PDP-11
PAL-11S ASSEMBLER
AND
LINK-11S LINKER
PROGRAMMER'S MANUAL

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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. Completion and return of the "Reader's Comments" page is beneficial to both you and DEC; all comments received are acknowledged and are considered when documenting subsequent manuals.

PREFACE

This document describes the PAL-11S Assembly Language and Assembler (Chapter 1) and the Link-11S Linker (Chapter 2).

PAL-11S and Link-11S are stand-alone programs which are compatible subsets of the Disk Operating System (DOS) PAL-11R and Link-11 system programs. Minimum hardware requirements are an 8K PDP-11 with a teleprinter. A PC11 (high-speed paper tape punch) and/or LP11 (line printer) may be used also.

The inputs and outputs of the stand-alone programs are also compatible with the DOS counterparts. Thus, a program assembled by PAL-11R can be linked by Link-11S, and vice versa. The output of Link-11S is loadable by the DOS Loader or the Absolute Loader from the paper tape system.

PAL-11S has all the capabilities of PAL-11R except for named .CSECT's. PAL-11S has only the unnamed .CSECT and the .ASECT. PAL-11S does not have the redundant mnemonics for some of the additional assembler directives. That is, it has .IFZ, .IFNZ, .IFL, and .IFG, but does not have the equivalent names .IFEQ, .IFNE, .IFLT, and .IFGT (PAL-11R has both sets).

Link-11S has most of the capabilities of Link-11 except for library searching. Link-11S has a simple initial dialogue which allows the operator to select the I/O devices, define the addresses where the program is to be linked, and to request a list of undefined globals. Link-11S does handle named and unnamed .CSECT's and therefore can link the output of PAL-11R.

C O N T E N T S

CHAPTER 1

PAL-11S ASSEMBLER

CHAPTER 1

PAL-11S ASSEMBLY LANGUAGE AND ASSEMBLER

PAL-11S (Program Assembly Language for the PDP-11, Relocatable, Stand Alone Version) 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 modules which are processed by the PDP-11 linker, LINK-11S. LINK-11S produces a load module which is loaded by the Absolute Loader for execution. Object modules may contain absolute and/or relocatable code and separately assembled object modules may be linked with global symbols. The object module 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 not only explains how to write PAL-11S programs but also how to assemble the source programs into object modules. 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-11S 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-11S are:

1. Selective assembly pass functions.
2. Device specification for pass functions.
3. Optional error listing on the teleprinter.
4. Double buffered and concurrent I/O (provided by IOXLPT).
5. Alphabetized, formatted symbol table listing.
6. Relocatable object modules.
7. Global symbols for linking between object modules.

8. Conditional assembly directives.

9. Program Sectioning Directives.

The PAL-11S Assembler requires 8K of memory and provides for about 900 user-defined symbols (see Section 3.2). In addition, it allows a line printer to be used for program listing and/or symbol table listing.

The following discussion of the PAL-11S Assembly Language assumes that you have read the PDP-11 Handbook 1971, with emphasis on those sections which deal with the PDP-11 instruction repertoire, formats, and timings -- a thorough knowledge of these is vital to efficient assembly language programming.

1.0 CHARACTER SET

A PAL-11S source program is composed of symbols, numbers, expressions, symbolic instructions, assembler directives, argument separators, and line terminators written using the following ASCII* 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 $. (These characters are reserved for systems use.)

4. The separating or terminating symbols:

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

carriage return tab space line feed form feed

2.0 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 which 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 10.0), 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, a typed carriage return (RETURN 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

---

*ASCII stands for American Standard Code for Information Interchange.

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.

2.1 Label

A label is a user-defined symbol (see Section 3.2) which is assigned the value of the current location counter. This value may be either absolute or relocatable depending on whether the location counter value is absolute or relocatable. In the latter case, the final absolute value is assigned by the Linker, i.e., the value + the relocation constant. A label 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 absolute 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. In the above case if the location counter were relocatable then the final value of ABCD would be 100_8+K, where K is the location of the beginning of the relocatable section in which the label ABCD appears. 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 counter is 100_8, 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.

2.2 Operator

An operator follows the label field in a statement, and may be an instruction mnemonic or an assembler directive (see Section 8 and 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.

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.

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.

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 automatically terminated after 56 lines.

3.0 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.

3.1 Permanent Symbols

Permanent symbols consist of the instruction mnemonics (see Appendix B.3) and assembler directives (see Section 8.0). These symbols are a permanent part of the Assembler's symbol table and need not be defined before being used in the source program.

3.2 User-Defined Symbols

User-defined symbols are those defined as labels (see Section 2.1) or by direct assignment (see Section 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 $'s and .'s are reserved for system software. Any other character is illegal and, if used, will result in the error message I or QU (see Section 10.0). I is a low priority error which may be flagged as QU first. 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.

User-defined symbols are either internal or global. All symbols are internal unless they are explicitly typed as global with the .GLOBL assembler directive (see Section 8.2). Global symbols are used to provide links between object modules. A global symbol which is defined (as a label or by direct assignment) in a program is called an entry symbol or entry point. Such symbols may be referred to from other object modules or assemblies. A global symbol which is not defined in the current assembly is called an external symbol. Some other assembly must define the same symbol as an entry point.

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 symbol takes on the relocatable or absolute attribute of the defining expression. However, if the defining expression is global, the defined symbol will not be global unless previously defined as such (see Section 4.0).

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 two levels of forward referencing (illegel):

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

X and Y are both undefined throughout pass 1 and will be listed on the teleprinter 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 EXPRESSION'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
```

3.4 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. In addition, the defining expression of a register symbol must be absolute. For example:

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

R3=R0+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 10.0).

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 7.11 and 7.12. 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
```

4.0 EXPRESSIONS

Arithmetic and logical operators (see Section 4.2) may be used to form expressions. A term of an expression may be a permanent or user-defined symbol (which may be absolute, relocatable or global), a number, ASCII data, or the present value of the assembly location counter represented by the period (see Section 5.0). 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 8.8) are evaluated as word expressions before truncation to the low-order eight bits. The evaluation of an expression includes the evaluation of the mode of the resultant expression; that is, absolute, relocatable or external. The definition of the modes of expression are given below in Section 4.4.

A missing term, expression or external symbol 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 + -100                ;OPERAND MISSING
```

will be evaluated as A + 0 - 100, and

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

will be evaluated as TAG ! LA+177777.

The value of an external expression will be the value of the absolute part of the expression; e.g., EXT+A will have a value of A. This will be modified by the linker to become EXT+A.

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 10.0) will be printed and the number will be 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. Numbers are always considered to be absolute quantities (that is, not relocatable).

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:

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

AND

0	&	0	=	0
0	&	1	=	0
1	&	0	=	0
1	&	1	=	1

OR

0	!	0	=	0
0	!	1	=	1
1	!	0	=	1
1	!	1	=	1

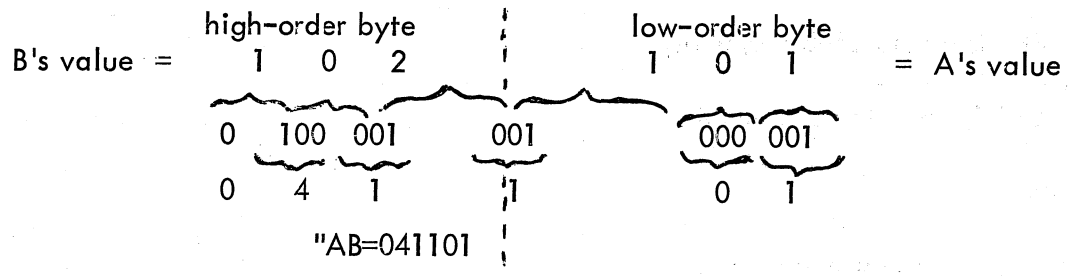
4.3 ASCII Conversion

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:



ASCII text is always absolute.

4.4 Mode of Expressions

The mode of an expression may be absolute, relocatable or external as defined below:

A term of an expression is absolute, relocatable or external depending on whether its definer (i.e., number, symbol, etc.) is absolute, relocatable or external. Numbers, permanent symbols and generated data are always treated as absolute.

An absolute expression is defined as:

1. Absolute term preceded optionally by a single plus or minus sign, or
2. Relocatable expression minus a relocatable term, or
3. Absolute expression followed by an operator followed by an absolute expression.

A relocatable expression is defined as:

1. Relocatable term, or
2. Relocatable expression followed by an arithmetic operator followed by an absolute expression, or
3. Absolute expression followed by a plus operator followed by a relocatable expression.

An external expression is defined as:

1. External term, or
2. External expression followed by an arithmetic operator followed by an absolute term, or
3. Absolute expression followed by a plus operator followed by an external expression.

In the following examples:

ABS is an absolute symbol,

REL is a relocatable symbol,

EXT is an external symbol.

Examples:

The following are valid expressions:

```
EXT + ABS              ;External expression

REL+REL-REL            ;Relocatable expression

ABS+REL-REL & ABS      ; Absolute expression
```

The following are illegal expressions:

```
EXT+REL
REL+REL
ABS-EXT
```

5.0 ASSEMBLY LOCATION COUNTER

The period (.) is the symbol for the assembly location counter. (Note difference of Program Counter. . ≠ PC. See Section 7.0.) 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 #.,R0      ;. refers to location A,
                   ;i.e., the address of the
                   ;MOV instruction
```

(# is explained in Section 7.9.)

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
```

Similar to other symbols, the location counter symbol "." has a mode associated with it. However, the mode cannot be external. Neither can one change the existing mode of the location counter by using a defining expression of a different mode.

The mode of the location counter symbol can be changed by the use of the .ASECT or .CSECT directive as explained in section 8.3.

The expression defining the location counter must not contain forward references or symbols that vary from one pass to another.

Examples:

```
.ASECT
      .=500            ;SET LOCATION COUNTER TO ABSOLUTE 500
```

```
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 DEPOSITED
                                 ;IN LOCATION COUNT.

          .=520                  ;THE ASSEMBLY LOCATION COUNTER NOW
                                 ;HAS A VALUE OF ABSOLUTE 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 INSTRUC-
                                 ;TION ITSELF, WILL BE DEPOSITED IN
                                 ;LOCATION INDEX.

.CSECT
          .=.+20                 ;SET LOCATION COUNTER TO RELOCATABLE
                                 ;20.

THIRD:    .WORD 0                ;THE LABEL THIRD HAS THE VALUE OF
                                 ;RELOCATABLE 20.
```

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

```
.=.+100
```

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

6.0 RELOCATION AND LINKING

The output of the relocatable assembler is an object module which must be processed by the PDP-11 Linker, LINK-11S, before loading and execution. The Linker essentially fixes (i.e., makes absolute) the values of external or relocatable symbols and creates another module (load module) which contains the binary data to be loaded and executed.

To enable the Linker to fix the value of an expression the assembler issues certain directives to the Linker together with the required parameters. In the case of relocatable expressions the Linker adds the base of the relocatable section (the location in memory of relocatable 0) to the value of the relocatable expression provided by the Assembler. In the case of an external expression the value of the external term in the expression is determined by the Linker (since the external symbol must be defined in one of the other object modules being linked and adds it to the value of the external expression provided by the Assembler.

All instructions that are to be modified as described above will be marked by a single apostrophe in the assembly listing. Thus the binary text output will look as follows for the given examples:

```
005065'  CLR    EXTERNAL(5)          ;
000000                                ;VALUE OF EXTERNAL SYMBOL
                                      ;ASSUMED ZERO; WILL BE
                                      ;MODIFIED BY THE LINKER.
005065'  CLR    EXTERNAL+6(5)        ;
000006                                ;
005065'  CLR    RELOCATABLE(5)       ;ASSUMING WE ARE IN THE
000040                                ;ABSOLUTE SECTION AND
                                      ;THE VALUE OF RELOCATABLE
                                      ;IS RELOCATABLE 40
```

7.0 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, the action of the Program Counter must be understood. The key rule is:

> Whenever the processor implicitly uses the Program Counter 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 7.7, 7.8 and 7.10), 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:

1. Let E be any expression as defined in Section 4.0.

2. Let R be a register expression. This is any expression containing a term preceded by a % character of 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
```

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

4. Let A be a general address specification which produces a 6-bit mode address field as described in the PDP-11 Handbook 1971.

The addressing specifications, 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.

7.1 Register Mode

The register contains the operand.

Format: R

Example:

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

7.2 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
```

7.3 Autoincrement Mode

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

Format: (ER)+

Examples:

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

NOTE

Both JMP and JSR instructions using mode 2 (non-deferred autoincrement mode), autoincrement the register before its use.

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 R0, (0)+    ;THE QUANTITY 102 IS MOVED TO LOCATION 100
MOV R0,-(0)     ;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.

7.4 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
```

7.5 Autodecrement Mode

The contents of the register are decremented before being used as the address of the operand (see note in Section 7.3).

Format: -(ER)

Examples:

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

7.6 Deferred Autodecrement Mode

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

Format: @ -(ER)

Example:

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

7.7 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
```

7.8 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 LOCATION
               ;114 HOLDS 2000, LOC.2000 IS CLEARED.
```

7.9 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:

```
0 1 2 7 0 3
0 0 0 1 0 0
```

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.

7.10 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 absolute location 20 then the assembled code is:

Location 20:	016703
Location 22	000054

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.

7.11 Table of Mode Forms and Codes (6-bit(A) format only - see Section 7.12)

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 modes, however, increases the instruction length by one word.

	Form	Mode	Meaning
None of these forms increases the instruction length.	R	0n	Register
	@R or (ER)	1n	Register deferred
	(ER)+	2n	Autoincrement
	@(ER)+	3n	Autoincrement deferred
	-(ER)	4n	Autodecrement
	@-(ER)	5n	Autodecrement deferred

	Form	Mode	Meaning
Any of these forms adds a word to the instruction length.	E (E R)	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.

The Assembler is not particular about left and right and dangling + and - signs in address fields. The following are some examples of incorrect syntax that assemble as indicated, without an error indication.

Form	Assembles As:	Form	Assembles As:
(R2)A	A(R2)	(R2)-	-(R2)
A-(R2)	A(R2) or A-Ø(R2)	@ (R2)A	@ A(R2)
A(Rw)+	A(R2)	A(R2)+B	A+B(R2)
+(R2)	(R2)+		

7.12 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 Sections 4.0 and 7.0 and let A be a 6-bit address specification of the forms:

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

Table 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	BR X+2
		BLO .-4
	where $-128<(E-.-2)/2\leq 127$	
Subroutine Call	JSR ER,A	JSR PC,SUBR
Subroutine Return	RTS ER	RTS PC
EMT/TRAP	Op or OP E	EMT
	where $0\leq E\leq 377_8$	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:

1. Extend the sign of the offset through bits 8-15.
2. Multiply the result by 2. This creates a word offset rather than a byte offset.
3. 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.

NOTE

It is illegal to branch to a location specified as an external symbol, or to a relocatable symbol when within an absolute section, or to an absolute symbol when within a relocatable section.

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 bit (>377_8) it is truncated to eight bits and a Truncation (T) error occurs.

Do not try to micro-program the condition code operators (see Appendix B, B.4). This makes sense in the PDP-11 hardware; however, the current PAL-11S Assembler does not support this capability. Thus:

```
CLC!CLV
```

results in a Q error (see Appendix B, B.5) and the statement is assembled as CLC.

Expressions in the Assembler do, however, allow logical operators and the use of instruction mnemonics. Thus, the proper ways to write the above statement:

```
.WORD CLC!      ;Operand of .WORD
+CLC!CLV        ;Operand of default .WORD
!CLC!CLV        ;Operand of default .WORD
```

8.0 ASSEMBLER DIRECTIVES

Assembler directives (sometimes called pseudo-ops) direct the assembly process and may generate data.

Assembler directives 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.

8.1 .TITLE

The .TITLE directive is used to name the object module. The name is assigned by the first symbol following the directive. If there is no .TITLE statement the default name assigned is ".MAIN.".

8.2 .GLOBL

The .GLOBL directive is used to declare a symbol as being global. It may be an entry symbol, in which case it is defined in the program, or it may be an external symbol, in which case it should be defined in another program which will be linked with this program by the linker.

The form of the .GLOBL directive is

```
.GLOBL  NAMA, NAMB,...,NAMN
```

NOTE

A symbol cannot be declared global by defining it as a global expression in a direct assignment statement.

If an illegal character is detected in the operand field of a .GLOBL statement, an error message is not generated; and the Assembler may ignore the remainder of the statement. Thus:

```
GLOBL A,B,@ C,D
```

assembles without error as:

```
.GLOBL A,B
```

8.3 Program Section Directives (.ASECT and .CSECT)

The relocatable assembler provides for two program sections, an absolute section declared by an .ASECT directive and a relocatable section declared by a .CSECT directive. These directives therefore enable the programmer to specify that parts of his program be assembled in the absolute section and others in a relocatable section. The scope of each directive extends until a directive to the contrary is given. The Assembler initially starts in the relocatable section. Thus, if the first statement of a program were

```
A: .ASECT
```

the label "A" would be a relocatable symbol which is assigned the value of relocatable zero. The absolute value of A will be calculated by the Linker by adding the value of the base of the relocatable section.

Example:

```
    .ASECT          ;ASSEMBLER IN ABSOLUTE SECTION
    .=1000          ;PC = 1000 ABSOLUTE
A:  CLR X           ;A = 1000 ABSOLUTE
    .CSECT          ;ASSEMBLE IN RELOCATABLE SECTION
X:  JMP A           ;X=0 RELOCATABLE
    .END
```

The absolute and/or relocatable section may be discontinued (by switching to the alternate section) and then continued where they left off by using another .ASECT or .CSECT statement.

Example:

```
.CSECT
.WORD 0,1,2          ;ASSEMBLED AT RELOCATABLE 0, 2 and 4
.ASECT
.WORD 0,1,2          ;ASSEMBLED AT ABSOLUTE 0, 2 and 4
.CSECT
.WORD 0              ;ASSEMBLED AT RELOCATABLE 6.
.END
```

If a label is defined twice, first in an absolute section and then in a relocatable section, the symbol will be relocatable but its value will be as defined in the absolute section.

8.4 .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 should be terminated by a .END directive (see Section 8.6) but may be terminated with .EOT (see .END emulation in Section 9.4).

8.5 .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.

8.6 .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 transfer address.

At load time, the load module will be loaded and program execution will begin at the transfer address indicated by the .END directive. If the address is not specified, the loader will halt after reading in the load module.

8.7 .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 expression. For example,

```
.=1420
SAL=0
.WORD 177535,.+4,SAL          ;STORED IN WORDS 1420, 1422 AND
                              ;1424 WILL BE 177535, 1426, AND 0
```

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,

```
.=1430                ;ZERO, FIVE, AND ZERO ARE STORED
.WORD ,5,             ;IN WORDS 1430, 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 mnemonic or assembler directive unless preceded by a +, -, or one of the logical operators, ! or &. For example,

```
.=440                 ;THE OP-CODE FOR MOV, WHICH IS 010000,
LABEL: +MOV,LABEL     ;IS STORED IN LOCATION 440.  440 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.

8.8 .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 410 WILL BE
.=410                 ;060 (THE OCTAL EQUIVALENT OF 48).
.BYTE 48.,SAM         ;IN 411 WILL BE 005.
```

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,

```
.=420                   ;ZERO WILL BE STORED IN
.BYTE , ,               ;BYTES 420, 421 AND 422.
```

If the expression is relocatable, a warning flag, A, will be given.

8.9 .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,

```
.=500                   ;THE ASCII CODE FOR  Y  WILL BE
.ASCII  /YES/           ;STORED IN 500, THE CODE FOR  E
                        ;IN 501, THE CODE FOR  S  IN 502.
.ASCII /5+3/2/          ;THE DELIMITING CHARACTER OCCURS
                        ;AMONG THE OPERANDS.  THE ASCII
                        ;CODES FOR  5 , + , AND  3  ARE
                        ;STORED IN BYTES 503, 504, AND
                        ;505.  2/ IS NOT ASSEMBLED.
```

The .ASCII directive may be terminated by any legal terminator except for = and : . Note that if the text delimiter is also a terminator, the leading text delimiter can also serve as the .ASCII directive terminator. For example,

```
.ASCII /ABCD/           ;THE SPACE IS REQUIRED
                        ;BECAUSE  /  IS NOT A TERMINATOR.
.ASCII+ABCD+            ;NO SPACE IS REQUIRED.
```

8.10 .RAD50

PDP-11 system programs often handle symbols in a specially coded form called "RADIX 50" (this form is sometimes referred to as "MOD40"). This form allows 3 characters to be packed into 16 bits; therefore, any symbol can be held in two words, the form of the directive is:

```
.RAD50  /CCC/
```

The single operand is of the form /CCC/ where the slash (the delimiter) can be any printable character except for = and : . The delimiters enclose the characters to be converted which may be A through Z, 0 through 9, dollar ($), dot (.) and space ( ). If there are fewer than 3 characters they are considered to be left-justified and trailing spaces are assumed. Any characters following the trailing delimiter are ignored and no error results.

Examples:

```
.RAD50 /ABC/        ;PACK ABC INTO ONE WORD
.RAD50 /AB/         ;PACK AB (SPACE) INTO ONE WORD;
.RAD50 //           ;PACK 3 SPACES INTO ONE WORD
```

The packing algorithm is as follows:

A. Each character is translated into its RADIX 50 equivalent as indicated in the following table:

Character	RADIX 50 Equivalent (octal)
(SPACE)	0
A-Z	1-32
$	33
.	34
0-9	36-47

Note that another character can be defined for code 35.

B. The RADIX 50 equivalents for characters 1 through 3 (C1, C2, C3) are combined as follows:

RESULT=((C1*50)+C2)*50+C3

8.11 .LIMIT

A program often wishes to know the boundaries of the relocatable code. The .LIMIT directive generates two words into which the linker puts the low and high addresses of the relocated code. The low address (inserted into the first word) is the address of the first byte of code. The high address is the address of the first free byte following the relocated code. These addresses will always be even since all relocatable sections are loaded at even addresses and if a relocatable section consists of an odd number of bytes the linker adds one to the size to make it even.

8.12 CONDITIONAL ASSEMBLY DIRECTIVES

Conditional assembly directives provide the programmer with the capability to conditionally include or not include portions of his source code in the assembly process. In what follows, E denotes an expression and S(i) denotes a symbol. The conditional directives are:

```
.IFZ      E              ;IF E=0
.IFNZ     E              ;IF E≠0
.IFL      E              ;IF E<0
.IFLE     E              ;IF E≤0
.IFG      E              ;IF E>0
.IFGE     E              ;IF E≥0
.IFDF     S (1) [ !,& ] S (2) [ !,& ] ...[ !,& ] S(N)   (!=OR,&=AND)
.IFNDF    S (1) [ !,& ] S (2) [ !,& ] ... [ !,& ] S(N)
```

If the condition is met, all statements up to the matching .ENDC are assembled. Otherwise, the statements are ignored until the matching .ENDC is detected.

In the above, .IFDF and .IFNDF mean "if defined" and "if undefined" respectively. The scan is left to right, no parentheses permitted.

Example:

.IFDF S!T&U	Means assemble if either S or T is defined and U is defined
.IFNDF T&U!S	Means assemble if both T and U are undefined or if S is undefined

General Remarks:

An errored or null expression takes the default value 0 for purposes of the conditional test. An error in syntax, e.g., a terminator other than ;, !, &, or CR results in the undefined situation for .IFDF and .IFNDF, as does an errored or null symbol.

All conditionals must end with the .ENDC directive. Anything in the operand field of .ENDC is ignored. Nesting is permitted up to a depth of 127_{10}. Labels are permitted on conditional directives, but the scan is purely left to right. For example:

```
        .IFZ 1
A:      .ENDC
```

A is ignored.

```
A:      .IFZ 1
        .ENDC
```

A is entered in the symbol table.

If a .END is encountered while inside a satisfied conditional, a Q flag will appear, but the .END directive will still be processed normally. If more .ENDC's appear than are required, Q flags appear on the extras.

9.0 OPERATING PROCEDURES

9.1 Introduction

The Assembler enables you to assemble an ASCII tape containing PAL-11 statements into a relocatable binary tape (object module). 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 9.3). The Assembler initiates the dialogue immediately after being loaded and after the last pass of an assembly.

9.2 Loading PAL--11S

PAL-11S is loaded by the Paper Tape Software Absolute Loader. 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 program which clears all of core up to the address specified in the Switch Register, and jumps to that address to start loading the Assembler.

9.3 Initial Dialogue

After being loaded, the Assembler prints its name and version and then initiates dialogue by printing on the teleprinter

```
*S
```

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

↵	use Low-speed reader (↵ denotes typing the RETURN key)
H	meaning High-speed reader
L	meaning Low-speed reader
T	meaning Teleprinter keyboard

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 during the third pass.
*B	)	The RETURN key alone 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
H	meaning High-speed punch
T	meaning Teleprinter
P	meaning Line Printer
)	meaning do not output listing ( ) denotes typing RETURN)

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 *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 RETURN 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 the RETURN key alone will cause the Assembler to omit symbol table output.

The symbol table is printed alphabetically, three 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 and external symbols will be listed as undefined direct assignments.

If the symbol is relocatable or global or both, the symbol's value will be followed by an R, a G or both.

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 listing to punch on pass 2.
     *L   H/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 object module so generated is acceptable to the Linker 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 Linker 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. If the low-speed reader is the source input device, turn it off before typing 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 (not including external

globals) 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 module, 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 (the low-speed punch and teleprinter conflict). Furthermore, if the binary object module is not requested, the listing will be produced on pass 2.

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	Teleprinter keyboard
L	Low-speed reader or punch
H	High-speed reader or punch
P	Line Printer
/1	Pass 1
/2	Pass 2
/3	Pass 3
/E	Errors listed on same pass (not meaningful response to *S or *T)
↵	Omit function (except in response to *S).

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.

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 ? messages 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 Linker 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 that forcing a .END in this manner causes the error counter to be incremented by one.

9.5 Assembly Listing

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

```
EELLLLLL  OOOOOOASSS.......S
          OOOOOO
          OOOOOO
```

The E's represent the error field. The L's represent the address. The O's represent the object data in octal. The S's represent the source statement. "A" represents a single apostrophe which indicates that either the second, third or both words of the instruction will be modified by the Linker. 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.

The .ASECT and .CSECT directives cause the current value of the appropriate location counter (absolute or relocatable) to be printed.

Each page of the listing is headed by a page number (octal).

9.6 Object Module Output

The output of the assembler during the binary object pass is an object module which is meaningful only to the linker. What follows gives an overview of what the object module contains and at what stage each part of it is produced.

The binary object module consists of three main types of data block:

a) Global symbol directory (GSD)
b) Text blocks (TXT)
c) Relocation Directory (RLD)

9.6.1 Global Symbol Directory

As the name suggests, the GSD contains a list of all the global symbols together with the name of the object module. Each symbol is in Radix-50 form and contains information regarding its mode and value whenever known.

The GSD is created at the start of the binary object pass.

9.6.2 Text Block

The text blocks consist entirely of the binary object data as shown in the listing. The operands are in the unmodified form.

9.6.3 Relocation Directory

The RLD blocks consist of directives to the Linker which may reference the text block preceding the RLD. These directives control the relocation and linking process.

Text and RLD blocks are constructed during the binary object pass. Outputting of each

block is done whenever either the TXT or RLD buffer is full and whenever the location counter needs to be modified.

10.0 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. Also may indicate a relocation error.
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 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 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.

Error Code	Meaning
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.

II.0 SOFTWARE ERROR HALTS

PAL-11S loads all of its 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.

Address of Halt (octal)	Meaning
12	Reserved instruction executed
16	Trace trap occurred
26	Power fail trap
32	EMT executed

A halt at address 40 indicates an IOXLPT detected error. R0 (displayed in the console lights) contains an identifying code:

Code in R0	Meaning
0	Illegal memory reference, SP overflow or illegal instruction.
1	Illegal IOX command.
2	Slot number out of range.
3	Device number illegal
4	Referenced slot not INITed.
5	Illegal Data Mode.

IOXLPT also sets R1 as follows:

If the error code is 0, R1 contains the PC at the time of the error.

If the error code is 1-5, R1 points to some element in the IOT argument list or to the instruction following the argument list, depending on whether IOXLPT has finished decoding all the arguments when it detects the error.

CHAPTER 2

LINK - 11S LINKER

Contents

CHAPTER 2

LINK - 11S LINKER

1.0 INTRODUCTION

1.1 General Description

LINK-11S (stand alone) is a PDP-11 system program designed to link and relocate programs previously assembled by PAL-11S. This capability allows the user to separately assemble his main program and each of his various subroutines without assigning an absolute load address at assembly time. The binary output of each assembly (called object modules) is processed by LINK-11S (hereafter called the Linker or LINK-11) to:

a. Relocate each object module and assign absolute addresses.

b. Link the modules by correlating global symbols defined in one module and referenced in another module.

c. Print a load map which displays the assigned absolute addresses.

d. Punch a load module which can subsequently be loaded (by the Absolute loader) and executed.

Some of the advantages of using PAL-11S and LINK-11 are:

a. The program is divided into segments (usually subroutines) which are assembled separately. If an error is discovered in one segment, only that segment needs to be reassembled. The new object module is then linked with the other object modules.

b. Absolute addresses need not be assigned at assembly time. The Linker automatically assigns absolute addresses. This keeps programs from overlaying each other. This also allows subroutines to change size without influencing the placement of other routines.

c. Separate assemblies allow the total number of symbols to exceed the number allowed in a single assembly.

d. Internal symbols (symbols which are not global) need not be unique among object modules. Thus, naming rules are required only for global symbols when separate programmers prepare separate subroutines of a single program.

e. Subroutines may be provided for general use in object module form to be linked into the user's program.

LINK-11 is designed to run on an 8K PDP-11 with an ASR-33. A PC11 (high speed paper tape reader and punch) and an LP11 (line printer) may be used if available. The PC11 significantly speeds up the linking process. An LP11 provides a fast device for the load map listing.

1.2 Absolute and Relocatable Program Sections

A program assembled by PAL-11S may consist of an absolute program section, declared by the .ASECT assembler directive, and a relocatable program section, declared by the .CSECT assembler directive. (If a program has neither an .ASECT or .CSECT directive, the assembler implicitly assumes a .CSECT directive.) The program and data in the absolute section are assigned absolute addresses as specified by the location counter setting statements (.=x). The program and data in the relocatable section are assigned absolute addresses by the linker. Addresses are normally assigned such that the relocatable section is at the high end of memo The assignment of addresses may be influenced by command string options (see Section 3.2).

The Linker appropriately modifies all instructions and/or data as necessary to account for the relocation of the control section.

LINK-11 has the capability to handle object modules containing named control (relocatable) sections as generated by PAL-11R. However, PAL-11S can only create the unnamed control section (which has the special default name of 6 blanks) and the absolute section (with the special name .ΔABS.). The unnamed control section is internal to each object module. That is, every object module may have an unnamed control section (each with the name 6 blanks) but the Linker treats them independently. Each is assigned an absolute address such that they occupy mutually exclusive areas of memory. Named control sections, on the other hand, are treated globally. That is, if different object modules each have control sections with the same name, they are all assigned the same absolute load address and the size of the area reserved for loading of the section is the maximum of the sizes of each section. Thus, named control sections allow the sharing of data and/or programs among object modules. Thi is very similar to the handling and function of labelled COMMON in FORTRAN IV.
A restriction of LINK-11S is that the name of a control section must not be the same as the name of a global entry symbol. This will result in multiple definition errors.

1.3 Global Symbols

Global symbols provide the links or communication between object modules (or assemblies). Global symbols are created with the .GLOBAL assembler directive. Symbols which are not global are called internal symbols. If the global symbol is defined (as a label or direct assignment) in an object module it is called an entry symbol, and other object modules may reference it. If the global symbol is not defined in the object module it is an external symbol. It is assumed to be defined (as an entry symbol) in some other object module.

As the Linker reads the object modules it keeps track of all the global symbol definitions and references. It then modifies the instructions and/or data which reference the global symbols.

2.0 INPUT AND OUTPUT

2.1 Object Module

LINK-11's input is the object module. This is the output of PAL-11S (or any other program which can create an object module). The Linker reads each object module twice; that is, it is a two pass processor.

On pass 1, the Linker reads each object module to gather enough information so that absolute addresses can be assigned to all relocatable sections and all globals can be assigned absolute values. This information appears in the global symbol directory (GSD) of the object module.

On pass 2, the Linker reads all of each object module and produces the load module (see Section 2.2). The data gathered on pass I guides the relocation and linking process on pass 2.

2.2 Load Modules

The normal output of the Linker is a load module which may be loaded and run.

A load module consists of formatted binary blocks holding absolute load addresses and object data as specified for the Paper Tape System Absolute Loader and the PDP-11 Disk Monitor. The first few words of data will be the communications directory (COMD) and will have an absolute load address equal to the lowest relocated address of the program. The absolute loader will load the COMD at the specified address but then the program will overlay the COMD*. The disk monitor loader will expect the COMD and will load it where the monitor wants it. The end of the load module will be indicated by a TRA block; that is, a block containing only a load address. The byte count in the formatted binary block will be 6 on this block; on all other blocks the byte count will be larger than 6. The TRA (transfer address) is selected by the Linker to be the first even transfer address seen. Thus, if four object modules are linked together and if the first and second had a .END statement, the third had a .END A and the fourth had a .END B , the transfer address would be A of module three.

---

*Note:
The overlaying of the COMD by the relocated program is a trick to allow the Absolute Loader to handle load modules with a COMD. However, a problem arises if a load module is to be loaded by the absolute loader and either of the following conditions is true:

a. The object modules used to construct the load module contained no relocatable code; or

b. The total sizes of the relocatable code is less than 2Ø(1Ø) bytes (the size of the COMD).

In either case, there is not enough relocatable code to overlay the COMD which means the COMD will load into parts of memory not intended to be altered by the user. The COMD's load address, selected by the linker in the above cases, is such that it will be up against the current top of memory (see *T option in section 3.1). If the top happens to be very low, the linker will not allow the COMD to be loaded below address Ø; it will load it at Ø.

2.3 Load Map

The load map provides several types of information concerning the load module's make-up. The map begins with an indication of the low and high limits of the relocatable code and the transfer address. Then there is a section of the map for each object module included in the linking process. Each of these sections begins with the module's name followed by a list of the control sections and the entry points for each control section. For each control section, the base of the section (its low address) and its size (in bytes) is printed to the right of the section name (enclosed in angle brackets). Following each section name printout is a list of entry points and their addresses. After all information has been printed for each object module, any undefined symbols are listed. Note that modules are loaded such that if modules A, B and C are linked together, A is lowest and C is highest in memory.

The format is quite self-explanatory as can be seen from the following example:

```
LOAD MAP

TRANSFER ADDRESS:  Ø37434
LOW LIMIT:  Ø374Ø6
HIGH LIMIT:  Ø3746Ø
**********
MODULE MOD1
SECTION ENTRY        ADDRESS SIZE
<.ABS.>              ØØØØØØ  ØØØØØØ
<      >             Ø374Ø6  ØØØØ44
          X3         Ø37452
          X4         Ø3744Ø
          X5         Ø3745Ø
          X7         Ø3743Ø
**********
MODULE MOD2
SECTION ENTRY        ADDRESS SIZE
<      >             Ø37452  ØØØØØ6
          X1         Ø37452
          X2         Ø37452
**********
**********
UNDEFINED REFERENCES
X6
```

3.0 OPERATING PROCEDURES

3.1 Loading and Command String

The Linker is loaded by the Absolute Loader and is self-starting. It will use a simple command dialogue which allows the object module, load module and load map devices to be specified. During pass 1 and pass 2, the Linker asks for each object module individually.

Note: The non-printing characters carriage return, line feed and space are represented in this chapter as <CR>, <LF> and <SPACE>.

Operation begins by the linker typing its name and version. This is followed by the input option printed as *I<SPACE> . The responses are:

<CR>	Read object module from HSR.
H<CR>	Read object module from HSR.
L<CR>	Read object module from LSR

The input option is followed by the output option *O<SPACE> . The responses are:

<CR>	Punch load module on HSP.
H<CR>	Punch load module on HSP.
L<CR>	Punch load module on LSP.

LINK-11 asks if a load map is desired by typing *M<SPACE> . The legal responses are <CR> for no map, T<CR> or H<CR> or P<CR> for a map on the teleprinter, high-speed punch, or line printer, respectively.

The next two options concern the placement of the relocated object program in memory. The standard version of the Linker assumes it is linking for an 8K machine. It relocates the program such that it is as high as possible in 8K but leaves room for the Absolute and Boot Loaders. These assumed values may be changed by altering parameters HGHMEM (highest legal memory address +1) and ALODSZ (number of bytes allocated for Absolute Loader and Boot Loader) and reassembling the linker 1. The user may control where a program is relocated to with the *T and *B options. After the option *T<SPACE> has been typed, the user may respond as follows:

<CR>	Relocate so that program is up against the current top of memory. If the top has not been changed, then the top is the assembled-in top (HGHMEM-ALODSZ). The standard assumption is 16384.-112.=16272 (37460(8)).
N<CR>	N is an octal number (unsigned) which defines a new top address.

If a new top is specified, the *B option is suppressed.

After the option *B<SPACE> has been printed the user may respond as follows:

<CR> Use current top of memory.

N<CR> N is an unsigned octal number which defines the bottom address of the program. That is, a new top of memory is calculated so that the bottom of the program corresponds with N.

Once a top of memory has been calculated (by *T or *B), that value is used until it is changed.

LINK-11 indicates the start of pass one by typing PASS 1. The input is requested by the Linker, one tape at a time, by typing *<SPACE>. The legal responses are:

<CR> Read a tape and request more input.

U<CR> List all undefined globals on the teleprinter and request more input.

E<CR> End of input. If there are undefined globals, list them on the teleprinter and request more input. Otherwise print the load map, if requested, and enter pass 2.

C<CR> End of input. Assign Ø to any undefined globals, print the load map (if requested), and enter pass 2.

The Linker indicates the start of pass 2 by typing PASS 2. It then requests each input tape as in pass 1.

A <CR> is the only useful response to * on pass 2. The modules must be read on pass 2 in the same order as pass 1. When the last module has been read the Linker will automatically finish the load module and restart itself.

Leader and trailer will be punched on the load module.

If the LSP is being used for the load module output, it should be turned on before pass 2 begins Thus, turn it on before typing E<CR> or C<CR>. The echo of these characters (and the load map, if printed on the TTY) will be punched on the load module but may be easily removed since leader is punched on the load module. In any case, ASCII information in a load module will be ignored by the Absolute and Disk Monitor loaders. However, the LSP can be turned on while leader is being punched (after the linker has typed PASS 2) to keep the load map, etc., from being punched onto the tape.

Note:

On all command string options, except for *T and *B, the linker only examines the last character typed preceding the carriage return. Thus,

ABCDEFGH<CR>

is equivalent to H<CR>.

3.1.1 Operational Cautions

The Linker does not give a warning if a program is linked so low in memory that it goes below address Ø. However, this case is easily seen by examining the low and high limits which are always printed (on the load map or on the teleprinter).

The Linker reads object modules until an end of medium is detected. Object modules from the DEC Program Library contain a special checksum at the end of the tape which must be removed before they are linked . Failure to remove this checksum can result in fatal Linker errors.

3.2 Error Procedure and Messages

3.2.1 Restarting

Control/P (symbolized as ↑ P) is used for two purposes by LINK-11. If a ↑ P is typed while a load map is being printed, the load map will be aborted and the Linker will continue. A ↑ P typed at any other time will cause the Linker to restart itself.

3.2.2 Non-Fatal Errors

a. Non-unique object module name - this error is detected during pass 1 and results in an error message and the module is rejected. The message is:

```
?MODULE NAME XXXXXX NOT UNIQUE
```

The Linker will then ask for more input.

b. Load map device EOM - this error allows the user an option to fix the device and continue or abort the map listing. The Linker prints:

```
?MAP DEVICE EOM.
TYPE <CR> TO CONTINUE
```

Any response, terminated by <CR> or <LF> will cause the Linker to continue. A ↑ P will cause the map be to aborted.

c. A byte relocation error - the Linker will try to relocate and link byte quantities. However, relocation will usually fail and linking may fail. Failure is defined as the high byte of the relocated value (or the linked value) not being all zero. In such a case, the value is truncated to 8 bits and the following message is printed:

```
?BYTE RELOC ERROR AT ABS ADDRESS XXXXXX.
```

The linker automatically continues.

d. If the object modules are not read in the same order on pass 2 as pass 1, the Linker will indicate which module should be loaded next by typing:

?LOAD XXXXXX NEXT!

The linker will then ask for more input.

e. Multiply-Defined Globals - this results, during pass 1, in the following error message:

?XXXXXX MULTIPLY DEFINED BY MODULE XXXXXX.

The second definition is ignored and the Linker continues.

3.2.3 Fatal Errors

All of the following errors cause the indicated error message to be printed and the Linker is restarted.

a. Symbol Table overflow - the message is:

?SYMBOL TABLE OVERFLOW - MODULE XXXXXX, SYMBOL XXXXXX

b. System Errors - this class of errors prints:

?SYSTEM ERROR XX

where XX is an identifying number as follows:

Number	Meaning
Ø1	Unrecognized symbol table entry found.
Ø2	A relocation directory references a global name which cannot be found in the symbol table.
Ø3	A relocation directory contains a location counter modification command which is not last.
Ø4	Object module does not start with a GSD.
Ø5	The first entry in the GSD is not the module name.

Ø6	An RLD references a section name which cannot be found.
Ø7	The TRA specification references a non-existent module name.
Ø8	The TRA specification references a non-existent section name.
Ø9	An internal jump table index is out of range.
1Ø	A checksum error occurred on the object module.
11	An object module binary block is too big (more than 64(1Ø) words of data).
12	A device error occurred on the load module output device.

All system errors except for numbers 1Ø and 12 indicate a program failure either in the Linker or the program which generated the object module. Error Ø5 can occur if a tape is read which is not an object module.

3.2.4 Error HALTs

LINK-11 loads all of its unused trap vectors with the code:

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

so that if the trap occurs, the processor will halt in the second word of the vector. The address of the halt, displayed in the console lights, therefore indicates the cause of the halt.

Address of HALT (octal)	Meaning
12	Reserved instruction executed.
16	Trace trap occurred.
26	Power fail trap.
32	EMT executed.

A halt at address 4Ø indicates an IOXLPT detected error. RØ (displayed in the console lights) contains an identifying code:

Code in RØ	Meaning
Ø	Illegal memory reference, SP overflow or illegal instruction.
1	Illegal IOX command.
2	Slot number out of range.
3	Device number illegal.
4	Referenced slot not INIT ed.
5	Illegal data mode.

IOXLPT also sets R1 as follows:

If the error code is Ø, R1 contains the PC at the time of the error.

If the error code is 1-5, R1 points to some element in the IOT argument list or to the instruction following the argument list, depending on whether IOXLPT has finished decoding all the arguments when it detects the error.

4.0 PREPARATION

LINK-11S is available as an absolute load module (for an 8K machine), as two object modules (for relinking) and as several ASCII source tapes. There is one object module for the Linker and one for IOXLPT. The supplied object modules may be relinked (using the supplied load module) to load into any size machine larger than 8K. However, the resulting Linker will still assume a top of memory corresponding to an 8K machine (this can be overridden in the command string options). The assumed top of memory and reserved Absolute Loader space may be changed by editing the first linker ASCII tape with ED-11. The parameters to be changed are HGHMEM (high memory address +1 (always even)) and ALODSZ (Absolute Loader size (always even)). The source tapes for the Linker may then be assembled with PAL-11S and the new object module can then replace the supplied Linker object module.

The tapes are identified as follows:

Library Code			
DEC-11-ZLQA-PA	Tape 1 of 6		LINK-11S (Main Program)
DEC-11-ZLQA-PA	Tape 2 of 6	One	
DEC-11-ZLQA-PA	Tape 3 of 6	Assembly	
DEC-11-ZLQA-PA	Tape 4 of 6		
DEC-11-ZLQA-PA	Tape 5 of 6	One	IOXLPT
DEC-11-ZLQA-PA	Tape 6 of 6	Assembly	
DEC-11-ZLQA-PR	Tape 1 of 2		LINK-11S Object Module
DEC-11-ZLQA-PR	Tape 2 of 2		IOXLPT Object Module
DEC-11-ZLQA-PL			LINK-11S Load Module

ASCII CHARACTER SET

EVEN PARITY BIT	7-BIT OCTAL CODE	CHARACTER	REMARKS
0	000	NUL	NULL, TAPE FEED, CONTROL SHIFT P.
1	001	SOH	START OF HEADING; ALSO SOM, START OF MESSAGE, CONTROL A,
1	002	STX	START OF TEXT; ALSO EOA, END OF ADDRESS, CONTROL B,
0	003	ETX	END OF TEXT: ALSO EOM, END OF MESSAGE, CONTROL C,
1	004	EOT	END OF TRANSMISSION(END): SHUTS OF TWX MACHINES,CONTROL D,
0	005	ENQ	ENQUIRY(ENQRY); ALSO WRU, CONTROL E,
0	006	ACK	ACKNOWLEDGE. ALSO RU, CONTROL F.
1	007	BEL	RINGS THE BELL. CONTROL G.
1	010	BS	BACKSPACE: ALSO FEO, FORMAT EFFECTOR. BACKSPACE SOME MACHINES, CONTROL H.
0	011	HT	HORIZONTAL TAB. CONTROL I.
0	012	LF	LINE FEED OR LINE SPACE(NEW LINE): ADVANCES PAPER TO NEXT LINE, DUPLICATED BY CONTROL J.
1	013	VT	VERTICAL TAB(VTAB). CONTROL K.
0	014	FF	FORM FEED TO TOP OF NEXT PAGE(PAGE). CONTROL L.
1	015	CR	CARRIAGE RETURN TO BEGINNING OF LINE. DUPLICATED BY CONTROL M.
1	016	SO	SHIFT OUT: CHANGES RIBBON COLOR TO RED. CONTROL N.
0	017	SI	SHIFT IN: CHANGES RIBBON COLOR TO BLACK. CONTROL O.
1	020	DLE	DATA LINK ESCAPE. CONTROL P(DC0).
0	021	DC1	DEVICE CONTROL 1, TURNS TRANSMITTER (READER) ON, CONTROL Q(XON).
0	022	DC2	DEVICE CONTROL 2, TURNS PUNCH OR AUXILIARY ON. CONTROL R (TAPE,AUX ON).
1	023	DC3	DEVICE CONTROL e, TURNS TRANSMITTER (READER) OFF, CONTROL S(XOFF).
0	024	DC4	DEVICE CONTROL 4. TURNS PUNCH OR AUXILIARY OFF. CONTROL T (TAPE,AUX OFF)
1	025	NAK	NEGATIVE ACKNOWLEDGE: ALSO ERR. ERROR. CONTROL U.
1	026	SYN	SYNCHRONOUS IDLE(SYNC). CONTROL V.
0	027	ETB	END OF TRANSMISSION BLOCK: ALSO LEM. LOGICAL END OF MEDIUM. CONTROL W.
0	030	CAN	CANCEL(CANCL). CONTROL X.
1	031	EM	END OF MEDIUM. CONTROL Y.
1	032	SUB	SUBSTITUTE. CONTROL Z.
0	033	ESC	ESCAPE. PREFIX.
1	034	FS	FILE SEPARATOR. CONTROL SHIFT L.
0	035	GS	GROUP SEPARATOR. CONTROL SHIFT M.
0	036	RS	RECORD SEPARATOR. CONTROL SHIFT N.
1	037	US	UNIT SEPARATOR. CONTROL SHIFT O.
1	040	SP	SPACE.

EVEN PARITY BIT	7-BIT OCTAL CODE	CHARACTER	REMARKS
0	041	!	
0	042	"	
1	043	#	
0	044	$	
1	045	%	
1	046	&	
0	047	'	ACCUTE ACCENT OR APOSTROPHE.
0	050	(	
1	051	)	
1	052	*	
0	053	+	
1	054	,	
0	055	-	
0	056	.	
1	057	/	
0	060	0	
1	061	1	
1	062	2	
0	063	3	
1	064	4	
0	065	5	
0	066	6	
1	067	7	
1	070	8	
0	071	9	
0	072	:	
1	073	;	
0	074	<	
1	075	=	
1	076	>	
0	077	?	
1	100	@	
0	101	A	
0	102	B	
1	103	C	
0	104	D	
1	105	E	
1	106	F	
0	107	G	
0	110	H	
1	111	I	
1	112	J	
0	113	K	
1	114	L	
0	115	M	
0	116	N	
1	117	O	
0	120	P	
1	121	Q	
1	122	R	
0	123	S	
1	124	T	
0	125	U	

EVEN PARITY BIT	7-BIT OCTAL CODE	CHARACTER	REMARKS
0	126	V	
1	127	W	
1	130	X	
0	131	Y	
0	132	Z	
1	133	[	SHIFT K
0	134		SHIFT L
1	135	]	SHIFT M
1	136	↑	SHIFT N
0	137	←	
0	140		ACCENT GRAVE.
0	175		THIS CODE GENERATED BY ALT MODE.
0	176		THIS CODE GENERATED BY ESC KEY(IF PRESEN
1	177	DEL	DELETE, RUB OUT.
			LOWER CASE ALPHABET FOLLOWS (TELETYPE MODEL 37 ONLY).
1	141	a	
1	142	b	
0	143	c	
1	144	d	
0	145	e	
0	146	f	
1	147	g	
1	150	h	
0	151	i	
0	152	j	
1	153	k	
0	154	l	
1	155	m	
1	156	n	
0	157	o	
1	160	p	
0	161	q	
0	162	r	
1	163	s	
0	164	t	
1	165	u	
1	166	v	
0	167	w	
0	170	x	
1	171	y	
1	172	z	
0	173		
1	174		

B.1 TERMINATORS

The list below defines all characters which are considered to be terminators. The order of the list implies the descending hierarchy of significance.

Character	Function
CTRL/FORM	Source line terminator.
LINE FEED	Source line terminator.
RETURN	Source line terminator
:	Label terminator
=	Direct assignment delineator
%	Register term delineator
TAB	Item terminator Field terminator
BLANK or SPACE	Item terminator Field terminator
#	Immediate expression field indicator
@	Deferred addressing indicator
(	Initial register field indicator
)	Terminal register field indicator
'	Operand field separator
;	Comments field delimiter
+	Arithmetic addition operator
-	Arithmetic subtraction operator
&	Logical AND operator
!	Logical OR operator
"	Double ASCII text indicator
'	Single ASCII text indicator.

B.2 ADDRESS MODE SYNTAX

r is an integer between 0 and 7.

R is a register expression, E is an expression, ER is either a register expression or an absolute expression in the range of 0 to 7.

Address Mode Number	Address Mode Name	Symbol in Operand Field	Meaning
0r	Register	R	Register R contains the operand. R is a register expression.
1r	Deferred Register	@R or (R)	Register R contains the operand address.
2r	Autoincrement	(ER)+	The contents of the register specified by ER is incremented after being used as the address of the operand.
3r	Deferred Autoincrement	@(ER)+	ER contains the pointer to the address of the operand. ER is incremented after use.
4r	Autodecrement	-(ER)	The contents of register ER is decremented before it is used as the address of the operand.
5r	Deferred Autodecrement	@-(ER)	The contents of register ER is decremented before it is used as the pointer to the address of the operand.
6r	Index by the register Specified	E(ER)	E plus the contents of the register specified, ER, is the address of the operand.
7r	Deferred index by the register specified	@E(ER)	E added to ER gives the pointer to the address of the operand.
27	Immediate Operand	#E	E is the operand.
37	Absolute address	@#E	E is the operand address.
67	Relative address	E	E is the address of the operand.
77	Deferred relative address.	@E	E is the pointer to the address of the operand.

B.3 INSTRUCTIONS

The tables of instructions which follow are grouped according to the operands they take and according to 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
→	becomes

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 result had an overflow
C	Carry bit:	set if the result had 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.

Logical operators 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

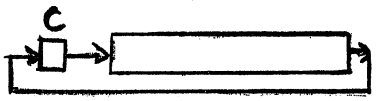
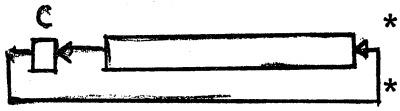
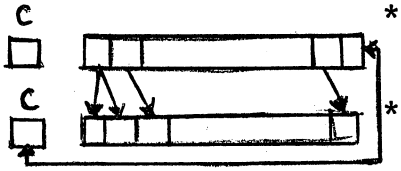
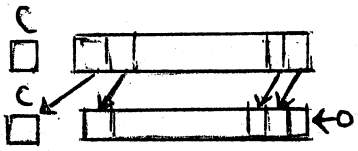
Op-code	MNEMONIC	Stands for	Operation	Condition Codes N	Z	V	C
01SSDD	MOV	MOVe	(SE) → DE	*	*	0	-
11SSDD	MOVB	MOVe Byte					
02SSDD	CMP	CoMPare	(SE)-(DE)	*	*	*	*
12SSDD	CMPB	CoMPare Byte					
03SSDD	BIT	BIt Test	(SE)& (DE)	*	*	0	-
13SSDD	BITB	BIt Test Byte					
04SSDD	BIC	BIt Clear	($\overline{SE}$) & (DE) → 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:	Condition Codes N	Z	V	C
0050DD	CLR	CLeaR	0→ DE	0	1	0	0
1050DD	CLRB	CLeaR Byte					
0051DD	COM	COMplement	($\overline{DE}$) → DE	*	*	0	1
1051DD	COMB	COMplement Byte					
0052DD	INC	INCrement	(DE) + 1 → DE	*	*	*	1
1052DD	INCB	INCrement Byte					
0053DD	DEC	DECrement	(DE) -1 → DE	*	*	*	-
1063DD	DECB	DECrement Byte					
0054DD	NEG	NEGate	($\overline{DE}$) + 1 → DE	*	*	*	*
1054DD	NEGB	NEGate Byte					
0055DD	ADC	ADd Carry	(DE) + (C) → DE	*	*	*	*
1055DD	ADCB	ADd Carry Byte					

Op-code	MNEMONIC	Stands for	Operation	Condition Codes N	Z	V	C
0056DD 1056DD	SBC SBCB	SuBtract Carry	(DE)-(C)→ DE	*	*	*	*
0057DD 10577DD	TST TSTB	TeST TeST Byte	(DE) - 0 → DE	*	*	0	0

B.3.3 Rotate/Shift

0060DD	ROR	ROtate Right		*	*	*	*
1060DD	RORB	ROtate Right Byte		*	*	*	*
0061DD	ROL	ROtate Left		*	*	*	*
1061DD	ROLB	ROtate Left Byte		*	*	*	*
0062DD	ASR	Arithmetic Shift Right		*	*	*	*
1062DD	ASRB	Arithmetic Shift Right Byte		*	*	*	*
0063DD	ASL	Arithmetic Shift Left		*	*	*	*
1063DD	ASLB	Arithmetic Shift Left Byte		*	*	*	*
0001DD	JMP	JuMP	DE ⟶ PC	-	-	-	-
0003DD	SWAB	SWAp Bytes		*	*	0	0

B.3.4 Operation Instructions Op

Op-Code	MNEMONIC	Stands for	Operation	Condition Codes N	Z	V	C
000000	HALT	HALT	The computer stops all functions.	-	-	-	-
000001	WAIT	WAIT	The computer stops and waits for an interrupt.	-	-	-	-
000002	RTI	ReTurn from Interrupt	The PC and ST are popped off the SP stack: ((SP))→ PC (SP)+2→ SP ((SP))→ ST	-	-	-	-

Op-code	MNEMONIC	Stands for	Operation	Condition Codes N	Z	V	C
				*	*	*	*
000003	000003	breakpoint trap	Trap to location 14. This is used to call ODT-11.				
000004	IOT	Input/Output Trap	Trap to location 20. This is used to call IOX.	*	*	*	*
000005	RESET	RESET	Returns all I/O device handlers to power-on state.	-	-	-	-
Trapping	Op or Op E where $0 \leq E \leq 377_8$						
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.
000252	CLV	CLear oVerflow bit.
000262	SEV	SEt oVerflow bit
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.
000240	NOP	No-operation

B.3.5 Branch Instructions Op E where $-128_{10} \leq (E--2)/2 < 127_{10}$

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 ⊕ V=0
0024XX	BLT	Branch if Less Than (zero)	N ⊕ V = 1
0030XX	BGT	Branch if Greater Than (zero)	Z!(N ⊕ V)=0
0034XX	BLE	Branch if Less than or Equal (to zero)	Z!(N ⊕ 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 HIgh or Same)	C=0
1034XX	BCS (or BLO)	Branch if Carry Set (or Branch if LOw)	C=1

B.3.6 Subroutine Call JSR ER,A

Op-code	MNEMONIC	Stands for	Operation
004RDD	JSR	Jump to Sub-Routine	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)+m REG -m depends upon the address mode. (TEMP)→ PC

B.3.7 Subroutine Return

Op-code	MNEMONIC	Stands for	Operation
00020R	RTS	ReTurn from Subroutine	Put register contents in PC and pop old contents from SP stack into register.

B.4 ASSEMBLER DIRECTIVES

MNEMONIC	Operand	Stands for	Operation
.EOT	none	End Of Tape	Indicates the physical end of the source input medium
.EVEN	none	EVEN	Insures that the assembly location counter is even by adding 1 if it is odd.
.END	E (E optional)	END	Indicates the physical and logical end of the program and optionally specifies the entry point (E)
.WORD	E, E,... E, E,...	WORD (the void operator)	Generates words of data Generates words of data
.BYTE	E,E,...	BYTE	Generates bytes of data
.ASCII	/xxx...x/	ASCII	Generates 7-bit ASCII characters for text enclosed by delimiters.
.TITLE	NAME	TITLE	Generates a name for the object module.
.ASECT	none	ASECT	Initiates the Absolute section.
.CSECT	none	CSECT	Initiates the Relocatable Control section.
.LIMIT	none	LIMIT	Generates two words containing the low and high limits of the relocatable section.
.GLOBL	NAME,NAME,...	GLOBAL	Specifies each name to be a global symbol
.RAD5Ø	/XXX/	RADIX 5Ø	Generates the RADIX 5Ø representation of the ASCII character in delimiters.

Mnemonic	Operand	Stands For	Operation
.IFZ	E	IF E=0	Assemble what follows up to the terminating .ENDC if the expression E is 0.
.IFNZ	E	IF E≠0	Assemble what follows up to the terminating .ENDC, if the expression E is not 0.
.IFL	E	IF E<0	Assemble what follows up to the terminating .ENDC, if the expression E is less than 0.
.IFLE	E	IF E≤0	Assemble what follows up to the terminating .ENDC, if the expression E is less than or equal to 0.
.IFG	E	IF E>0	Assemble what follows up to the terminating .ENDC, if the expression E is greater than 0.
.IFGE	E	IF E≥0	Assemble what follows up to the terminating .ENDC, if the expression E is greater than or equal to 0.
.IFDF	NAME	IF NAME defined	Assemble what follows up to the terminating .ENDC if the symbol NAME is defined.
.IFNDF	NAME	IF NAME undefined	Assemble what follows up to the terminating .ENDC if the symbol NAME is undefined.
.ENDC	none	End of Conditional	Terminates the range of a conditional directive.

B.5 ERROR CODES

Error Code	Meaning
A	Addressing error. An address within the instruction is incorrect. Also includes relocation errors.
B	Bounding error. Instructions or word data are being assembled at an odd address in memory.
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. All extra characters beyond 72 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 was not terminated by a 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 followed by a linefeed 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. More than the allotted number of bits were input so 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. The start address of the Loader must be in the console switches.

Storage Requirements: PAL-11S uses 8K of memory.

Starting: Immediately upon loading, PAL-11S will be in control and initiate dialogue.

Initial Dialogue:

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?

Each of these questions may be answered by any one of the following characters:

Character	Answer Indicated
T	Teleprinter keyboard
L	Low-speed reader or punch
H	High-speed reader or punch
P	Line Printer

Each of these answers may be followed by the 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 only for *B or *L).

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 the end-of-medium is on the listing device, the device may be readied and the assembly may be continued by typing RETURN. If the end-of-medium is on the binary device, the assembler will discontinue the assembly and restart itself.
Restarting:	Type CTRL/P. The initial dialogue will be started again.

APPENDIX C

ASSEMBLING AND LINKING PAL-11S

PAL-11S consists of two independent programs. The first program is a memory clear program. The second is the assembler. All programs are available as ASCII source tapes, object modules and as a load module.

The memory clear program, MEMCLR, consists of one ASCII tape. This program should never need to be assembled. The object module may be used when constructing a new load module of PAL-11S.

The assembler consists of three program modules which are assembled separately and then linked together. The first is the main program called PAL-11S. It consists of 13 ASCII tapes. The second module is the symbol table, PALSYM, which consists of 2 ASCII tapes. The third is IOXLPT consisting of 2 ASCII tapes.

If changes are made in any of these modules, that module must be assembled by PAL-11S and the new object module can be linked with the other object modules. It should be noted that assembly of these programs will result in:

Program	Pages of Listing (Decimal)	Number of Symbols (Decimal)
PAL-11S	160	756
PALSYM	11	32
IOXLPT	29	191

Also note that there will be two undefined symbols listed at the end of pass 1. These are forward references on direct assignments which get defined properly in pass 2.

The final load module is constructed by LINK-11S. First the memory clear program object module is processed by the linker and the resulting load module is left in the punch while the PAL-11S, PALSYM and IOXLPT object modules are linked to create a second load module. The resulting tape contains two load modules. The first clears memory and then jumps to the absolute loader to load the second.

Do not re-link PAL-11S to run above 16K. The size of the symbol table is fixed, and there is no need to re-link at a higher address even on large systems.

The supplied tapes are identified as follows:

Library Code			Contents
DEC-11-ASQA-PA	Tape 1 of 18	One Assembly	RELMEM (Memory Clear Program)
DEC-11-ASQA-PA	Tape 2 of 18	One Assembly	PAL-11S (Main Program)
DEC-11-ASQA-PA	Tape 3 of 18		
DEC-11-ASQA-PA	Tape 4 of 18		
DEC-11-ASQA-PA	Tape 5 of 19		
DEC-11-ASQA-PA	Tape 6 of 18		
DEC-11-ASQA-PA	Tape 7 of 18		
DEC-11-ASQA-PA	Tape 8 of 18		
DEC-11-ASQA-PA	Tape 9 of 18		
DEC-11-ASQA-PA	Tape 10 of 18		
DEC-11-ASQA-PA	Tape 11 of 18		
DEC-11-ASQA-PA	Tape 12 of 18		
DEC-11-ASQA-PA	Tape 13 of 18		
DEC-11-ASQA-PA	Tape 14 of 18		
DEC-11-ASQA-PA	Tape 15 of 18	One Assembly	PALSYM (Symbol Table)
DEC-11-ASQA-PA	Tape 16 of 18		
DEC-11-ASQA-PA	Tape 17 of 18	One Assembly	IOXLPT
DEC-11-ASQA-PA	Tape 18 of 18		
DEC-11-ASQA-PR	Tape 1 of 4		RELMEM Object Module
DEC-11-ASQA-PR	Tape 2 of 4		PAL-11S Object Module
DEC-11-ASQA-PR	Tape 3 of 4		PALSYM Object Module
DEC-11-ASQA-PR	Tape 4 of 4		IOXLPT Object Module
DEC-11-ASQA-PL			PAL-11S Load Module*

*This tape is the concatenation of a link of the RELMEM object module followed by a link of the PAL-11S, PALSYM, and IOXLPT object modules.

HOW TO OBTAIN SOFTWARE INFORMATION

Announcements for new and revised software, as well as programming notes, software problems, and documentation corrections are published by Software Information Service in the following newsletters.

Digital Software News for the PDP-8 & PDP-12
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Digital Software News for the PDP-9/15 Family

These newsletters contain information applicable to software available from Digital's Program Library, Articles in Digital Software News update the cumulative Software Performance Summary which is contained in each basic kit of system software for new computers. To assure that the monthly Digital Software News is sent to the appropriate software contact at your installation, please check with the Software Specialist or Sales Engineer at your nearest Digital office.

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Maynard, Massachusetts 01754

These forms which are provided in the software kit should be fully filled out and accompanied by teletype output as well as listings or tapes of the user program to facilitate a complete investigation. An answer will be sent to the individual and appropriate topics of general interest will be printed in the newsletter.

Orders for new and revised software and manuals, additional Software Performance Report forms, and software price lists should be directed to the nearest Digital Field office or representative. U.S.A. customers may order directly from the Program Library in Maynard. When ordering, include the code number and a brief description of the software requested.

Digital Equipment Computer Users Society (DECUS) maintains a user library and publishes a catalog of programs as well as the DECUSCOPE magazine for its members and non-members who request it. For further information please write to:

DECUS
Digital Equipment Corporation
146 Main Street, Bldg. 3-5
Maynard, Massachusetts 01754

DEC-11-YRWB-D and
DEC-11-YRWB-DN
PDP-11 PAL-11S ASSEMBLER
and LINK-11S LINKER
PROGRAMMER'S MANUAL

READER'S COMMENTS

NOTE: This form is for document comments only. Problems with software should be reported on a Software Problem Report (SPR) form (see the HOW TO OBTAIN SOFTWARE INFORMATION page).

Did you find errors in this manual? If so, specify by page.

_____

_____

_____

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_____

Did you find this manual understandable, usable, and well-organized? Please make suggestions for improvement.

_____

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Is there sufficient documentation on associated system programs required for use of the software described in this manual? If not, what material is missing and where should it be placed?

_____

_____

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Please indicate the type of user/reader that you most nearly represent.

- ☐ Assembly language programmer
- ☐ Higher-level language programmer
- ☐ Occasional programmer (experienced)
- ☐ User with little programming experience
- ☐ Student programmer
- ☐ Non-programmer interested in computer concepts and capabilities

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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 acknowledged and are considered when documenting subsequent documents.

Technical changes to this manual are indicated by a bar in the margin.

This document is for information purposes and is subject to change without notice.

Associated documents:

PDP-11 Paper Tape Software Programming Handbook
DEC-11-GGPC-D

PDP-11 PAL-11R Assembler Programmer's Manual
DEC-11-ASDC-D

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The attached pages should be inserted in the PAL-11S Assembler and LINK-11S LINKER Programmer's Manual. Technical changes have been marked with a bar in the page margin.

CONTENTS

as for *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 RETURN 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 the RETURN key alone will cause the Assembler to omit symbol table output.

The symbol table is printed alphabetically, three 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 and external symbols will be listed as undefined direct assignments. Multiply-defined symbols are not flagged in the symbol table printout but are flagged wherever they are used in the program.

If the symbol is relocatable or global or both, the symbol's value will be followed by an R, a G or both.

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

4.0 PREPARATION

LINK-11S is available as an absolute load module (for an 8K machine), as two object modules (for relinking) and as several ASCII source tapes. There is one object module for the Linker and one for IOXLPT. The supplied object modules may be relinked (using the supplied load module) to load into any size machine larger than 8K. However, the resulting Linker will still assume a top of memory corresponding to an 8K machine (this can be overridden in the command string options). The assumed top of memory and reserved Absolute Loader space may be changed by editing the first linker ASCII tape with ED-11. The parameters to be changed are HGHMEM (high memory address +1 (always even)) and ALODSZ (Absolute Loader size (always even)). The source tapes for the Linker may then be assembled with PAL-11S and the new object module can then replace the supplied Linker object module.

The tapes are identified as follows:

Library Code			
DEC-11-ULKSA-A-PA1	Tape 1 of 6		LINK-11S (Main Program)
DEC-11-ULKSA-A-PA2	Tape 2 of 6	One	
DEC-11-ULKSA-A-PA3	Tape 3 of 6	Assembly	
DEC-11-ULKSA-A-PA4	Tape 4 of 6		
DEC-11-ULKSA-A-PA5	Tape 5 of 6	One	IOXLPT
DEC-11-ULKSA-A-PA6	Tape 6 of 6	Assembly	
DEC-11-ULKSA-A-PR1	Tape 1 of 2		LINK-11S Object Module
DEC-11-ULKSA-A-PR2	Tape 2 of 2		IOXLPT Object Module
DEC-11-ULKSA-A-PL			LINK-11S Load Module

APPENDIX C

ASSEMBLING AND LINKING PAL-11S

PAL-11S consists of two independent programs. The first program is a memory clear program. The second is the assembler. All programs are available as ASCII source tapes, object modules and as a load module.

The memory clear program, MEMCLR, (DEC-11-UPLSA-A-PA1) consists of one ASCII tape. This program should never need to be assembled. The object module may be used when constructing a new load module of PAL-11S.

The assembler consists of three program modules which are assembled separately and then linked together. The first is the main program called PAL-11S. It consists of 13 ASCII tapes (DEC-UPLSA-A-PA2-PA14). The second module is the symbol table, PALSYM, which consists of 2 ASCII tapes (DEC-11-UPLSA-A-PA15-PA16). The third is IOXLPT consisting of 2 ASCII tapes (DEC-11-UPLSA-A-PA17-PA18). Also included is PALSYM, specially created for 12K and 16K, consisting of one tape each (DEC-11-UPLSA-A-PA19-PA20).

If changes are made in any of these modules, that module must be assembled by PAL-11S (V003A) and the new object module can be linked with the other object modules. It should be noted that assembly of these programs will result in:

Program	Pages of Listing (Decimal)	Number of Symbols (Decimal)
PAL-11S	160	756
PALSYM	11	32
IOXLPT	29	191

Also note that there will be two undefined symbols listed at the end of pass 1. These are forward references on direct assignments which get defined properly in pass 2.

An example of the PAL-11S assembly follows:

```
PAL-11S    VØØ3A
*S H
*B H
*L P
*T P/2                          (first pass on PA1)
END ?                           (2nd pass on PA1)
ØØØØØØ ERRORS                   (End of Tape #1 assembly)
                                (Remove tape from punch)

PAL-11S    VØØ3A
*S H
*B H
*L P
*T P/2                          (Insert PA2 for 1st pass)
EOF ?                           (End of PA2, insert PA3)
EOF ?                           (End of PA3, insert PA4)
EOF ?                           (End of PA4, insert PA5)
EOF ?                           (End of PA5, insert PA6)
EOF ?                           (End of PA6, insert PA7)
EOF ?                           (End of PA7, insert PA8)
EOF ?                           (End of PA8, insert PA9)
```

```
EOF ?                                   (End of PA9, insert PA10)
EOF ?                                   (End of PA10, insert PA11)
EOF ?                                   (End of PA11, insert PA12)
EOF ?                                   (End of PA12, insert PA13)
EOF ?                                   (End of PA13, insert PA14)
BINCNT = ******     SIMBC = ******      (End of PA14 and 1st pass)
END ?                                   (Insert PA2 for 2nd pass)
EOF ?                                   (End of PA2, insert PA3)
EOF ?                                   (End of PA3, insert PA4)
EOF ?                                   (End of PA4, insert PA5)
EOF ?                                   (End of PA5, insert PA6)
EOF ?                                   (End of PA6, insert PA7)
EOF ?                                   (End of PA7, insert PA8)
EOF ?                                   (End of PA8, insert PA9)
EOF ?                                   (End of PA9, insert PA10)
EOF ?                                   (End of PA10, insert PA11)
EOF ?                                   (End of PA11, insert PA12)
EOF ?                                   (End of PA12, insert PA13)
EOF ?                                   (End of PA13, insert PA14)
ØØØØØØ ERRORS                           (End of PA14 and 2nd pass)
                                        (Remove tape from punch)

PAL-11S  VØØ3A
*S H
*B H
*L P
*T P/2                                  (1st pass on PA15)
EOF ?                                   (End of PA15, insert PA16)
END ?                                   (End of PA16, insert PA15 for 2nd pass)
EOF ?                                   (End of PA15, insert PA16)
ØØØØØØ ERRORS                           (End of 2nd pass)
                                        (Remove tape from punch)

PAL-11S  VØØ3A
*S H
*B H
*L P
*T P/2                                  (1st pass on PA17)
EOF ?                                   (End of PA17, insert PA18)
END ?                                   (End of PA18, insert PA17 for 2nd pass)
EOF ?                                   (End of PA17, insert PA18)
ØØØØØØ ERRORS                           (End of 2nd pass)
                                        (Remove tape from punch)

PAL-11S  VØØ3A
*S H
*B H
*L P
*T P/2                                  (Pass 1 on PA20)
END ?                                   (Pass 2 on PA20)
ØØØØØØ ERRORS                           (End of pass 2)
                                        (Remove tape from punch)
```

The final load module is constructed by LINK-11S. First the memory clear program object module is processed by the linker and the resulting load module is left in the punch while the PAL-11S, PALSYM and IOXLPT object modules are linked to create a second load module. The resulting tape contains two load modules. The first clears memory and then jumps to the absolute loader to load the second.

In order to take advantage of core sizes larger than 8K, PALSYM, the symbol table, specially created for 12K core and 16K core, and the object modules are included with the assembler. To link for 12K (or 16K), simply substitute the appropriate object tape for PALSYM (use DEC-11-UPLSA-A-PR5 for 12K or DEC-11-UPLSA-A-PR6 for 16K) specify a top address to LINK-11S of 57460 for 12K (77460 for 16K) and link as described in the preceding paragraph.

Do not relink PAL-11S to run above 16K. The size of the symbol table is fixed, and there is no need to re-link at a higher address even on large systems.

The supplied tapes are identified as follows:

Library Code			Contents
DEC-11-UPLSA-A-PA1	Tape 1 of 20	One Assembly	RELMEM (Memory Clear Program)
DEC-11-UPLSA-A-PA2	Tape 2 of 20		PAL-11S (Main Program)
DEC-11-UPLSA-A-PA3	Tape 3 of 20		
DEC-11-UPLSA-A-PA4	Tape 4 of 20		
DEC-11-UPLSA-A-PA5	Tape 5 of 20		
DEC-11-UPLSA-A-PA6	Tape 6 of 20		
DEC-11-UPLSA-A-PA7	Tape 7 of 20	One	
DEC-11-UPLSA-A-PA8	Tape 8 of 20	Assembly	
DEC-11-UPLSA-A-PA9	Tape 9 of 20		
DEC-11-UPLSA-A-PA10	Tape 10 of 20		
DEC-11-UPLSA-A-PA11	Tape 11 of 20		
DEC-11-UPLSA-A-PA12	Tape 12 of 20		
DEC-11-UPLSA-A-PA13	Tape 13 of 20		
DEC-11-UPLSA-A-PA14	Tape 14 of 20		
DEC-11-UPLSA-A-PA15	Tape 15 of 20	One	PALSYM (Symbol Table) for 8K
DEC-11-UPLSA-A-PA16	Tape 16 of 20	Assembly	
DEC-11-UPLSA-A-PA17	Tape 17 of 20	One	IOXLPT
DEC-11-UPLSA-A-PA18	Tape 18 of 20	Assembly	
DEC-11-UPLSA-A-PA19	Tape 19 of 20	One Assembly	PALSYM (Symbol Table) for 12K
DEC-11-UPLSA-A-PA20	Tape 20 of 20	One Assembly	PALSYM (Symbol Table) for 16K
DEC-11-UPLSA-A-PR1	Tape 1 of 6		RELMEM Object Module
DEC-11-UPLSA-A-PR2	Tape 2 of 6		PAL-11S Object Module
DEC-11-UPLSA-A-PR3	Tape 3 of 6		PALSYM Object Module for 8K
DEC-11-UPLSA-A-PR4	Tape 4 of 6		IOXLPT Object Module
DEC-11-UPLSA-A-PR5	Tape 5 of 6		PALSYM Object Module for 12K assembler
DEC-11-UPLSA-A-PR6	Tape 6 of 6		PALSYM Object Module for 16K Assembler
DEC-11-UPLSA-A-PL			PAL-11S Load Module*

*This tape is the concatenation of a link of the RELMEM object module followed by a link of the PAL-11S, PALSYM for 8K, and IOXLPT object modules.

APPENDIX D

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 LINK-11S and PAL-11S 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 the Papertape Software Programming Handbook (DEC-11-XPTSA-A-D).

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 instructions for use in section 6.3 of DEC-11-XPTSA-A-D).

The above changes only affect output to the console teleprinter.

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