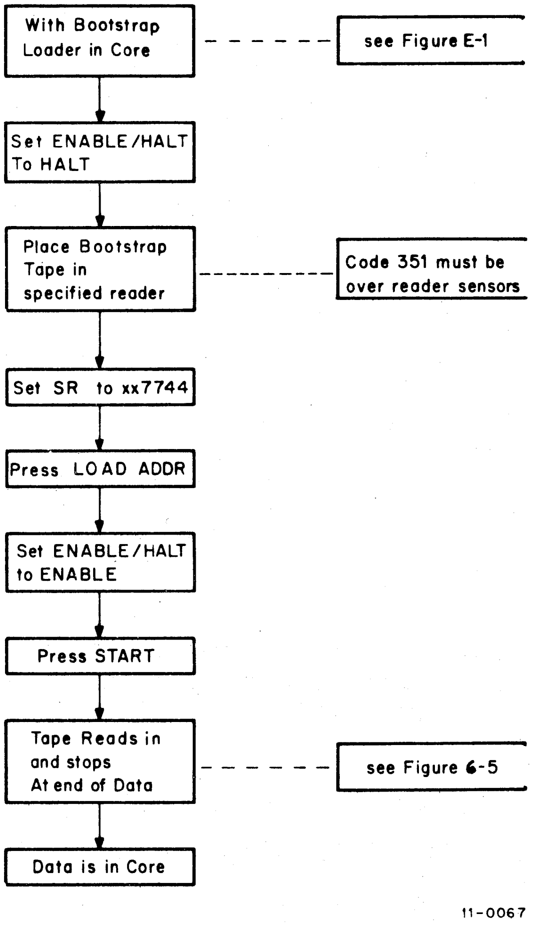

With Bootstrap Loader in Core
see Figure E-1
Set ENABLE/HALT To HALT
Place Bootstrap Tape in specified reader
Code 351 must be over reader sensors
Set SR to xx7744
Press LOAD ADDR
Set ENABLE/HALT to ENABLE
Press START
Tape Reads in and stops At end of Data
see Figure 6-5
Data is in Core
11-0067

Figure E-2. Loading Bootstrap Tapes into Core

E.2 THE ABSOLUTE LOADER

1. Loading the Absolute Loader

The Bootstrap Loader is used to load the Absolute Loader into core. (See Figure E-2.) The Absolute Loader occupies locations xx7474 through xx7743, and its starting address is xx7500.

2. Loading with the Absolute Loader

When using the Absolute Loader, there are three types of loads available: normal, relocated to specific address, and continued relocation.

Optional switch register settings for the three types of loads are listed below.

	Switch Register	
Type of Load	Bits 1-14	Bit 0
Normal	(ignored)	0

	Switch Register	
Type of Load	Bits 1-14	Bit 0
Relocated - continue loading where left off	0	1
Relocated - load in specified area of core	nnnnn (specified address)	1

E.3 CORE MEMORY DUMPS

The two dump programs are

DUMPTT, which dumps the octal representation of the contents of all or specified portions of core onto the teleprinter, low-speed or high-speed punch, or line printer.

DUMPAB, which dumps the absolute binary code of the contents of specified portions of core onto the low-speed (Teletype) or high-speed punch.

Both dumps are supplied on punched paper tape in bootstrap and absolute binary formats. The following figure summarizes loading and using the Absolute binary tapes.

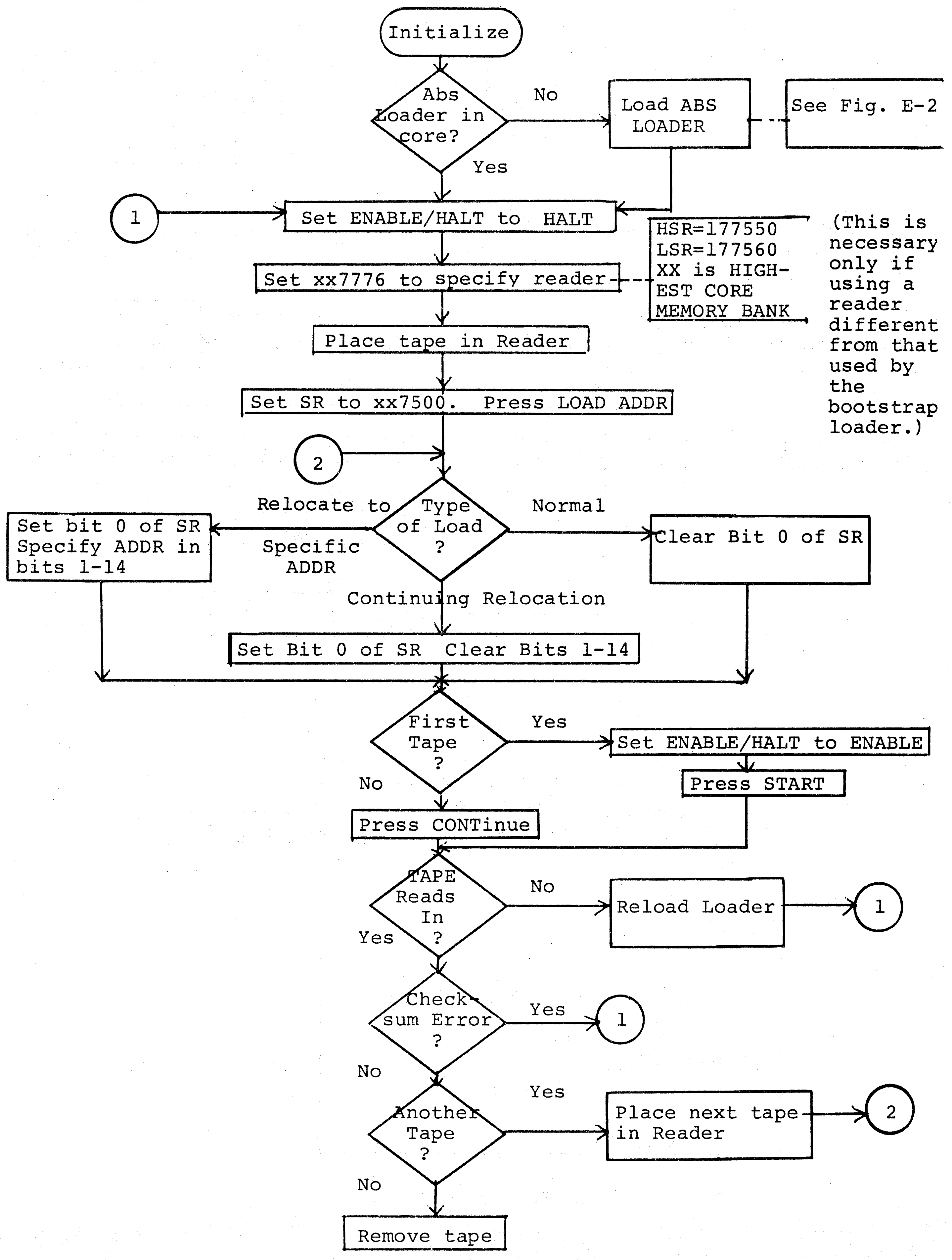

Initialize
Abs Loader in core?
No
Yes
Load ABS LOADER
See Fig. E-2
1
Set ENABLE/HALT to HALT
Set xx7776 to specify reader
HSR=177550
LSR=177560
XX is HIGHEST CORE MEMORY BANK
(This is necessary only if using a reader different from that used by the bootstrap loader.)
Place tape in Reader
Set SR to xx7500. Press LOAD ADDR
2
Type of Load ?
Relocate to Specific ADDR
Normal
Set bit 0 of SR Specify ADDR in bits 1-14
Clear Bit 0 of SR
Continuing Relocation
Set Bit 0 of SR Clear Bits 1-14
First Tape ?
Yes
No
Set ENABLE/HALT to ENABLE
Press START
Press CONTinue
TAPE Reads In ?
No
Yes
Reload Loader
1
Checksum Error ?
Yes
No
1
Another Tape ?
Yes
No
Place next tape in Reader
2
Remove tape

Figure E-3. Loading with the Absolute Loader

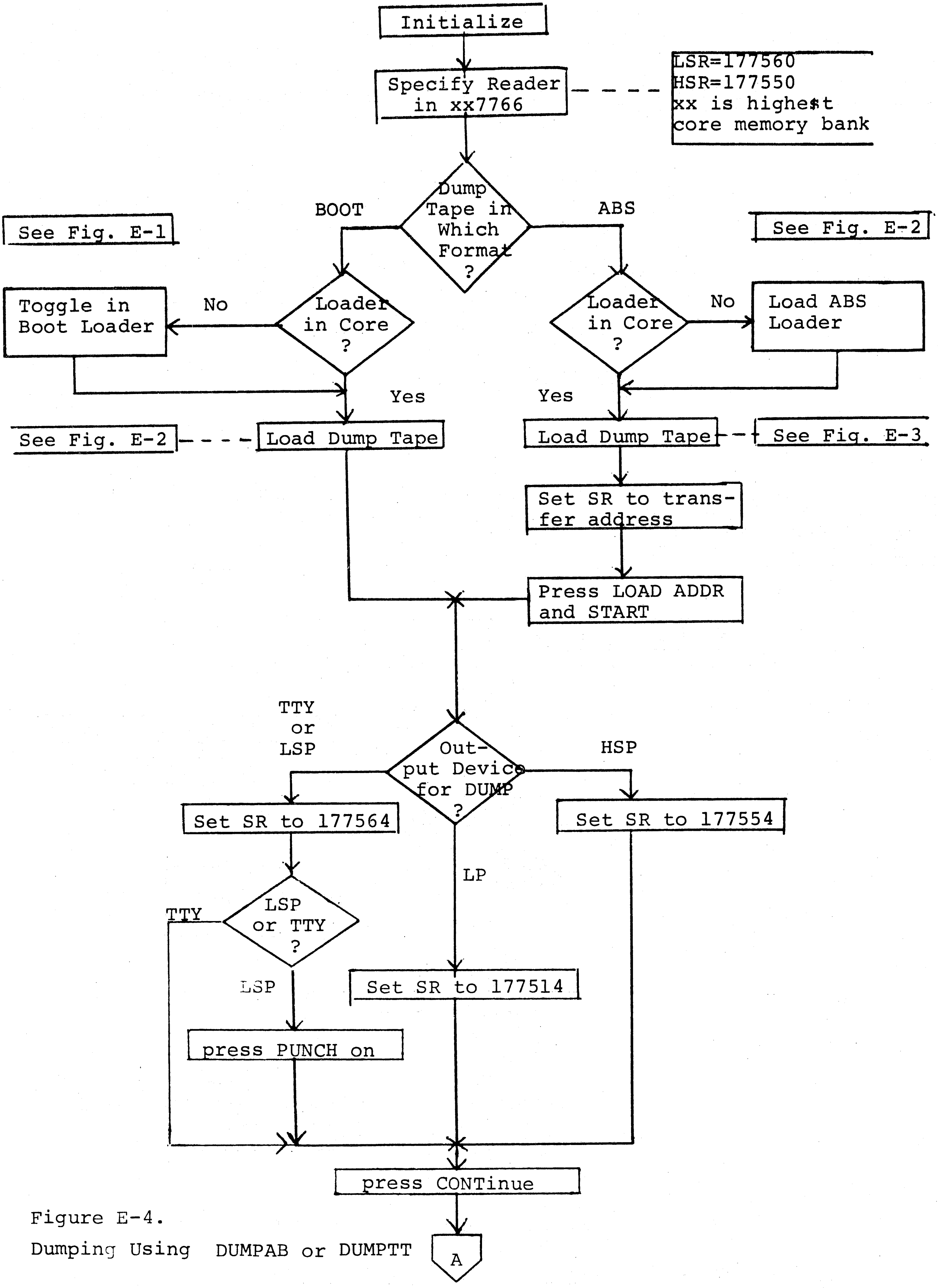


Figure E-4.
Dumping Using DUMPAB or DUMPTT

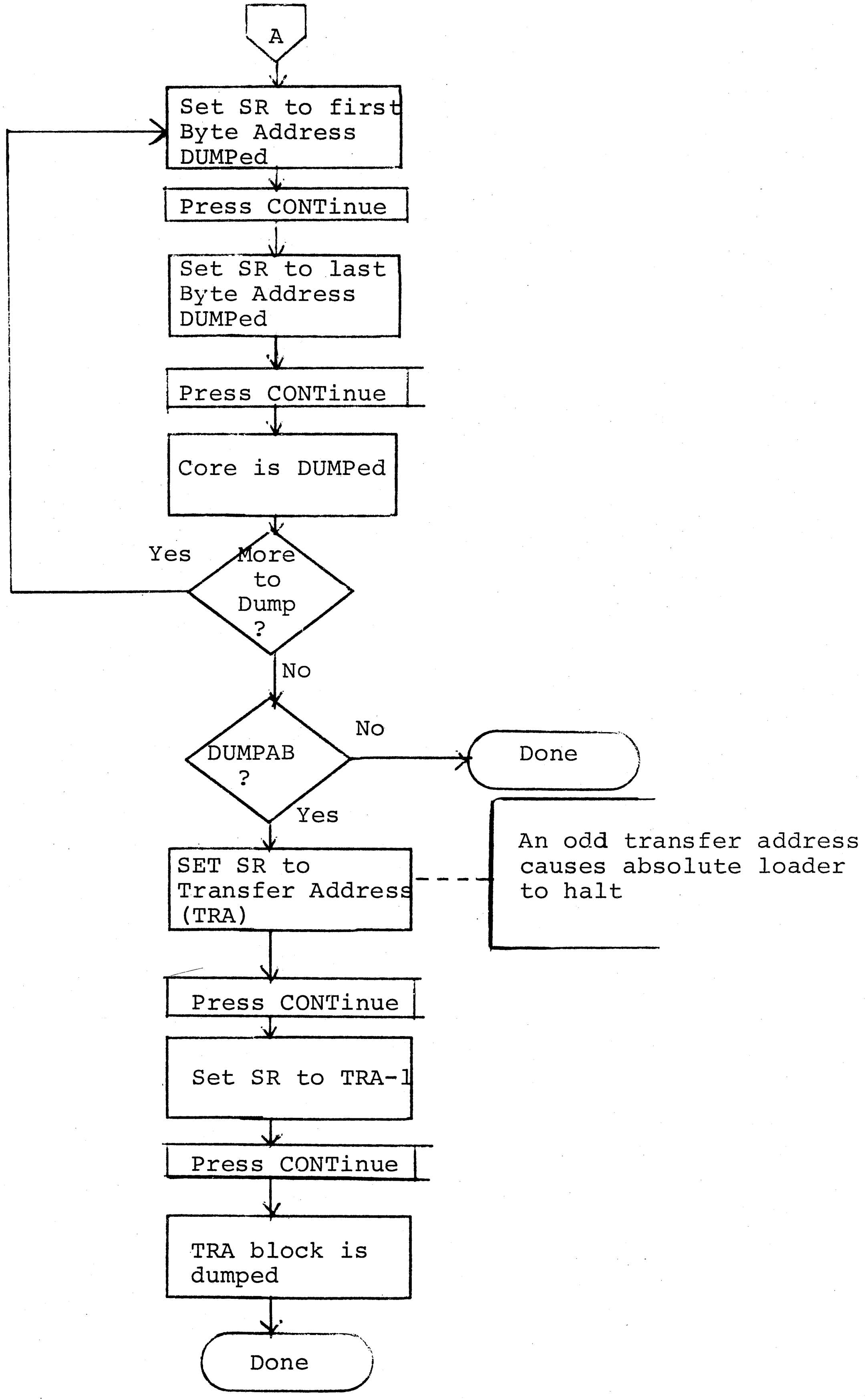

A
Set SR to first Byte Address DUMPed
Press CONTinue
Set SR to last Byte Address DUMPed
Press CONTinue
Core is DUMPed
Yes
More to Dump ?
No
DUMPAB ?
No
Done
Yes
SET SR to Transfer Address (TRA)
An odd transfer address causes absolute loader to halt
Press CONTinue
Set SR to TRA-1
Press CONTinue
TRA block is dumped
Done

Figure E-4 (continued). Dumping Using DUMPAB or DUMPTT

APPENDIX F

INPUT/OUTPUT PROGRAMMING, IOX

F.1 INSTRUCTION SUMMARY

1. Format:

```
IOT
.WORD (an address)
.BYTE (a command code, a slot number of a device)
.WORD (done address)                ;READR AND WRITR ONLY
```

2. Command Codes:

```
 INIT  = 1
RESET  = 2
RSTRT  = 3
WAITR  = 4
 SEEK  = 5
 READ  = 11
WRITE  = 12
READR  = 13
WRITR  = 14
```

F.2 PROGRAM FLOW SUMMARY

1. Set up buffer header:

	Location	Contents
BUFFER HEADER	Buffer and Buffer+1	Maximum number of data bytes (unsigned integer)
	Buffer+2	Mode of data (byte)
	Buffer+3	Status of data (byte)
	Buffer+4 and Buffer+5	Number of data bytes involved in transfer (unsigned integer)
	Buffer+6	Actual data begins here.

Mode Byte Format

Bits	7	6	5	4	3	2	1	0	Bits
1=	No Echo						Unformatted	Binary	=1
0=	Echo						Formatted	ASCII	=0

Coding Mode Byte

Formatted ASCII	0	(or 200 to suppress echo)
Formatted Binary	1	
Unformatted ASCII	2	(or 202 to suppress echo)
Unformatted Binary	3	

Status Byte Format

7	6	5	4	3	2	1	0
1= DONE	1= EOM	1= EOF	SEE CODES				
			NON-FATAL ERRORS				

Coding Non-Fatal Errors

2_8 = checksum error (formatted binary)

3_8 = truncation of a long line

4_8 = an improper mode

2. Assign devices to slots in Device Assignment Table:

(RESET and INIT commands)

Slot numbers are in the range 0 to 7.

Device Codes:

KBD = 1	LSP = 4	LPT = 10
TTY = 2	HSR = 5	
LSR = 3	HSP = 6	

3. Use a data transfer command to initiate the transfer.

F.3 FATAL ERRORS

Fatal errors result in a jump to 40_8 with R0 set to the error code. R1 is set to the value of the PC for error code 0. Errors 1-5 cause R1 to be set to an IOT argument or to the instruction following the arguments.

Fatal Error Code	Reason
0	Illegal Memory Reference, SP overflow, illegal instruction
1	Illegal command
2	Slot out of range
3	Device out of range
4	Slot not inited
5	Illegal data mode

APPENDIX G

SUMMARY OF FLOATING POINT MATH PACKAGE, FPMP-11

This appendix lists all the global entry points of FPMP-11 and provides a brief description of the purposes of each. Sections G.1 and G.2 are for reference when it is desired to call FPMP-11 routines directly (i.e., without the use of the TRAP handler). Entry names preceded by an octal number can be referenced via the TRAP handler. The number is the "routine number" referred to in the FPMP-11 manual. If the number is enclosed in parentheses, the routine cannot be accessed by the present TRAP handler, but has been assigned a number for future use. For a more detailed explanation of the Floating Point Math Package, refer to the FPMP-11 User's Manual DEC-11-NFPMA-A-D.

Examples of the calling conventions are:

```
POLISH MODE:    .
                .
                .
                JSR R4,$POLSH      ;enter Polish mode
                $subr1             ;call desired subroutines
                $subr2
                .
                .
                .
                $subrn             ;call last subroutine desired
                .WORD   .+2        ;leave Polish mode
                .
                .
                .
                .
------------------------------------------------------------------
J5RR:           .
                .
                .
                JSR  R5,subr       ;call desired subroutine
                BR       XX
                .WORD    arg1      ;subroutine argument address
                .WORD    arg2
                .
                .
                .
                .WORD    argn      ;last argument
XX:             .                  ;return point
                .
                .
------------------------------------------------------------------
```

```
JPC:                 .
                     .
                     .
                     push args onto stack
                     JSR PC,subr
                     .
                     .
                     .
```

G.1 OTS ROUTINES

These are the routine taken from the FORTRAN operating time system. The codes used in the following table are:

S = Routine is included in the standard single precision (2-word) package.
D = Routine is included in the standard double precision (4-word) package.
SD = Routine is included in both standard packages.

Octal codes shown in parentheses are not yet implemented.

NAME	OCTAL CODE	PKG	# OF ARGU	MODE	DESCRIPTION
$ADD	14	D	2	Polish	The double precision add routine. Adds the top stack item (4-words) to the second item (4-words) and leaves the four word sum in their place.
$ADR	12	S	2	Polish	The single precision add routine. Same as $ADD except it uses 2 word numbers.
AINT	26	S	1	J5RR	Returns sign of argument * greatest real integer = absolute value of the argument in R0,Rl.
ALOG	53	S	1	J5RR	Calculates natural logarithm of its single argument and returns a two word result in R0,Rl.
ALOG10	54	S	1	J5RR	Same as ALOG, except calculates base-10 logarithm.
ATAN	42	S	1	J5RR	Returns the arctangent of its argument in R0,Rl.

NAME	OCTAL CODE	PKG	# OF ARGU	MODE	DESCRIPTION
ATAN2	(43)	S	2	J5RR	Returns ARCTAN(ARG1/ARG2) in R0,R1.
$CMD	16	D	2	Polish	Compares top 4 word items on the stack, flushes the two items, and returns the following condition codes: 4(SP) @SP N=1,Z=0 4(SP) = @SP N=0,Z=1 4(SP) @SP N=0,Z=0
$CMR	17	S	2	Polish	Same as $CMD except it is for 2 word arguments.
COS	37	S	1	J5RR	Single precision version of DCOS.
DATAN	44	D	1	J5RR	Double precision version of ATAN.
DATAN2	(45)	D	2	J5RR	Double precision version of ATAN2.
DBLE	(34)		1	J5RR	Returns in R0-R3 the double precision equivalent of the single precision (two word) argument.
$DCI	(57)	SD	4	JPC	ASCII to double conversion. Calling sequence: Push address of start of ASCII field. Push length of ASCII field in bytes. Push format scale D (from W.D) position of assumed decimal point (see FORTRAN manual). Push P format scale (see FORTRAN manual). JSR PC,$DCI. Returns 4 word result on top of stack.
$DCO	(61)	SD	5	JPC	Double precision to ASCII conversion. Calling sequence: Push address of start of ASCII field. Push length in bytes of ASCII field (W part of W.D) Push D part of W.D (position of decimal point). Push P scale. Push 4 word value to be converted, lowest order word first. JSR PC,$DCO.

NAME	OCTAL CODE	PKG	# OF ARGU	MODE	DESCRIPTION
DCOS	41	D	1	J5RR	Calculates the cosine of its double precision argument and returns the double precision result in R0-R3.
DEXP	52	D	1	J5RR	Calculates the exponential of its double precision argument, and returns the double precision result in R0-R3.
$DI	(11)	SD		Polish	Converts double precision number on the top of the stack to integer. Leaves result on stack.
$DINT	(76)	D	1	Polish	OTS internal function to find the integer part of a double precision number.
DLOG	55	D	1	J5RR	Double precision (4 word) version of ALOG.
DLOG10	56	D	1	J5RR	Double precision (4 word) version of ALOG10.
$DR	(6)		1	Polish	Replaces the double precision item at the top of the stack with its two word, rounded form.
DSIN	40	D	1	J5RR	Calculates the sine of its double precision arg. and returns the double precision result in R0-R3.
DSQRT	47	D	1	J5RR	Calculates the square root of its double precision arg. and returns the double precision result in R0-R3.
$DVD	23	D	2	Polish	The double precision division routine. Divides the second 4-word item on the stack by the top item and leaves the quotient in their place.
$DVI	(24)		2	Polish	The integer division routine. Calculates 2(SP)/@SP and returns the integer quotient on the top of the stack.
$DVR	25	S	2	Polish	The single precision division routine. Same as $DVD, but for 2 word floating point numbers.

	OCTAL		# OF		
NAME	CODE	PKG	ARGU	MODE	DESCRIPTION
$ECO	(62)	SD	5	JPC	Single precision to ASCII conversion according to E format. Same calling sequence as $DCO except that a 2-word value is to be converted.
EXP	51	S	1	J5RR	Single precision version of DEXP. Returns result in R0,R1.
$FCALL	-	S			Internal OTS routine.
$FCO	(64)	SD	5	JPC	Same as $ECO except uses F format conversion.
FLOAT	(32)		1	J5RR	Returns in R0-R1, the real equivalent of its integer argument.
$GCO	(63)	SD	5	JPC	Same as $ECO except uses G format conversion.
$ICI	(65)		2	JPC	ASCII to integer conversion calling sequence: Push address of start of ASCII field. Push length in bytes of ASCII field. JSR PC,$ICI Returns with integer result on top of stack.
$ICO	(67)		3	JPC	Integer to ASCII conversion. Calling sequence: Push address of ASCII field. Push length in bytes of ASCII field. Push integer value to be converted JSR PC,$ICO Error will return with C bit set on. R0-R3 destroyed.
IDINT	(31)		1	J5RR	Returns sign of arg * greatest integer <= |arg| in R0. Arg is double precision.
$ID	(5)	SD	1	Polish	Convert full word argument on the top of the stack to double precision and return result as top 4-words of stack.
IFIX	(35)		1	J5RR	Returns the truncated and fixed real argument in R0.

NAME	OCTAL CODE	PKG	# OF ARGU	MODE	DESCRIPTION
INT	(30)		1	J5RR	Same as IDINT for single precision args.
$INTR	(27)	S	1	Polish	Same function as AINT, but called in Polish mode with argument and returns result on the stack.
$IR	(4)	SD	1	Polish	Convert full word argument on the top of the stack to single precision and return result as top 2-words of stack.
$MLD	22	D	2	Polish	Double precision multiply. Replaces the top two doubles on the stack with their product.
$MLI	(20)		2	Polish	Integer multiply. Replaces the top 2 integers on the stack with their full word product.
$MLR	21	S	2	Polish	Single precision multiply. Replaces the top two singles on the stack with their product.
$NGD	(3)	SD	2	Polish	Negate the double precision number on the top of the stack.
$NGI	(1)	SD	1	Polish	Negate the integer on the top of the stack.
$NGR	(2)	SD	1	Polish	Negate the single precision number on the top of the stack.
$OCI	(66)		2	JPC	ASCII to octal conversion. Same call as $ICI.
$OCO	(70)		3	JPC	Octal to ASCII conversion. Some call as $ICO.
$POLSH	-	SD	-	-	Called whenever it is desired to enter Polish mode from normal in-line code. It must be called via a JSR R4,$POLSH.
$POPR3	-	D	-	Polish	Internal routine to pop 2-words from the stack and place them into R0,R1.
$POPR4	-	D	-	Polish	Internal routine to pop 4-words from the stack and place them in R0-R3.

	OCTAL		# OF		
NAME	CODE	PKG	ARGU	MODE	DESCRIPTION
$POPR5	-	D	-	Polish	Internal routine to pop 4-words from the stack and place them in registers R0-R3.
$PSHR1	-	SD		Polish	Internal routine to push the contents of R0 onto the stack.
$PSHR2	-	SD	-	Polish	Same as $PSHR1.
$PSHR3	-	SD	-	Polish	Push R0,R1 onto stack.
$PSHR4	-	SD	-	Polish	Push R0-R3 onto stack.
$PSHR5	-	SD	-	Polish	Same as $PSHR4.
$RCI	(60)	SD	4	JPC	ASCII to single precision conversion. Same calling sequence as $DCI. Returns 2-word result on top of stack.
$RD	(7)			Polish	Converts the single precision number on the top of the stack to double precision format. Leaves result on stack.
$RI	(10)	SD		Polish	Converts single precision number on the top of the stack to integer. Leaves result on stack.
$SBD	15	D		Polish	The double precision subtract routine. Subtracts the double precision number on the top of the stack from the second double precision number on the stack and leaves the result on the top of the stack in their place.
$SBR	13	S		Polish	Same as $SBD but for single precision.
SIN	36	S	1	J5RR	Single precision version of DSIN.
SNGL	(33)		1	J5RR	Rounds double precision argument to single precision. Returns result in R0,R1.
SQRT	46	S	1	J5RR	Single precision version of DSQRT.
TANH	50	S	1	J5RR	Single precision hyperbolic tangent function. Returns (EXP(2*ARG)-1)/(EXP(2*ARG)+1) in R0,R1.

G.2 NON-OTS ROUTINES

These routines are written especially for FPMP-11 and should not be called directly by the user.

NAME	OCTAL CODE	PKG	DESCRIPTION
$ERR	-	SD	Internal error handler.
$ERRA	-	SD	Similar to $ERR.
$LDR	71	S	Load FLAC, single precision.
$LDD	72	D	Load FLAC, double precision.
$STR	73	S	Store FLAC, single precision.
$STD	74	D	Store FLAC, double precision.
TRAPH	-	SD	The TRAP handler routines and tables.

G.3 ROUTINES ACCESSED VIA TRAP HANDLER

The following is a table of the FPMP-11 routines which can be accessed via TRAPH, the trap handler. Each routine name (entry point) is preceded by its TRAP code number to be used to access it, and followed by a brief description of its operation when called via the TRAP handler. Those entries which are preceded by an asterisk (*) perform operations only on the FLAC, and address no operands. For example, a TRAP call to the single precision square root routine can be coded as follows:

```
              .
              .
              .
       TRAP   46
              .
              .
              .
```

The net effect of the above TRAP instruction is to replace the contents of the FLAC with its square root and then set the condition codes to reflect the result. Note that since the FLAC is implicitly addressed in this instruction, the TRAP call supplies no other address. For such a TRAP call, the addressing mode bits (bits 6 and 7 of the TRAP instruction) are ignored.

All entries not marked by an asterisk require an operand when called. The operand is addressed in one of the 4 addressing modes explained in section 3.1.1. of the FPMP-11 User's Manual. The addressing mode is specified in bit 6-7 of the TRAP instruction.

("Operand" is the contents of the location addressed in the TRAP call.)

	OCTAL CODE	NAME	DESCRIPTION
	14	$ADD	Double precision addition routine. Adds operand to the FLAC. Assumes 4-word operand.
	12	$ADR	Single precision addition routine. Adds operand to the FLAC. Assumes 2-word operand.
*	26	AINT	Replaces contents of the FLAC by its integer part. SIGN(FLAC) * greatest integer <= |FLAC|. Assumes 2-word argument in FLAC.
*	53	ALOG	Replaces contents of the FLAC by its natural logarithm. Assumes 2-word argument in FLAC.
*	54	ALOG10	Same as ALOG, except calculates base-10 log.
*	42	ATAN	Replaces contents of the FLAC by its arctangent. Assumes 2-word argument in FLAC.
	16	$CMD	Compares operand to the contents of the FLAC, and returns the following condition codes. FLAC<operand, N=1,Z=0 FLAC=operand, N=0,Z=1 FLAC>operand, N=0,Z=0 Assumes 4-word operands.
	17	$CMR	Same as $CMD, but for 2-word operands.
*	37	COS	Same as DCOS, but for 2-word argument.
*	44	DATAN	Same as ATAN, but for 4-word argument.
*	52	DEXP	Replaces the contents of the FLAC by its exponential. Assumes 4-word argument in the FLAC.
*	55	DLOG	Same as ALOG, but for 4-word argument.
*	56	DLOG10	Same as ALOG10, but for 4-word argument.
*	41	DCOS	Replaces the contents of the FLAC by its cosine. Assumes 4-word argument in the FLAC.

	OCTAL CODE	NAME	DESCRIPTION
*	40	DSIN	Same as DCOS, but calculates sine instead of cosine.
*	47	DSQRT	Replaces the contents of the FLAC by its square root. Assumes 4-word argument in the FLAC.
	23	$DVD	Double precision division routine. Divides the FLAC by the operand and stores the result in the FLAC. Assumes 4-word operands.
	25	$DVR	Same as $DVD, but for 2-word operands.
*	51	EXP	Same as DEXP, but for 2-word argument.
	72	$LDD	Same as $LDR, but assumes 4-word operand.
	71	$LDR	Replaces the contents of the FLAC by the operand. Assumes 2-word operand.
	22	MLD	Double precision multiplication routine. Multiplies the contents of the FLAC by the operand and stores the result in the FLAC. Assumes 4-word operands.
	21	$MLR	Same as $MLD, but for 2-word operands.
	15	$SBD	The double precision subtraction routine. Subtracts the operand from the contents of the FLAC. Assumes a 4-word operand.
	13	$SBR	Same as $SBD, but for 2-word operand.
*	36	SIN	Same as DSIN, but for 2-word argument.
*	46	SQRT	Same as DSQRT, but for 2-word argument.
	73	$STR	Stores the contents of the FLAC into the operand location. The contents of the FLAC are unchanged.
	74	$STD	Same as $STR, but assumes 4-word operand location.
*	50	TANH	Replaces the contents of the FLAC by its hyperbolic tangent. Assumes 2-word argument.

APPENDIX I

ASSEMBLING THE PAL-11A ASSEMBLER

The following procedures are for assembling the PAL-11 Assembler source tapes. An 8K version of the PAL-11A (V007A) Assembler is required, thus also requiring at least an 8K PDP-11 system.

The Assembler consists of two programs. The first program, on tape 1, is a memory clear program and is very short (DEC-11-UPLAA-A-PA1). The second program is the Assembler proper, and consists of eleven ASCII tapes (DEC-11-UPLAA-A-PA2-PA12). They are assembled as follows:

1. Generate a sufficient amount of blank leader tape.
2. Assemble the memory clear program source tape (DEC-11-UPLAA-A-PA1) and assign the binary output to the high-speed punch. For example, PAL-11A's initial dialogue to specify the 2-pass assembly would be:

```
*S  H
*B  H/E
*L
*T
                           (PA1 assembly - 1st pass)
END?
                           (PA1 assembly - 2nd pass)
ØØØØØØ ERRORS              (No errors - Do not remove
C                          the binary tape from the punch.)
```

3. Assemble the rest of the Assembler's source tapes (PA2 - PA12) in numerical sequence.

   Assign the binary output to the high-speed punch. For example, the initial dialogue should be answered as follows:

```
*S  H
*B  H/E
*L
*T
EOF  ?                     (Enter tape PA2 for 1st pass)
EOF  ?                     (End of tape PA2, enter PA3)
EOF  ?                     (End of tape PA3, enter PA4)
EOF  ?                     (End of tape PA4, enter PA5)
EOF  ?                     (End of tape PA5, enter PA6)
EOF  ?              (End of tape PA6, enter PA7)
EOF  ?              (End of tape PA7, enter PA8)
EOF  ?              (End of tape PA8, enter PA9)
EOF  ?              (End of tape PA9, enter PA10)
EOF  ?              (End of tape PA10, enter PA11)
EOF  ?              (End of tape PA11, enter PA12)
MAXC13 = ******     SIMBC  = ******   (End of first pass)
END ?
EOF  ?              (Enter tape PA2  for 2nd pass)
EOF  ?              (End of tape PA2, enter PA3)
EOF  ?              (End of tape PA3, enter PA4)
EOF  ?              (End of tape PA4, enter PA5)
EOF  ?              (End of tape PA5, enter PA6)
EOF  ?              (End of tape PA6, enter PA7)
EOF  ?              (End of tape PA7, enter PA8)
EOF  ?              (End of tape PA8, enter PA9)
EOF  ?              (End of tape PA9, enter PA10)
EOF  ?              (End of tape PA10, enter PA11)
EOF  ?              (End of tape PA11, enter PA12)
ØØØØØØ ERRORS       (End of 2nd pass)
C
*S
```

Note that at the end of the first pass there are two undefined symbols: MAXC13 and SIMBC. These undefined symbols are resolved so that there are no errors reported during the second pass.

Be sure that there is sufficient blank trailer tape on the binary output tape before removing the assembled tape from the punch.

Normally, using high-speed paper tape input and output, this process requires about 45 minutes. If a symbol table and listing are requested, there will be about 750 symbols and about 4500 lines of listing.

APPENDIX H

TAPE DUPLICATION

Duplication of paper tapes can be accomplished via low- or high-speed I/O devices by toggling (as with the Bootstrap Loader) the following program directly into memory through the Switch Register. (Refer to Section 6.1.1 in Chapter 6 if necessary, for toggling procedure.)

1. Turn on appropriate device switches and place tape in desired reader.
2. Set ENABLE/HALT switch to HALT.
3. Set Switch Register to the desired starting address and press LOAD ADDR.
4. Set Switch Register to each value listed in the CONTENTS column below, lifting the DEP switch after each setting. (Addresses are automatically incremented.) The desired input device (either Low- or High-Speed Reader) and output device (Low- or High-Speed Punch) are specified in the last two words.

ADDRESS	CONTENTS
0	016700
2	000024
4	016701
6	000022
10	005210
12	105710
14	100376
16	105711
20	100376
22	022021
24	111011
26	000764
30	177560 (LSR) or 177550 (HSR)
32	177564 (LSP) or 177554 (HSP)

5. Set Switch Register to starting address specified in 3 above and press LOAD ADDR.
6. Set ENABLE/HALT switch to ENABLE.
7. Press START switch.

NOTE

This program is recommended as a simple way of duplicating the system tapes. However, for extensive tape duplication, the program shown in section 7.8 is recommended.

APPENDIX J
STANDARD PDP-11 ABBREVIATIONS

Abbreviation	Definition
ABS	absolute
A/D	analog-to-digital
ADC	add carry
ADRS	address
ASCII	American Standard Code for Information Interchange
ASL	arithmetic shift left
ASR	arithmetic shift right automatic send/receive
B	byte
BAR	bus address register
BBSY	bus busy
BCC	branch if carry clear
BCS	branch if carry set
BEQ	branch if equal
BG	bus grant
BGE	branch if greater or equal
BGT	branch if greater than
BHI	branch if higher
BHIS	branch if higher or same
BIC	bit clear
BIS	bit set
BIT	bit test
BLE	branch if less or equal
BLOS	branch if lower or same
BLT	branch if less than
BMI	branch if minus
BNE	branch if not equal
BPL	branch if plus
BR	branch
BRD	bus register data
BRX	bus request
BSP	back space
BSR	bus shift register back space record
BSY	busy
BVC	branch if overflow clear
BVS	branch if overflow set

Abbreviation	Definition
CBR	console bus request
CLC	clear carry
CLK	clock
CLN	clear negative
CLR	clear
CLV	clear overflow
CLZ	clear zero
CMP	compare
CNPR	console nonprocessor request
CNTL	control
COM	complement
COND	condition
CONS	console
CONT	contents continue
CP	central processor
CSR	control and status register
D	data
D/A	digital-to-analog
DAR	device address register
DATI	data in
DATIP	data in, pause
DATO	data out
DATOB	data out, byte
DBR	data buffer register
DCDR	decoder
DE	destination effective address
DEC	decrement Digital Equipment Corp.
DEL	delay
DEP	deposit
DEPF	deposit flag
DIV	divide
DMA	direct memory access
DSEL	device select
DST	destination
DSX	display, X-deflection register

Abbreviation	Definition	Abbreviation	Definition
EMT	emulator trap	LSB	least significant bit
ENB	enable	LSBY	least significant byte
EOF	end-of-file	LSD	least significant digit
EOM	end-of-medium		
ERR	error	MA	memory address
EX	external	MAR	memory address register
EXAM	examine	MBR	memory buffer register
EXAMF	examine flag	MEM	memory
EXEC	execute	ML	memory location
EXR	external reset	MOV	move
		MSB	most significant bit
F	flag (part of signal name)	MSBY	most significant byte
FCTN	function	MSD	most significant digit
FILO	first in, last out	MSEL	memory select
FLG	flag	MSYN	master sync
GEN	generator	ND	negative driver
		NEG	negate
INDIVR	integer divide routine	NOR	normalize
INC	increment	NPG	nonprocessor grant
	increase	NPR	nonprocessor request
INCF	increment flag	NPRF	nonprocessor request flag
IND	indicator	NS	negative switch
INH	inhibit		
INIT	initialize	ODT	octal debugging technique
INST	instruction	OP	operate
INTR	interrupt		operation
INTRF	interrupt flag	OPR	operator
I/O	input/output		operand
IOT	input/output trap		
IOX	input/output executive routine	PA	parity available
IR	instruction register	PAL	program assembly language
IRD	instruction register decoder	PB	parity bit
ISR	instruction shift register	PC	program counter
		PD	positive driver
JMP	jump	PDP	programmed data processor
JSR	jump to subroutine	PERIF	peripheral
		PGM	program
LIFO	last in, first out	PP	paper tape punch
LKS	line time clock status register	PPB	paper tape punch buffer register
LOC	location	PPS	paper tape punch status register
LP	line printer	PR	paper tape reader

Abbreviation	Definition
PRB	paper tape reader buffer register
PROC	processor
PRS	paper tape reader status register
PS	processor status positive switch
PTR	priority transfer
PTS	paper tape software system
PUN	punch
RD	read
RDR	reader
REG	register
REL	release
RES	reset
ROL	rotate left
ROM	read-only memory
ROR	rotate right
R/S	rotate/shift
RTI	return from interrupt
RTS	return from subroutine
R/W	read/write
R/WSR	read/write shift register
S	single
SACK	selection acknowledge
SBC	subtract carry
SC	single cycle
SE	source effective address
SEC	set carry
SEL	select
SEN	set negative
SEV	set overflow
SEX	sign extend
SEZ	set zero
SI	single instruction
SP	stack pointer spare
SR	switch register
SRC	source
SSYN	slave sync

Abbreviation	Definition
ST	start
STPM	set trap marker
STR	strobe
SUB	subtract
SVC	service
SWAB	swap byte
TA	trap address track address
TEMP	temporary
TK	teletype keyboard
TKB	teletype keyboard buffer register
TKS	teletype keyboard status register
TP	teletype printer
TPS	teletype printer status register
TRT	trace trap
TSC	timing state control
TST	test
UTR	user trap
VEC	vector
WC	word count
WCR	word count register
XDR	X-line driver
XRCG	X-line read control group
XWCG	X-line write control group
YDR	Y-line driver
YRCG	Y-line read control group
YWCG	Y-line write control group

APPENDIX K

CONVERSION TABLES

K.1 OCTAL-DECIMAL INTEGER CONVERSIONS

0000 to 0777 (Octal) | 0000 to 0511 (Decimal)

Octal	Decimal
10000	4096
20000	8192
30000	12288
40000	16384
50000	20480
60000	24576
70000	28672

	0	1	2	3	4	5	6	7
0000	0000	0001	0002	0003	0004	0005	0006	0007
0010	0008	0009	0010	0011	0012	0013	0014	0015
0020	0016	0017	0018	0019	0020	0021	0022	0023
0030	0024	0025	0026	0027	0028	0029	0030	0031
0040	0032	0033	0034	0035	0036	0037	0038	0039
0050	0040	0041	0042	0043	0044	0045	0046	0047
0060	0048	0049	0050	0051	0052	0053	0054	0055
0070	0056	0057	0058	0059	0060	0061	0062	0063
0100	0064	0065	0066	0067	0068	0069	0070	0071
0110	0072	0073	0074	0075	0076	0077	0078	0079
0120	0080	0081	0082	0083	0084	0085	0086	0087
0130	0088	0089	0090	0091	0092	0093	0094	0095
0140	0096	0097	0098	0099	0100	0101	0102	0103
0150	0104	0105	0106	0107	0108	0109	0110	0111
0160	0112	0113	0114	0115	0116	0117	0118	0119
0170	0120	0121	0122	0123	0124	0125	0126	0127
0200	0128	0129	0130	0131	0132	0133	0134	0135
0210	0136	0137	0138	0139	0140	0141	0142	0143
0220	0144	0145	0146	0147	0148	0149	0150	0151
0230	0152	0153	0154	0155	0156	0157	0158	0159
0240	0160	0161	0162	0163	0164	0165	0166	0167
0250	0168	0169	0170	0171	0172	0173	0174	0175
0260	0176	0177	0178	0179	0180	0181	0182	0183
0270	0184	0185	0186	0187	0188	0189	0190	0191
0300	0192	0193	0194	0195	0196	0197	0198	0199
0310	0200	0201	0202	0203	0204	0205	0206	0207
0320	0208	0209	0210	0211	0212	0213	0214	0215
0330	0216	0217	0218	0219	0220	0221	0222	0223
0340	0224	0225	0226	0227	0228	0229	0230	0231
0350	0232	0233	0234	0235	0236	0237	0238	0239
0360	0240	0241	0242	0243	0244	0245	0246	0247
0370	0248	0249	0250	0251	0252	0253	0254	0255

	0	1	2	3	4	5	6	7
0400	0256	0257	0258	0259	0260	0261	0262	0263
0410	0264	0265	0266	0267	0268	0269	0270	0271
0420	0272	0273	0274	0275	0276	0277	0278	0279
0430	0280	0281	0282	0283	0284	0285	0286	0287
0440	0288	0289	0290	0291	0292	0293	0294	0295
0450	0296	0297	0298	0299	0300	0301	0302	0303
0460	0304	0305	0306	0307	0308	0309	0310	0311
0470	0312	0313	0314	0315	0316	0317	0318	0319
0500	0320	0321	0322	0323	0324	0325	0326	0327
0510	0328	0329	0330	0331	0332	0333	0334	0335
0520	0336	0337	0338	0339	0340	0341	0342	0343
0530	0344	0345	0346	0347	0348	0349	0350	0351
0540	0352	0353	0354	0355	0356	0357	0358	0359
0550	0360	0361	0362	0363	0364	0365	0366	0367
0560	0368	0369	0370	0371	0372	0373	0374	0375
0570	0376	0377	0378	0379	0380	0381	0382	0383
0600	0384	0385	0386	0387	0388	0389	0390	0391
0610	0392	0393	0394	0395	0396	0397	0398	0399
0620	0400	0401	0402	0403	0404	0405	0406	0407
0630	0408	0409	0410	0411	0412	0413	0414	0415
0640	0416	0417	0418	0419	0420	0421	0422	0423
0650	0424	0425	0426	0427	0428	0429	0430	0431
0660	0432	0433	0434	0435	0436	0437	0438	0439
0670	0440	0441	0442	0443	0444	0445	0446	0447
0700	0448	0449	0450	0451	0452	0453	0454	0455
0710	0456	0457	0458	0459	0460	0461	0462	0463
0720	0464	0465	0466	0467	0468	0469	0470	0471
0730	0472	0473	0474	0475	0476	0477	0478	0479
0740	0480	0481	0482	0483	0484	0485	0486	0487
0750	0488	0489	0490	0491	0492	0493	0494	0495
0760	0496	0497	0498	0499	0500	0501	0502	0503
0770	0504	0505	0506	0507	0508	0509	0510	0511

1000 to 1777 (Octal) | 0512 to 1023 (Decimal)

	0	1	2	3	4	5	6	7
1000	0512	0513	0514	0515	0516	0517	0518	0519
1010	0520	0521	0522	0523	0524	0525	0526	0527
1020	0528	0529	0530	0531	0532	0533	0534	0535
1030	0536	0537	0538	0539	0540	0541	0542	0543
1040	0544	0545	0546	0547	0548	0549	0550	0551
1050	0552	0553	0554	0555	0556	0557	0558	0559
1060	0560	0561	0562	0563	0564	0565	0566	0567
1070	0568	0569	0570	0571	0572	0573	0574	0575
1100	0576	0577	0578	0579	0580	0581	0582	0583
1110	0584	0585	0586	0587	0588	0589	0590	0591
1120	0592	0593	0594	0595	0596	0597	0598	0599
1130	0600	0601	0602	0603	0604	0605	0606	0607
1140	0608	0609	0610	0611	0612	0813	0614	0615
1150	0616	0617	0618	0619	0620	0621	0622	0623
1160	0624	0625	0626	0627	0628	0629	0630	0631
1170	0632	0633	0634	0635	0636	0637	0638	0639
1200	0640	0641	0642	0643	0644	0645	0646	0647
1210	0648	0649	0650	0651	0652	0653	0654	0655
1220	0656	0657	0658	0659	0660	0661	0662	0663
1230	0664	0665	0666	0667	0668	0669	0670	0671
1240	0672	0673	0674	0675	0676	0677	0678	0679
1250	0680	0681	0682	0683	0684	0685	0686	0687
1260	0688	0689	0690	0691	0692	0693	0694	0695
1270	0696	0697	0698	0699	0700	0701	0702	0703
1300	0704	0705	0706	0707	0708	0709	0710	0711
1310	0712	0713	0714	0715	0716	0717	0718	0719
1320	0720	0721	0722	0723	0724	0725	0726	0727
1330	0728	0729	0730	0731	0732	0733	0734	0735
1340	0736	0737	0738	0739	0740	0741	0742	0743
1350	0744	0745	0746	0747	0748	0749	0750	0751
1360	0752	0753	0754	0755	0756	0757	0758	0759
1370	0760	0761	0762	0763	0764	0765	0766	0767

	0	1	2	3	4	5	6	7
1400	0768	0769	0770	0771	0772	0773	0774	0775
1410	0776	0777	0778	0779	0780	0781	0782	0783
1420	0784	0785	0786	0787	0788	0789	0790	0791
1430	0792	0793	0794	0795	0796	0797	0798	0799
1440	0800	0801	0802	0803	0804	0805	0806	0807
1450	0808	0809	0810	0811	0812	0813	0814	0815
1460	0816	0817	0818	0819	0820	0821	0822	0823
1470	0824	0825	0826	0827	0828	0829	0830	0831
1500	0832	0833	0834	0835	0836	0837	0838	0839
1510	0840	0841	0842	0843	0844	0845	0846	0847
1520	0848	0849	0850	0851	0852	0853	0854	0855
1530	0856	0857	0858	0859	0860	0861	0852	0863
1540	0864	0865	0866	0867	0868	0869	0870	0871
1550	0872	0873	0874	0875	0876	0877	0878	0879
1560	0880	0881	0882	0883	0884	0885	0886	0887
1570	0888	0889	0890	0891	0892	0893	0894	0895
1600	0896	0897	0898	0899	0900	0901	0902	0903
1610	0904	0905	0906	0907	0908	0909	0910	0911
1620	0912	0913	0914	0915	0916	0917	0918	0919
1630	0920	0921	0922	0923	0924	0925	0926	0927
1640	0928	0929	0930	0931	0932	0933	0934	0935
1650	0936	0937	0938	0939	0940	0941	0942	0943
1660	0944	0945	0946	0947	0948	0949	0950	0951
1670	0952	0953	0954	0955	0956	0957	0958	0959
1700	0960	0961	0962	0963	0964	0965	0966	0967
1710	0968	0969	0970	0971	0972	0973	0974	0975
1720	0976	0977	0978	0979	0980	0981	0982	0983
1730	0984	0985	0986	0987	0988	0989	0990	0991
1740	0992	0993	0994	0995	0996	0997	0998	0999
1750	1000	1001	1002	1003	1004	1005	1006	1007
1760	1008	1009	1010	1011	1012	1013	1014	1015
1770	1016	1017	1018	1019	1020	1021	1022	1023

K.1 OCTAL-DECIMAL INTEGER CONVERSIONS (Continued)

2000 to 2777 (Octal) | 1024 to 1535 (Decimal)

Octal	Decimal
10000 -	4096
20000 -	8192
30000 -	12288
40000 -	16384
50000 -	20480
60000 -	24576
70000 -	28672

	0	1	2	3	4	5	6	7
2000	1024	1025	1026	1027	1028	1029	1030	1031
2010	1032	1033	1034	1035	1036	1037	1038	1039
2020	1040	1041	1042	1043	1044	1045	1046	1047
2030	1048	1049	1050	1051	1052	1053	1054	1055
2040	1056	1057	1058	1059	1060	1061	1062	1063
2050	1064	1065	1066	1067	1068	1069	1070	1071
2060	1072	1073	1074	1075	1076	1077	1078	1079
2070	1080	1081	1082	1083	1084	1085	1086	1087
2100	1088	1089	1090	1091	1092	1093	1094	1095
2110	1096	1097	1098	1099	1100	1101	1102	1103
2120	1104	1105	1106	1107	1108	1109	1110	1111
2130	1112	1113	1114	1115	1116	1117	1118	1119
2140	1120	1121	1122	1123	1124	1125	1126	1127
2150	1128	1129	1130	1131	1132	1133	1134	1135
2160	1136	1137	1138	1139	1140	1141	1142	1143
2170	1144	1145	1146	1147	1148	1149	1150	1151
2200	1152	1153	1154	1155	1156	1157	1158	1159
2210	1160	1161	1162	1163	1164	1165	1166	1167
2220	1168	1169	1170	1171	1172	1173	1174	1175
2230	1176	1177	1178	1179	1180	1181	1182	1183
2240	1184	1185	1186	1187	1188	1189	1190	1191
2250	1192	1193	1194	1195	1196	1197	1198	1199
2260	1200	1201	1202	1203	1204	1205	1206	1207
2270	1208	1209	1210	1211	1212	1213	1214	1215
2300	1216	1217	1218	1219	1220	1221	1222	1223
2310	1224	1225	1226	1227	1228	1229	1230	1231
2320	1232	1233	1234	1235	1236	1237	1238	1239
2330	1240	1241	1242	1243	1244	1245	1246	1247
2340	1248	1249	1250	1251	1252	1253	1254	1255
2350	1256	1257	1258	1259	1260	1261	1262	1263
2360	1264	1265	1266	1267	1268	1269	1270	1271
2370	1272	1273	1274	1275	1276	1277	1278	1279

	0	1	2	3	4	5	6	7
2400	1280	1281	1282	1283	1284	1285	1286	1287
2410	1288	1289	1290	1291	1292	1293	1294	1295
2420	1296	1297	1298	1299	1300	1301	1302	1303
2430	1304	1305	1306	1307	1308	1309	1310	1311
2440	1312	1313	1314	1315	1316	1317	1318	1319
2450	1320	1321	1322	1323	1324	1325	1326	1327
2460	1328	1329	1330	1331	1332	1333	1334	1335
2470	1336	1337	1338	1339	1340	1341	1342	1343
2500	1344	1345	1346	1347	1348	1349	1350	1351
2510	1352	1353	1354	1355	1356	1357	1358	1359
2520	1360	1361	1362	1363	1364	1365	1366	1367
2530	1368	1369	1370	1371	1372	1373	1374	1375
2540	1376	1377	1378	1379	1380	1381	1382	1383
2550	1384	1385	1386	1387	1388	1389	1390	1391
2560	1392	1393	1394	1395	1396	1397	1398	1399
2570	1400	1401	1402	1403	1404	1405	1406	1407
2600	1408	1409	1410	1411	1412	1413	1414	1415
2610	1416	1417	1418	1419	1420	1421	1422	1423
2620	1424	1425	1426	1427	1428	1429	1430	1431
2630	1432	1433	1434	1435	1436	1437	1438	1439
2640	1440	1441	1442	1443	1444	1445	1446	1447
2650	1448	1449	1450	1451	1452	1453	1454	1455
2660	1456	1457	1458	1459	1460	1461	1462	1463
2670	1464	1465	1466	1467	1468	1469	1470	1471
2700	1472	1473	1474	1475	1476	1477	1478	1479
2710	1480	1481	1482	1483	1484	1485	1486	1487
2720	1488	1489	1490	1491	1492	1493	1494	1495
2730	1496	1497	1498	1499	1500	1501	1502	1503
2740	1504	1505	1506	1507	1508	1509	1510	1511
2750	1512	1513	1514	1515	1516	1517	1518	1519
2760	1520	1521	1522	1523	1524	1525	1526	1527
2770	1528	1529	1530	1531	1532	1533	1534	1535

3000 to 3777 (Octal) | 1536 to 2047 (Decimal)

	0	1	2	3	4	5	6	7
3000	1536	1537	1538	1539	1540	1541	1542	1543
3010	1544	1545	1546	1547	1548	1549	1550	1551
3020	1552	1553	1554	1555	1556	1557	1558	1559
3030	1560	1561	1562	1563	1564	1565	1566	1567
3040	1568	1569	1570	1571	1572	1573	1574	1575
3050	1576	1577	1578	1579	1580	1581	1582	1583
3060	1584	1585	1586	1587	1588	1589	1590	1591
3070	1592	1593	1594	1595	1596	1597	1598	1599
3100	1600	1601	1602	1603	1604	1605	1606	1607
3110	1608	1609	1610	1611	1612	1613	1614	1615
3120	1616	1617	1618	1619	1620	1621	1622	1623
3130	1624	1625	1626	1627	1628	1629	1630	1631
3140	1632	1633	1634	1635	1636	1637	1638	1639
3150	1640	1641	1642	1643	1644	1645	1646	1647
3160	1648	1649	1650	1651	1652	1653	1654	1655
3170	1656	1657	1658	1659	1660	1661	1662	1663
3200	1664	1665	1666	1667	1668	1669	1670	1671
3210	1672	1673	1674	1675	1676	1677	1678	1679
3220	1680	1681	1682	1683	1684	1685	1686	1687
3230	1688	1689	1690	1691	1692	1693	1694	1695
3240	1696	1697	1698	1699	1700	1701	1702	1703
3250	1704	1705	1706	1707	1708	1709	1710	1711
3260	1712	1713	1714	1715	1716	1717	1718	1719
3270	1720	1721	1722	1723	1724	1725	1726	1727
3300	1728	1729	1730	1731	1732	1733	1734	1735
3310	1736	1737	1738	1739	1740	1741	1742	1743
3320	1744	1745	1746	1747	1748	1749	1750	1751
3330	1752	1753	1754	1755	1756	1757	1758	1759
3340	1760	1761	1762	1763	1764	1765	1766	1767
3350	1768	1769	1770	1771	1772	1773	1774	1775
3360	1776	1777	1778	1779	1780	1781	1782	1783
3370	1784	1785	1786	1787	1788	1789	1790	1791

	0	1	2	3	4	5	6	7
3400	1792	1793	1794	1795	1796	1797	1798	1799
3410	1800	1801	1802	1803	1804	1805	1806	1807
3420	1808	1809	1810	1811	1812	1813	1814	1815
3430	1816	1817	1818	1819	1820	1821	1822	1823
3440	1824	1825	1826	1827	1828	1829	1830	1831
3450	1832	1833	1834	1835	1836	1837	1838	1839
3460	1840	1841	1842	1843	1844	1845	1846	1847
3470	1848	1849	1850	1851	1852	1853	1854	1855
3500	1856	1857	1858	1859	1860	1861	1862	1863
3510	1864	1865	1866	1867	1868	1869	1870	1871
3520	1872	1873	1874	1875	1876	1877	1878	1879
3530	1880	1881	1882	1883	1884	1885	1886	1887
3540	1888	1889	1890	1891	1892	1893	1894	1895
3550	1896	1897	1898	1899	1900	1901	1902	1903
3560	1904	1905	1906	1907	1908	1909	1910	1911
3570	1912	1913	1914	1915	1916	1917	1918	1919
3600	1920	1921	1922	1923	1924	1925	1926	1927
3610	1928	1929	1930	1931	1932	1933	1934	1935
3620	1936	1937	1938	1939	1940	1941	1942	1943
3630	1944	1945	1946	1947	1948	1949	1950	1951
3640	1952	1953	1954	1955	1956	1957	1958	1959
3650	1960	1961	1962	1963	1964	1965	1966	1967
3660	1968	1969	1970	1971	1972	1973	1974	1975
3670	1976	1977	1978	1979	1980	1981	1982	1983
3700	1984	1985	1986	1987	1988	1989	1990	1991
3710	1992	1993	1994	1995	1996	1997	1998	1999
3720	2000	2001	2002	2003	2004	2005	2006	2007
3730	2008	2009	2010	2011	2012	2013	2014	2015
3740	2016	2017	2018	2019	2020	2021	2022	2023
3750	2024	2025	2026	2027	2028	2029	2030	2031
3760	2032	2033	2034	2035	2036	2037	2038	2039
3770	2040	2041	2042	2043	2044	2045	2046	2047

K.1 OCTAL-DECIMAL INTEGER CONVERSIONS (Continued)

4000 to 4777 (Octal)	2048 to 2559 (Decimal)

Octal	Decimal
10000 -	4096
20000 -	8192
30000 -	12288
40000 -	16384
50000 -	20480
60000 -	24576
70000 -	28672

	0	1	2	3	4	5	6	7
4000	2048	2049	2050	2051	2052	2053	2054	2055
4010	2056	2057	2058	2059	2060	2061	2062	2063
4020	2064	2065	2066	2067	2068	2069	2070	2071
4030	2072	2073	2074	2075	2076	2077	2078	2079
4040	2080	2081	2082	2083	2084	2085	2086	2087
4050	2088	2089	2090	2091	2092	2093	2094	2095
4060	2096	2097	2098	2099	2100	2101	2102	2103
4070	2104	2105	2106	2107	2108	2109	2110	2111
4100	2112	2113	2114	2115	2116	2117	2118	2119
4110	2120	2121	2122	2123	2124	2125	2126	2127
4120	2128	2129	2130	2131	2132	2133	2134	2135
4130	2136	2137	2138	2139	2140	2141	2142	2143
4140	2144	2145	2146	2147	2148	2149	2150	2151
4150	2152	2153	2154	2155	2156	2157	2158	2159
4160	2160	2161	2162	2163	2164	2165	2166	2167
4170	2168	2169	2170	2171	2172	2173	2174	2175
4200	2176	2177	2178	2179	2180	2181	2182	2183
4210	2184	2185	2186	2187	2188	2189	2190	2191
4220	2192	2193	2194	2195	2196	2197	2198	2199
4230	2200	2201	2202	2203	2204	2205	2206	2207
4240	2208	2209	2210	2211	2212	2213	2214	2215
4250	2216	2217	2218	2219	2220	2221	2222	2223
4260	2224	2225	2226	2227	2228	2229	2230	2231
4270	2232	2233	2234	2235	2236	2237	2238	2239
4300	2240	2241	2242	2243	2244	2245	2246	2247
4310	2248	2249	2250	2251	2252	2253	2254	2255
4320	2256	2257	2258	2259	2260	2261	2262	2263
4330	2264	2265	2266	2267	2268	2269	2270	2271
4340	2272	2273	2274	2275	2276	2277	2278	2279
4350	2280	2281	2282	2283	2284	2285	2286	2287
4360	2288	2289	2290	2291	2292	2293	2294	2295
4370	2296	2297	2298	2299	2300	2301	2302	2303

	0	1	2	3	4	5	6	7
4400	2304	2305	2306	2307	2308	2309	2310	2311
4410	2312	2313	2314	2315	2316	2317	2318	2319
4420	2320	2321	2322	2323	2324	2325	2326	2327
4430	2328	2329	2330	2331	2332	2333	2334	2335
4440	2336	2337	2338	2339	2340	2341	2342	2343
4450	2344	2345	2346	2347	2348	2349	2350	2351
4460	2352	2353	2354	2355	2356	2357	2358	2359
4470	2360	2361	2362	2363	2364	2365	2366	2367
4500	2368	2369	2370	2371	2372	2373	2374	2375
4510	2376	2377	2378	2379	2380	2381	2382	2383
4520	2384	2385	2386	2387	2388	2389	2390	2391
4530	2392	2393	2394	2395	2396	2397	2398	2399
4540	2400	2401	2402	2403	2404	2405	2406	2407
4550	2408	2409	2410	2411	2412	2413	2414	2415
4560	2416	2417	2418	2419	2420	2421	2422	2423
4570	2424	2425	2426	2427	2428	2429	2430	2431
4600	2432	2433	2434	2435	2436	2437	2438	2439
4610	2440	2441	2442	2443	2444	2445	2446	2447
4620	2448	2449	2450	2451	2452	2453	2454	2455
4630	2456	2457	2458	2459	2460	2461	2462	2463
4640	2464	2465	2466	2467	2468	2469	2470	2471
4650	2472	2473	2474	2475	2476	2477	2478	2479
4660	2480	2481	2482	2483	2484	2485	2486	2487
4670	2488	2489	2490	2491	2492	2493	2494	2495
4700	2496	2497	2498	2499	2500	2501	2502	2503
4710	2504	2505	2506	2507	2508	2509	2510	2511
4720	2512	2513	2514	2515	2516	2517	2518	2519
4730	2520	2521	2522	2523	2524	2525	2526	2527
4740	2528	2529	2530	2531	2532	2533	2534	2535
4750	2536	2537	2538	2539	2540	2541	2542	2543
4760	2544	2545	2546	2547	2548	2549	2550	2551
4770	2552	2553	2554	2555	2556	2557	2558	2559

5000 to 5777 (Octal)	2560 to 3071 (Decimal)

	0	1	2	3	4	5	6	7
5000	2560	2561	2562	2563	2564	2565	2566	2567
5010	2568	2569	2570	2571	2572	2573	2574	2575
5020	2576	2577	2578	2579	2580	2581	2582	2583
5030	2584	2585	2586	2587	2588	2589	2590	2591
5040	2592	2593	2594	2595	2596	2597	2598	2599
5050	2600	2601	2602	2603	2604	2605	2606	2607
5060	2608	2609	2610	2611	2612	2613	2614	2615
5070	2616	2617	2618	2619	2620	2621	2622	2623
5100	2624	2625	2626	2627	2628	2629	2630	2631
5110	2632	2633	2634	2635	2636	2637	2638	2639
5120	2640	2641	2642	2643	2644	2645	2646	2647
5130	2648	2649	2650	2651	2652	2653	2654	2655
5140	2656	2657	2658	2659	2660	2661	2662	2663
5150	2664	2665	2666	2667	2668	2669	2670	2671
5160	2672	2673	2674	2675	2676	2677	2678	2679
5170	2680	2681	2682	2683	2684	2685	2686	2687
5200	2688	2689	2690	2691	2692	2693	2694	2695
5210	2696	2697	2698	2699	2700	2701	2702	2703
5220	2704	2705	2706	2707	2708	2709	2710	2711
5230	2712	2713	2714	2715	2716	2717	2718	2719
5240	2720	2721	2722	2723	2724	2725	2726	2727
5250	2728	2729	2730	2731	2732	2733	2734	2735
5260	2736	2737	2738	2739	2740	2741	2742	2743
5270	2744	2745	2746	2747	2748	2749	2750	2751
5300	2752	2753	2754	2755	2756	2757	2758	2759
5310	2760	2761	2762	2763	2764	2765	2766	2767
5320	2768	2769	2770	2771	2772	2773	2774	2775
5330	2776	2777	2778	2779	2780	2781	2782	2783
5340	2784	2785	2786	2787	2788	2789	2790	2791
5350	2792	2793	2794	2795	2796	2797	2798	2799
5360	2800	2801	2802	2803	2804	2805	2806	2807
5370	2808	2809	2810	2811	2812	2813	2814	2815

	0	1	2	3	4	5	6	7
5400	2816	2817	2818	2819	2820	2821	2822	2823
5410	2824	2825	2826	2827	2828	2829	2830	2831
5420	2832	2833	2834	2835	2836	2837	2838	2839
5430	2840	2841	2842	2843	2844	2845	2846	2847
5440	2848	2849	2850	2851	2852	2853	2854	2855
5450	2856	2857	2858	2859	2860	2861	2862	2863
5460	2864	2865	2866	2867	2868	2869	2870	2871
5470	2872	2873	2874	2875	2876	2877	2878	2879
5500	2880	2881	2882	2883	2884	2885	2886	2887
5510	2888	2889	2890	2891	2892	2893	2894	2895
5520	2896	2897	2898	2899	2900	2901	2902	2903
5530	2904	2905	2906	2907	2908	2909	2910	2911
5540	2912	2913	2914	2915	2916	2917	2918	2919
5550	2920	2921	2922	2923	2924	2925	2926	2927
5560	2928	2929	2930	2931	2932	2933	2934	2935
5570	2936	2937	2938	2939	2940	2941	2942	2943
5600	2944	2945	2946	2947	2948	2949	2950	2951
5610	2952	2953	2954	2955	2956	2957	2958	2959
5620	2960	2961	2962	2963	2964	2965	2966	2967
5630	2968	2969	2970	2971	2972	2973	2974	2975
5640	2976	2977	2978	2979	2980	2981	2982	2983
5650	2984	2985	2986	2987	2988	2989	2990	2991
5660	2992	2993	2994	2995	2996	2997	2998	2999
5670	3000	3001	3002	3003	3004	3005	3006	3007
5700	3008	3009	3010	3011	3012	3013	3014	3015
5710	3016	3017	3018	3019	3020	3021	3022	3023
5720	3024	3025	3026	3027	3028	3029	3030	3031
5730	3032	3033	3034	3035	3036	3037	3038	3039
5740	3040	3041	3042	3043	3044	3045	3046	3047
5750	3048	3049	3050	3051	3052	3053	3054	3055
5760	3056	3057	3058	3059	3060	3061	3062	3063
5770	3064	3065	3066	3067	3068	3069	3070	3071

K.1 OCTAL-DECIMAL INTEGER CONVERSIONS (Concluded)

6000 to 6777 (Octal)	3072 to 3583 (Decimal)

Octal	Decimal
10000	4096
20000	8192
30000	12288
40000	16384
50000	20480
60000	24576
70000	28672

	0	1	2	3	4	5	6	7
6000	3072	3073	3074	3075	3076	3077	3078	3079
6010	3080	3081	3082	3083	3084	3085	3086	3087
6020	3088	3089	3090	3091	3092	3093	3094	3095
6030	3096	3097	3098	3099	3100	3101	3102	3103
6040	3104	3105	3106	3107	3108	3109	3110	3111
6050	3112	3113	3114	3115	3116	3117	3118	3119
6060	3120	3121	3122	3123	3124	3125	3126	3127
6070	3128	3129	3130	3131	3132	3133	3134	3135
6100	3136	3137	3138	3139	3140	3141	3142	3143
6110	3144	3145	3146	3147	3148	3149	3150	3151
6120	3152	3153	3154	3155	3156	3157	3158	3159
6130	3160	3161	3162	3163	3164	3165	3166	3167
6140	3168	3169	3170	3171	3172	3173	3174	3175
6150	3176	3177	3178	3179	3180	3181	3182	3183
6160	3184	3185	3186	3187	3188	3189	3190	3191
6170	3192	3193	3194	3195	3196	3197	3198	3199
6200	3200	3201	3202	3203	3204	3205	3206	3207
6210	3208	3209	3210	3211	3212	3213	3214	3215
6220	3216	3217	3218	3219	3220	3221	3222	3223
6230	3224	3225	3226	3227	3228	3229	3230	3231
6240	3232	3233	3234	3235	3236	3237	3238	3239
6250	3240	3241	3242	3243	3244	3245	3246	3247
6260	3248	3249	3250	3251	3252	3253	3254	3255
6270	3256	3257	3258	3259	3260	3261	3262	3263
6300	3264	3265	3266	3267	3268	3269	3270	3271
6310	3272	3273	3274	3275	3276	3277	3278	3279
6320	3280	3281	3282	3283	3284	3285	3286	3287
6330	3288	3289	3290	3291	3292	3293	3294	3295
6340	3296	3297	3298	3299	3300	3301	3302	3303
6350	3304	3305	3306	3307	3308	3309	3310	3311
6360	3312	3313	3314	3315	3316	3317	3318	3319
6370	3320	3321	3322	3323	3324	3325	3326	3327

	0	1	2	3	4	5	6	7
6400	3328	3329	3330	3331	3332	3333	3334	3335
6410	3336	3337	3338	3339	3340	3341	3342	3343
6420	3344	3345	3346	3347	3348	3349	3350	3351
6430	3352	3353	3354	3355	3356	3357	3358	3359
6440	3360	3361	3362	3363	3364	3365	3366	3367
6450	3368	3369	3370	3371	3372	3373	3374	3375
6460	3376	3377	3378	3379	3380	3381	3382	3383
6470	3384	3385	3386	3387	3388	3389	3390	3391
6500	3392	3393	3394	3395	3396	3397	3398	3399
6510	3400	3401	3402	3403	3404	3405	3406	3407
6520	3408	3409	3410	3411	3412	3413	3414	3415
6530	3416	3417	3418	3419	3420	3421	3422	3423
6540	3424	3425	3426	3427	3428	3429	3430	3431
6550	3432	3433	3434	3435	3436	3437	3438	3439
6560	3440	3441	3442	3443	3444	3445	3446	3447
6570	3448	3449	3450	3451	3452	3453	3454	3455
6600	3456	3457	3458	3459	3460	3461	3462	3463
6610	3464	3465	3466	3467	3468	3469	3470	3471
6620	3472	3473	3474	3475	3476	3477	3478	3479
6630	3480	3481	3482	3483	3484	3485	3486	3487
6640	3488	3489	3490	3491	3492	3493	3494	3495
6650	3496	3497	3498	3499	3500	3501	3502	3503
6660	3504	3505	3506	3507	3508	3509	3510	3511
6670	3512	3513	3514	3515	3516	3517	3518	3519
6700	3520	3521	3522	3523	3524	3525	3526	3527
6710	3528	3529	3530	3531	3532	3533	3534	3535
6720	3536	3537	3538	3539	3540	3541	3542	3543
6730	3544	3545	3546	3547	3548	3549	3550	3551
6740	3552	3553	3554	3555	3556	3557	3558	3559
6750	3560	3561	3562	3563	3564	3565	3566	3567
6760	3568	3569	3570	3571	3572	3573	3574	3575
6770	3576	3577	3578	3579	3580	3581	3582	3583

7000 to 7777 (Octal)	3584 to 4095 (Decimal)

	0	1	2	3	4	5	6	7
7000	3584	3585	3586	3587	3588	3589	3590	3591
7010	3592	3593	3594	3595	3596	3597	3598	3599
7020	3600	3601	3602	3603	3604	3605	3606	3607
7030	3608	3609	3610	3611	3612	3613	3614	3615
7040	3616	3617	3618	3619	3620	3621	3622	3623
7050	3624	3625	3626	3627	3628	3629	3630	3631
7060	3632	3633	3634	3635	3636	3637	3638	3639
7070	3640	3641	3642	3643	3644	3645	3646	3647
7100	3648	3649	3650	3651	3652	3653	3654	3655
7110	3656	3657	3658	3659	3660	3661	3662	3663
7120	3664	3665	3666	3667	3668	3669	3670	3671
7130	3672	3673	3674	3675	3676	3677	3678	3679
7140	3680	3681	3682	3683	3684	3685	3686	3687
7150	3688	3689	3690	3691	3692	3693	3694	3695
7160	3696	3697	3698	3699	3700	3701	3702	3703
7170	3704	3705	3706	3707	3708	3709	3710	3711
7200	3712	3713	3714	3715	3716	3717	3718	3719
7210	3720	3721	3722	3723	3724	3725	3726	3727
7220	3728	3729	3730	3731	3732	3733	3734	3735
7230	3736	3737	3738	3739	3740	3741	3742	3743
7240	3744	3745	3746	3747	3748	3749	3750	3751
7250	3752	3753	3754	3755	3756	3757	3758	3759
7260	3760	3761	3762	3763	3764	3765	3766	3767
7270	3768	3769	3770	3771	3772	3773	3774	3775
7300	3776	3777	3778	3779	3780	3781	3782	3783
7310	3784	3785	3786	3787	3788	3789	3790	3791
7320	3792	3793	3794	3795	3796	3797	3798	3799
7330	3800	3801	3802	3803	3804	3805	3806	3807
7340	3808	3809	3810	3811	3812	3813	3814	3815
7350	3816	3817	3818	3819	3820	3821	3822	3823
7360	3824	3825	3826	3827	3828	3829	3830	3831
7370	3832	3833	3834	3835	3836	3837	3838	3839

	0	1	2	3	4	5	6	7
7400	3840	3841	3842	3843	3844	3845	3846	3847
7410	3848	3849	3850	3851	3852	3853	3854	3855
7420	3856	3857	3858	3859	3860	3861	3862	3863
7430	3864	3865	3866	3867	3868	3869	3870	3871
7440	3872	3873	3874	3875	3876	3877	3878	3879
7450	3880	3881	3882	3883	3884	3885	3886	3887
7460	3888	3889	3890	3891	3892	3893	3894	3895
7470	3896	3897	3898	3899	3900	3901	3902	3903
7500	3904	3905	3906	3907	3908	3909	3910	3911
7510	3912	3913	3914	3915	3916	3917	3918	3919
7520	3920	3921	3922	3923	3924	3925	3926	3927
7530	3928	3929	3930	3931	3932	3933	3934	3935
7540	3936	3937	3938	3939	3940	3941	3942	3943
7550	3944	3945	3946	3947	3948	3949	3950	3951
7560	3952	3953	3954	3955	3956	3957	3958	3959
7570	3960	3961	3962	3963	3964	3965	3966	3967
7600	3968	3969	3970	3971	3972	3973	3974	3975
7610	3976	3977	3978	3979	3980	3981	3982	3983
7620	3984	3985	3986	3987	3988	3989	3990	3991
7630	3992	3993	3994	3995	3996	3997	3998	3999
7640	4000	4001	4002	4003	4004	4005	4006	4007
7650	4008	4009	4010	4011	4012	4013	4014	4015
7660	4016	4017	4018	4019	4020	4021	1022	4023
7670	4024	4025	4026	4027	4028	4029	4030	4031
7700	4032	4033	4034	4035	4036	4037	4038	4039
7710	4040	4041	4042	4043	4044	4045	4046	4047
7720	4048	4049	4050	4051	4052	4053	4054	4055
7730	4056	4057	4058	4059	4060	4061	4062	4063
7740	4064	4065	4066	4067	4068	4069	4070	4071
7750	4072	4073	4074	4075	4076	4077	4078	4079
7760	4080	4081	4082	4083	4084	4085	4086	4087
7770	4088	4089	4090	4091	4092	4093	4094	4095

K.2 POWERS OF TWO

POWERS OF TWO

2^n	n	n^{-2}
1	0	1.0
2	1	0.5
4	2	0.25
8	3	0.125
16	4	0.062 5
32	5	0.031 25
64	6	0.015 625
128	7	0.007 812 5
256	8	0.003 906 25
512	9	0.001 953 125
1 024	10	0.000 976 562 5
2 048	11	0.000 488 281 25
4 096	12	0.000 244 140 625
8 192	13	0.000 122 070 312 5
16 384	14	0.000 061 035 156 25
32 768	15	0.000 030 517 578 125
65 536	16	0.000 015 258 789 062 5
131 072	17	0.000 007 629 394 531 25
262 144	18	0.000 003 814 697 265 625
524 288	19	0.000 001 907 348 632 812 5
1 048 576	20	0.000 000 953 674 316 406 25
2 097 152	21	0.000 000 476 837 158 203 125
4 194 304	22	0.000 000 238 418 579 101 562 5
8 388 608	23	0.000 000 119 209 289 550 781 25
16 777 216	24	0.000 000 059 604 644 775 390 625
33 554 432	25	0.000 000 029 802 322 387 695 312 5
67 108 864	26	0.000 000 014 901 161 193 847 656 25
134 217 728	27	0.000 000 007 450 580 596 923 808 125
268 435 456	28	0.000 000 003 725 290 298 461 914 062 5
536 870 912	29	0.000 000 001 862 645 149 230 957 031 25
1 073 741 824	30	0.000 000 000 931 322 574 615 478 515 625
2 147 483 848	31	0.000 000 000 465 661 287 307 739 257 812 5
4 294 967 296	32	0.000 000 000 232 830 643 653 869 628 906 25
8 589 934 592	33	0.000 000 000 116 415 321 826 934 814 453 125
17 179 869 184	34	0.000 000 000 058 207 660 913 467 407 226 562 5
34 359 738 368	35	0.000 000 000 029 103 830 456 733 703 613 081 25
68 719 476 736	36	0.000 000 000 014 551 915 228 366 851 806 640 625
137 438 953 472	37	0.000 000 000 007 275 957 614 183 425 903 320 312 5
274 877 906 944	38	0.000 000 000 003 637 978 807 091 712 951 660 156 25
549 755 813 888	39	0.000 000 000 001 818 989 403 545 856 475 830 078 125
1 099 511 627 776	40	0.000 000 000 000 909 494 701 772 928 237 915 039 062 5
2 199 023 255 552	41	0.000 000 000 000 454 747 350 886 464 118 957 519 531 25
4 398 046 511 104	42	0.000 000 000 000 227 373 675 443 232 059 478 759 765 625
8 796 093 022 208	43	0.000 000 000 000 113 686 837 721 616 029 739 379 882 812 5
17 592 186 044 416	44	0.000 000 000 000 056 843 418 860 808 014 869 689 941 406 25
35 184 372 088 832	45	0.000 000 000 000 028 421 709 430 404 007 434 844 970 703 125
70 368 744 177 664	46	0.000 000 000 000 014 210 854 715 202 003 717 422 485 351 562 5
140 737 488 355 328	47	0.000 000 000 000 007 105 427 357 601 001 858 711 242 675 781 25
281 474 976 710 656	48	0.000 000 000 000 003 552 713 678 800 500 929 355 621 337 890 625
562 949 953 421 312	49	0.000 000 000 000 001 776 356 839 400 250 464 677 810 668 945 312 5
1 125 899 906 842 634	50	0.000 000 000 000 000 888 178 419 700 125 232 338 905 334 472 656 25
2 251 799 813 985 248	51	0.000 000 000 000 000 444 089 209 850 062 616 169 452 667 236 328 125
4 503 599 627 370 496	52	0.000 000 000 000 000 222 044 604 925 031 308 084 726 333 668 164 062 5
9 007 199 254 740 992	53	0.000 000 000 000 000 111 022 302 462 515 654 042 363 166 834 582 031 25
18 014 398 509 481 984	54	0.000 000 000 000 000 055 511 151 231 257 827 021 171 513 417 041 015 625
36 028 797 018 963 968	55	0.000 000 000 000 000 027 755 575 615 628 913 510 590 791 708 520 507 812 5
72 057 594 037 927 936	56	0.000 000 000 000 000 013 877 787 807 814 456 755 215 395 854 260 253 906 25
144 115 188 075 855 872	57	0.000 000 000 000 000 006 938 893 903 907 228 377 647 697 927 130 126 953 125
288 230 376 151 711 744	58	0.000 000 000 000 000 003 469 446 951 953 614 188 823 848 963 565 063 476 562 5
576 460 752 303 423 488	59	0.000 000 000 000 000 001 734 723 475 976 807 094 411 924 481 782 531 738 281 25
1 152 921 504 606 846 976	60	0.000 000 000 000 000 000 867 361 737 988 403 547 205 962 240 891 265 869 140 625

K.3 SCALES OF NOTATION

K.3.1 2^x In Decimal

x	2^x	x	2^x	x	2^x
0.001	1.00069 33874 62581	0.01	1.00695 55500 56719	0.1	1.07177 34625 36293
0.002	1.00138 72557 11335	0.02	1.01395 94797 90029	0.2	1.14869 83549 97035
0.003	1.00208 16050 79633	0.03	1.02101 21257 07193	0.3	1.23114 44133 44916
0.004	1.00277 64359 01078	0.04	1.02811 38266 56067	0.4	1.31950 79107 72894
0.005	1.00347 17485 09503	0.05	1.03526 49238 41377	0.5	1.41421 35623 73095
0.006	1.00416 75432 38973	0.06	1.04246 57608 41121	0.6	1.51571 65665 10398
0.007	1.00486 38204 23785	0.07	1.04971 66836 23067	0.7	1.62450 47927 12471
0.008	1.00556 05803 98468	0.08	1.05701 80405 61380	0.8	1.74110 11265 92248
0.009	1.00625 78234 97782	0.09	1.06437 01824 53360	0.9	1.86606 59830 73615

K.3.2 $10^{\pm n}$ In Octal

10^n	n	10^{-n}	10^n	n	10^{-n}
1	0	1.000 000 000 000 000 000 00	112 402 762 000	10	0.000 000 000 006 676 337 66
12	1	0.063 146 314 631 463 146 31	1 351 035 564 000	11	0.000 000 000 000 537 657 77
144	2	0.005 075 341 217 270 243 66	16 432 451 210 000	12	0.000 000 000 000 043 136 32
1 750	3	0.000 406 111 564 570 651 77	221 411 634 520 000	13	0.000 000 000 000 003 411 35
23 420	4	0.000 032 155 613 530 704 15	2 657 142 036 440 000	14	0.000 000 000 000 000 264 11
303 240	5	0.000 002 476 132 610 706 64	34 327 724 461 500 000	15	0.000 000 000 000 000 022 01
3 641 100	6	0.000 000 206 157 364 055 37	434 157 115 760 200 000	16	0.000 000 000 000 000 001 63
46 113 200	7	0.000 000 015 327 745 152 75	5 432 127 413 542 400 000	17	0.000 000 000 000 000 000 14
575 360 400	8	0.000 000 001 257 143 561 06	67 405 553 164 731 000 000	18	0.000 000 000 000 000 000 01
7 346 545 000	9	0.000 000 000 104 560 276 41			

K.3.3 n log 2 and 10 In Decimal

n	n $\log_{10} 2$	n $\log_2 10$	n	n $\log_{10} 2$	n $\log_2 10$
1	0.30102 99957	3.32192 80949	6	1.80617 99740	19.93156 85693
2	0.60205 99913	6.64385 61898	7	2.10720 99696	23.25349 66642
3	0.90308 99870	9.96578 42847	8	2.40823 99653	26.57542 47591
4	1.20411 99827	13.28771 23795	9	2.70926 99610	29.89735 28540
5	1.50514 99783	16.60964 04744	10	3.01029 99566	33.21928 09489

K.3.4 Addition and Multiplication, Binary and Octal

Addition

Multiplication

Binary Scale

$$\begin{aligned} 0+0 &= 0 \\ 0+1 = 1+0 &= 1 \\ 1+1 &= 10 \end{aligned} \qquad \begin{aligned} 0\times 0 &= 0 \\ 0\times 1 = 1\times 0 &= 0 \\ 1\times 1 &= 1 \end{aligned}$$

Octal Scale

0	01	02	03	04	05	06	07
1	02	03	04	05	06	07	10
2	03	04	05	06	07	10	11
3	04	05	06	07	10	11	12
4	05	06	07	10	11	12	13
5	06	07	10	11	12	13	14
6	07	10	11	12	13	14	15
7	10	11	12	13	14	15	16

1	02	03	04	05	06	07
2	04	06	10	12	14	16
3	06	11	14	17	22	25
4	10	14	20	24	30	34
5	12	17	24	31	36	43
6	14	22	30	36	44	52
7	16	25	34	43	52	61

K.3.5 Mathematical Constants In Octal

$\pi = 3.11037\ 552421_8$	$e = 2.55760\ 521305_8$	$\gamma = 0.44742\ 147707_8$
$\pi^{-1} = 0.24276\ 301556_8$	$e^{-1} = 0.27426\ 530661_8$	$\ln \gamma = -\ 0.43127\ 233602_8$
$\sqrt{\pi} = 1.61337\ 611067_8$	$\sqrt{e} = 1.51411\ 230704_8$	$\log_2 \gamma = -\ 0.62573\ 030645_8$
$\ln \pi = 1.11206\ 404435_8$	$\log_{10} e = 0.33626\ 754251_8$	$\sqrt{2} = 1.32404\ 746320_8$
$\log_2 \pi = 1.51544\ 163223_8$	$\log_2 e = 1.34252\ 166245_8$	$\ln 2 = 0.54271\ 027760_8$
$\sqrt{10} = 3.12305\ 407267_8$	$\log_2 10 = 3.24464\ 741136_8$	$\ln 10 = 2.23273\ 067355_8$

K.2 POWERS OF TWO

POWERS OF TWO

2^n	n	n^{-2}
1	0	1.0
2	1	0.5
4	2	0.25
8	3	0.125
16	4	0.062 5
32	5	0.031 25
64	6	0.015 625
128	7	0.007 812 5
256	8	0.003 906 25
512	9	0.001 953 125
1 024	10	0.000 976 562 5
2 048	11	0.000 488 281 25
4 096	12	0.000 244 140 625
8 192	13	0.000 122 070 312 5
16 384	14	0.000 061 035 156 25
32 768	15	0.000 030 517 578 125
65 536	16	0.000 015 258 789 062 5
131 072	17	0.000 007 629 394 531 25
262 144	18	0.000 003 814 697 265 625
524 288	19	0.000 001 907 348 632 812 5
1 048 576	20	0.000 000 953 674 316 406 25
2 097 152	21	0.000 000 476 837 158 203 125
4 194 304	22	0.000 000 238 418 579 101 562 5
8 388 608	23	0.000 000 119 209 289 550 781 25
16 777 216	24	0.000 000 059 604 644 775 390 625
33 554 432	25	0.000 000 029 802 322 387 695 312 5
67 108 864	26	0.000 000 014 901 161 193 847 656 25
134 217 728	27	0.000 000 007 450 580 596 923 808 125
268 435 456	28	0.000 000 003 725 290 298 461 914 062 5
536 870 912	29	0.000 000 001 862 645 149 230 957 031 25
1 073 741 824	30	0.000 000 000 931 322 574 615 478 515 625
2 147 483 848	31	0.000 000 000 465 661 287 307 739 257 812 5
4 294 967 296	32	0.000 000 000 232 830 643 653 869 628 906 25
8 589 934 592	33	0.000 000 000 116 415 321 826 934 814 453 125
17 179 869 184	34	0.000 000 000 058 207 660 913 467 407 226 562 5
34 359 738 368	35	0.000 000 000 029 103 830 456 733 703 613 081 25
68 719 476 736	36	0.000 000 000 014 551 915 228 366 851 806 640 625
137 438 953 472	37	0.000 000 000 007 275 957 614 183 425 903 320 312 5
274 877 906 944	38	0.000 000 000 003 637 978 807 091 712 951 660 156 25
549 755 813 888	39	0.000 000 000 001 818 989 403 545 856 475 830 078 125
1 099 511 627 776	40	0.000 000 000 000 909 494 701 772 928 237 915 039 062 5
2 199 023 255 552	41	0.000 000 000 000 454 747 350 886 464 118 957 519 531 25
4 398 046 511 104	42	0.000 000 000 000 227 373 675 443 232 059 478 759 765 625
8 796 093 022 208	43	0.000 000 000 000 113 686 837 721 616 029 739 379 882 812 5
17 592 186 044 416	44	0.000 000 000 000 056 843 418 860 808 014 869 689 941 406 25
35 184 372 088 832	45	0.000 000 000 000 028 421 709 430 404 007 434 844 970 703 125
70 368 744 177 664	46	0.000 000 000 000 014 210 854 715 202 003 717 422 485 351 562 5
140 737 488 355 328	47	0.000 000 000 000 007 105 427 357 601 001 858 711 242 675 781 25
281 474 976 710 656	48	0.000 000 000 000 003 552 713 678 800 500 929 355 621 337 890 625
562 949 953 421 312	49	0.000 000 000 000 001 776 356 839 400 250 464 677 810 668 945 312 5
1 125 899 906 842 634	50	0.000 000 000 000 000 888 178 419 700 125 232 338 905 334 472 656 25
2 251 799 813 985 248	51	0.000 000 000 000 000 444 089 209 850 062 616 169 452 667 236 328 125
4 503 599 627 370 496	52	0.000 000 000 000 000 222 044 604 925 031 308 084 726 333 668 164 062 5
9 007 199 254 740 992	53	0.000 000 000 000 000 111 022 302 462 515 654 042 363 166 834 582 031 25
18 014 398 509 481 984	54	0.000 000 000 000 000 055 511 151 231 257 827 021 171 513 417 041 015 625
36 028 797 018 963 968	55	0.000 000 000 000 000 027 755 575 615 628 913 510 590 791 708 520 507 812 5
72 057 594 037 927 936	56	0.000 000 000 000 000 013 877 787 807 814 456 755 215 395 854 260 253 906 25
144 115 188 075 855 872	57	0.000 000 000 000 000 006 938 893 903 907 228 377 647 697 927 130 126 953 125
288 230 376 151 711 744	58	0.000 000 000 000 000 003 469 446 951 953 614 188 823 848 963 565 063 476 562 5
576 460 752 303 423 488	59	0.000 000 000 000 000 001 734 723 475 976 807 094 411 924 481 782 531 738 281 25
1 152 921 504 606 846 976	60	0.000 000 000 000 000 000 867 361 737 988 403 547 205 962 240 891 265 869 140 625

K.3 SCALES OF NOTATION

K.3.1 2^x In Decimal

x	2^x	x	2^x	x	2^x
0.001	1.00069 33874 62581	0.01	1.00695 55500 56719	0.1	1.07177 34625 36293
0.002	1.00138 72557 11335	0.02	1.01395 94797 90029	0.2	1.14869 83549 97035
0.003	1.00208 16050 79633	0.03	1.02101 21257 07193	0.3	1.23114 44133 44916
0.004	1.00277 64359 01078	0.04	1.02811 38266 56067	0.4	1.31950 79107 72894
0.005	1.00347 17485 09503	0.05	1.03526 49238 41377	0.5	1.41421 35623 73095
0.006	1.00416 75432 38973	0.06	1.04246 57608 41121	0.6	1.51571 65665 10398
0.007	1.00486 38204 23785	0.07	1.04971 66836 23067	0.7	1.62450 47927 12471
0.008	1.00556 05803 98468	0.08	1.05701 80405 61380	0.8	1.74110 11265 92248
0.009	1.00625 78234 97782	0.09	1.06437 01824 53360	0.9	1.86606 59830 73615

K.3.2 $10^{\pm n}$ In Octal

10^n	n	10^{-n}
1	0	1.000 000 000 000 000 000 00
12	1	0.063 146 314 631 463 146 31
144	2	0.005 075 341 217 270 243 66
1 750	3	0.000 406 111 564 570 651 77
23 420	4	0.000 032 155 613 530 704 15
303 240	5	0.000 002 476 132 610 706 64
3 641 100	6	0.000 000 206 157 364 055 37
46 113 200	7	0.000 000 015 327 745 152 75
575 360 400	8	0.000 000 001 257 143 561 06
7 346 545 000	9	0.000 000 000 104 560 276 41
112 402 762 000	10	0.000 000 000 006 676 337 66
1 351 035 564 000	11	0.000 000 000 000 537 657 77
16 432 451 210 000	12	0.000 000 000 000 043 136 32
221 411 634 520 000	13	0.000 000 000 000 003 411 35
2 657 142 036 440 000	14	0.000 000 000 000 000 264 11
34 327 724 461 500 000	15	0.000 000 000 000 000 022 01
434 157 115 760 200 000	16	0.000 000 000 000 000 001 63
5 432 127 413 542 400 000	17	0.000 000 000 000 000 000 14
67 405 553 164 731 000 000	18	0.000 000 000 000 000 000 01

K.3.3 n log 2 and 10 In Decimal

n	$n \log_{10} 2$	$n \log_2 10$	n	$n \log_{10} 2$	$n \log_2 10$
1	0.30102 99957	3.32192 80949	6	1.80617 99740	19.93156 85693
2	0.60205 99913	6.64385 61898	7	2.10720 99696	23.25349 66642
3	0.90308 99870	9.96578 42847	8	2.40823 99653	26.57542 47591
4	1.20411 99827	13.28771 23795	9	2.70926 99610	29.89735 28540
5	1.50514 99783	16.60964 04744	10	3.01029 99566	33.21928 09489

K.3.4 Addition and Multiplication, Binary and Octal

Addition

Multiplication

Binary Scale

$$0 + 0 = 0$$
$$0 + 1 = 1 + 0 = 1$$
$$1 + 1 = 10$$

$$0 \times 0 = 0$$
$$0 \times 1 = 1 \times 0 = 0$$
$$1 \times 1 = 1$$

Octal Scale

0	01	02	03	04	05	06	07
1	02	03	04	05	06	07	10
2	03	04	05	06	07	10	11
3	04	05	06	07	10	11	12
4	05	06	07	10	11	12	13
5	06	07	10	11	12	13	14
6	07	10	11	12	13	14	15
7	10	11	12	13	14	15	16

1	02	03	04	05	06	07
2	04	06	10	12	14	16
3	06	11	14	17	22	25
4	10	14	20	24	30	34
5	12	17	24	31	36	43
6	14	22	30	36	44	52
7	16	25	34	43	52	61

K.3.5 Mathematical Constants In Octal

$\pi = 3.11037\ 552421_8$	$e = 2.55760\ 521305_8$	$\gamma = 0.44742\ 147707_8$
$\pi^{-1} = 0.24276\ 301556_8$	$e^{-1} = 0.27426\ 530661_8$	$\ln \gamma = -\ 0.43127\ 233602_8$
$\sqrt{\pi} = 1.61337\ 611067_8$	$\sqrt{e} = 1.51411\ 230704_8$	$\log_2 \gamma = -\ 0.62573\ 030645_8$
$\ln \pi = 1.11206\ 404435_8$	$\log_{10} e = 0.33626\ 754251_8$	$\sqrt{2} = 1.32404\ 746320_8$
$\log_2 \pi = 1.51544\ 163223_8$	$\log_2 e = 1.34252\ 166245_8$	$\ln 2 = 0.54271\ 027760_8$
$\sqrt{10} = 3.12305\ 407267_8$	$\log_2 10 = 3.24464\ 741136_8$	$\ln 10 = 2.23273\ 067355_8$

APPENDIX L

NOTE TO USERS OF SERIAL LA3Ø AND 6ØØ, 12ØØ, AND 24ØØ BAUD VTØ5'S

The serial LA3Ø requires that filler characters follow each carriage return; the 6ØØ, 12ØØ, and 24ØØ baud VTØ5's require that filler characters follow each line feed. The following table lists the filler characters needed. The byte at location 44_8 has been established as the filler count and the byte at location 45_8 contains the character to be filled. These locations are initially set to zero by PAL-11A and ED-11 to allow normal operation of the program.

Depending on the terminal, change the locations as follows:

	LOC 44	LOC 45	Resulting Word (binary)
LA3Ø	Ø11$_8$	Ø15$_8$	ØØØØ11Ø1ØØØØ1ØØ1
VTØ5 6ØØ Baud	ØØ1$_8$	Ø12$_8$	ØØØØ1Ø1ØØØØØØØØ1
VTØ5 12ØØ Baud	ØØ2$_8$	Ø12$_8$	ØØØØ1Ø1ØØØØØØØ1Ø
VTØ5 24ØØ Baud	ØØ4$_8$	Ø12$_8$	ØØØØ1Ø1ØØØØØØ1ØØ

The proper binary word can be stored at location 44_8 by using the console switches as described in section 2.1.2 of this manual. Furthermore, users with a 24ØØ baud VTØ5 should avoid the use of vertical tab characters in their programs. Vertical tabs will not be properly filled and may cause characters to be lost.

Once the changes have been made, the program may be dumped to paper tape by using the bootstrap version of DUMPAB (see section 6.3 in this manual).

The above changes only affect output to the console teleprinter.

Users of IOX or IOXLPT source tapes will find the byte at location 44 tagged "I.44:" and the byte at location 45 tagged "I.45:". These locations are defined near the end of the second source tape and can be changed to appropriate values using ED-11.

ODT-11 uses the locations (44 and 45) but does not set them to zero initially.

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Did you find errors in this manual? If so, specify by page.

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