PAL III SYMBOLIC ASSEMBLER
PROGRAMMING MANUAL

PDP-8

DIGITAL EQUIPMENT CORPORATION • MAYNARD, MASSACHUSETTS
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PREFACE

The PDP-8 comes to the user complete with an extensive selection of system programs and routines making the full data processing capability of the new computer immediately available to each user, eliminating many commonly experienced initial programming delays.

The programs described in these abstracts come from two sources, past programming effort on the PDP-5 computer, and present and continuing programming effort on the PDP-8. Thus the PDP-8 programming system takes advantage of the many man-years of program development and field testing by PDP-5 users.

Although in many cases PDP-8 programs originated as PDP-5 programs, all utility and functional program documentation is issued in a new, recursive format introduced with the PDP-8.

Programs written by users of either the PDP-5 or the PDP-8 and submitted to the users' library (DECUS - Digital Equipment Corporation Users' Society) are immediately available to PDP-8 users.

Consequently, users of either computer can take immediate advantage of the continuing program developments for the other.
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CHAPTER 1

INTRODUCTION

The use of an assembly program has become standard practice in the programming of digital computers. Use of an assembler permits a programmer to code in a more convenient language than basic machine code. The advantages of this practice are widely recognized: Easily recognized mnemonic codes are used instead of numeric codes; instructions or data may be referred to by a symbolic name; decimal data may be used as such with the assembler making the required decimal-to-binary conversion; programs may be altered without extensive changes in the source language; and debugging is simplified.

The basic process performed by the Assembler is the substitution of numeric values for symbols, according to associations found in the symbol table. In addition, the user may request that the Assembler itself assign values to the user's own symbols at assembly time. These symbols are normally used to name memory locations, which may then be referenced by name.

The ability to use mnemonic names to represent machine instructions is of great value. The name TAD reminds the user of the Two's complement ADdition instruction, while the number 10000 does not. Consequently, the instructions are easier to remember when mnemonics are used. The same is true of location names. It is much easier to associate the name TOTAL with the location containing the accumulated total than it is to remember that location 1374 contains the total.

Another advantage is that, since the assignment of absolute numbers to symbolic locations is done by the Assembler, the updating of a program by adding or removing instructions is simplified.

In addition to translating statements directly into their binary equivalents, the Assembler will accept instructions for performing translations. These instructions may not look different from other instructions, but they do not generate binary codes. For this reason, they are referred to as pseudo-instructions. For example, the pseudo-instruction DECIMAL tells the Assembler that all numbers following in the program are to be taken as decimal rather than as octal. This instruction is important to the assembly process but has no binary equivalent in the object program. Certain other features of assembly can be directed to the Assembler by the setting of the switch register, abbreviated SR.

The PDP-8 Assembly system consists of the Assembler (PAL III) and the Binary Loader (Digital-8-2-U). A source program prepared in the source language using ASCII code is translated by the Assembler into a binary object tape in two passes through the Assembler. The object binary tape is loaded by the Binary Loader into the computer ready for execution.
During the first pass of the assembly, all symbols are defined and placed in the Assembler's symbol table. During the second pass, the binary equivalents of the input source language are generated and punched. The Assembler has an optional third pass, which produces an "assembly listing," or a listing with the location, generated binary, and source code side by side on a line.

The PDP-8 Assembly system also includes the Symbolic Tape Editor (Digital-8-1-S) for altering or editing the source language tape; the DEC Debugging Tape (DDT-8, Digital-8-4-S) for debugging the object program by communicating with it in the source language, and various other utility programs such as dumps, etc.

The Assembler requires a basic PDP-8 system consisting of the 33 ASR Tape Reader and Punch and a 4K core memory. The Assembler can use either the 750C Photo-Electric Reader, the 75E High-Speed Punch, or both. The basic Assembler allows 590 user symbols when using the 33 ASR and allows 495 user symbols when using the photoelectric reader. The Extended Assembler contains additional symbols for all optional devices. This symbol list is to be found in the Appendix.
CHAPTER 2

ILLUSTRATIONS OF PDP-8 ASSEMBLER FEATURES

THE LOCATION COUNTER

In general, statements generate 12-bit binary words which are placed into consecutive memory locations when the object tape is loaded. The location counter is a register used by the PDP-8 Assembler to keep track of the next memory location available. It is updated after processing each statement. The location counter may be explicitly set by an element or expression preceded by an asterisk. The element or expression following the asterisk sets the current location counter to the value of that element or expression. Subsequent instructions are assembled into subsequent locations.

Example:

*300

The next instruction would be placed in location 300. The location counter is initially set to 0200.

CODING ILLUSTRATIONS

To illustrate some of the features of the PDP-8 Assembler, a small routine has been chosen and coded in a number of different ways. The routine continually adds 1 to the contents of a location until the result is positive, then halts. The instructions used are represented as their octal codes (more compact than the binary actually used). The number being incremented is in location 170. The notation C(A) means the contents of location A.

*100  1170  /C(170) INTO AC
*101  7001  /ADD 1 TO AC
*102  3170  /STORE IN LOCATION 170
*103  1170  /FETCH C(170)
*104  7710  /SKIP ON POSITIVE AC, CLEAR AC
*105  5100  /JUMP TO LOCATION 100
*106  7402  /HALT
*170  0    /WILL CONTAIN NUMBER TO BE INCREMENTED

Since the location counter is automatically incremented, specifying sequential addresses could have been avoided after the first address in the progression. In addition, the names of the PDP-8 instructions could have been used in place of the octal codes. The octal representation of these instructions is substituted by the Assembler whenever symbols appear in the program.
Example 2:

*100
TAD  170
IAC
DCA  170
TAD  170
SPA  CLA
JMP  100
HLT

*170  \(\emptyset\)

The same program could have been written using symbolic address tags. The comma after the symbol A indicates to the Assembler that the location in which it places the instruction TAD B is to be named A. Information associating the symbol A with the number of actual locations is placed in the Assembler's symbol table. Consequently, when processing the instruction JMP A, the Assembler finds the symbols JMP and A in the symbol table and uses these values to form the binary equivalent of the instruction JMP A.

Example 3:

*100
A.  TAD B
    IAC
    DCA B
    TAD B
    SPA CLA
    JMP A
    HLT

*170  \(\emptyset\)

B.  \(\emptyset\)

Unless the user specifically wanted to use location 170 for storage, he could let the Assembler assign the location.

Example 4:

*100
A.  TAD B
    IAC
    DCA B
    TAD B
    SPA CLA
    JMP A
    HLT

B.  \(\emptyset\)
CHAPTER 3

THE SOURCE LANGUAGE

This chapter explains the features of the ASCII source language available to the user of PAL III.

THE CHARACTER SET

Letters

A B C D E...X Y Z

Digits

1 2 3 4 5 6 7 8 9 Ø

Punctuation Characters

Since a number of characters are invisible (i.e. nonprinting), the following notation is used to represent them in the examples:

L......J

space

→| tab

) carriage return

The following characters are used to specify operations to be performed upon symbols or numbers:

<table>
<thead>
<tr>
<th>Character</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>space</td>
</tr>
<tr>
<td>+</td>
<td>combine symbols or numbers</td>
</tr>
<tr>
<td>-</td>
<td>combine symbols or numbers</td>
</tr>
<tr>
<td>)</td>
<td>terminate line</td>
</tr>
<tr>
<td>→</td>
<td></td>
</tr>
<tr>
<td>,</td>
<td>assign symbolic address</td>
</tr>
<tr>
<td>=</td>
<td>define parameters</td>
</tr>
<tr>
<td>*</td>
<td>set current location counter</td>
</tr>
<tr>
<td>;</td>
<td>terminate coding line</td>
</tr>
<tr>
<td>$</td>
<td>terminate pass</td>
</tr>
</tbody>
</table>

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Ignored Characters

form feed      end of a logical page of a source program (See Symbolic Editor 8-1-S)
blank tape     used for leader/trailer
rubout         used for deleting characters
code 200       used for leader/trailer
line feed      follows carriage return

Illegal Characters

All other characters are illegal and cause the Illegal Character error printout: IC dddd AT dddd during PASS1. The first number is the value of the offending character, and the second is the value of the current location counter where it occurred. Illegal characters are ignored.

ELEMENTS

Any group of letters, digits, and punctuation which represents binary values less than $2^{12}$ is an element.

Number

Any sequence of numbers delimited by punctuation characters forms a number.

Example:

1
12
4372

The radix control pseudo-instructions indicate to the Assembler the radix to be used in number interpretation. The pseudo-instruction DECIMAL indicates that all numbers are to be interpreted as decimal until the next occurrence of the pseudo-instruction OCTAL.

The pseudo-instruction OCTAL indicates that all numbers are to be interpreted as octal until the next occurrence of the pseudo-instruction DECIMAL. The radix is initially set to octal and remains octal unless otherwise specified.
Symbol

Any sequence of letters and digits beginning with a letter and delimited by punctuation characters is a symbol. Although a symbol may be any length, only the first six characters are considered, and any additional characters are ignored; symbols which are identical in their first six characters are considered identical.

The Assembler has in its permanent symbol table definitions of the symbols for all PDP-8 operation codes, operate commands, and many IOT commands (see the Appendix for a complete list). These may be used without prior definition by the user.

Examples:

JMS is a symbol whose value of 40000 is taken from the operation code definitions.

A is a user-created symbol. When used as a symbolic address tag, its value is the address of the instruction it tags. This value is assigned by the Assembler.

PARAMETER ASSIGNMENTS

A parameter may be assigned by use of the equal sign. The symbol to the left of the equal sign is assigned the value of the expression on the right.

Examples:

A=6
EXIT=RETURN=JMP 10

Symbols defined by use of the equal sign may be used in any valid expression.

Example:

A=100
B=400
A+B has the value 500
TAD A has the value 1100

If the expression to the left of the equal sign has already been defined, the ReDefinition diagnostic:

RD XXXXXXX AT dddd

Will be typed where XXXXXXX is the symbol’s name and dddd is the contents of the current location counter at the point of redefinition. The new value will be stored in the symbol table.

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Example:

\[
\begin{align*}
*100 & \quad \text{CLA}=7600 \\
\end{align*}
\]

will cause the diagnostic:

\[
\begin{align*}
RD & \quad \text{CLA} & \quad \text{AT} & \quad 0100 \\
\end{align*}
\]

Whenever CLA is used after this point, it will have the value 7600.

**Symbol Definition**

A symbol may be defined by the user in one of two ways:

1. by use of parameter assignment

Example:

\[
\begin{align*}
\text{DISMIS} &= \text{JMP I} \quad 0 \\
\end{align*}
\]

and (2) by use of the comma

When a symbol is terminated by a comma, it is assigned a value equal to the current location counter.

If it is defined more than once in this manner, the Assembler will type the duplicate tag diagnostic:

\[
\begin{align*}
\text{DT} & \quad \text{XXXXXX} \quad \text{AT} \quad \text{dddd} \\
\end{align*}
\]

where XXXXXXX is the symbol, and dddd is the current location counter at the second occurrence of the attempted symbol definition. The symbol is not redefined.

Example:

\[
\begin{align*}
*300 & \quad \text{TAD A} \\
\text{START} & \quad \text{DCA COUNTER} \\
\text{CONTIN} & \quad \text{JMS LEAVE} \\
\text{A} & \quad \text{JMP START} \\
\text{COUNTER} & \quad -74 \\
\text{START} & \quad \emptyset \\
\end{align*}
\]

The symbol "START" would have a value of \(0300\), the symbol "CONTIN" would have a value of \(0302\), the symbol "A" would have a value of \(0304\), the symbol "COUNTER" (considered by the Assembler to be COUNTTE) would have a value of \(0305\), and when the Assembler processed the next line, it would type during PASS1:
Since the first PASS of PAL III is used to define all symbols in the symbol table, the Assembler will type a diagnostic if, at the end of PASS1, there are any symbols remaining undefined. For example:

```
*7170
A, TAD C
CLA CMA
HLT
JMP A1
C, 0
$
```

would produce the Undefined Address diagnostic:

```
UA XXXXXX AT dddd
```

where XXXXXX is the symbol and dddd is the location at which it was first seen. The entire symbol table is printed at the end of PASS1. In the case of the above example, this would be:

```
A  7170
UA A1 AT 7173
C  7174
```

If, during PASS1, PAL III detects that its symbol table is full (in other words, that there is no more memory space to store symbols and their associated values), the Symbol Table full diagnostic:

```
ST XXXXXX AT dddd
```

is typed. XXXXXX is the symbol that caused overflow, and dddd is the current location when the overflow occurred. The Assembler halts and may not be restarted. The source program should be segmented, or more address arithmetic used, to reduce the number of symbols. PAL III's symbol capacity is:

Using 33 ASR; 655 symbols. The basic symbol table contains 65 symbols (see Appendix) leaving 590 user-defined symbols. Using the 750 Photo-Electric Reader; 560 symbols. The basic symbol table contains 65 symbols leaving 495 user-defined symbols.

**EXPRESSIONS**

Symbols and numbers are combined with certain operators to form expressions. There are three operators:

```
+   plus   this signifies 2's complement addition
-   minus  this signifies 2's complement subtraction
space space is interpreted in context. Since a PDP-8 instruction has an operation code of three bits as well as an indirect bit, a page bit, and seven address bits, the Assembler must combine memory reference instructions
```

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in a manner somewhat different from the way in which it combines operate or IOT instructions. The Assembler accomplishes this by differentiating the symbols in its permanent symbol table. The following symbols are used as memory reference instruction op codes:

<table>
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<tr>
<th>Symbol</th>
<th>Opcode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AND</td>
<td>0000</td>
<td>logical AND</td>
</tr>
<tr>
<td>TAD</td>
<td>1000</td>
<td>Two's complement ADDition</td>
</tr>
<tr>
<td>ISZ</td>
<td>2000</td>
<td>Index and Skip if Zero</td>
</tr>
<tr>
<td>DCA</td>
<td>3000</td>
<td>Deposit and Clear Accumulator</td>
</tr>
<tr>
<td>JMS</td>
<td>4000</td>
<td>Jump to Subroutine</td>
</tr>
<tr>
<td>JMP</td>
<td>5000</td>
<td>Jump</td>
</tr>
<tr>
<td>FADD</td>
<td>1000</td>
<td>Floating ADDition</td>
</tr>
<tr>
<td>FSUB</td>
<td>2000</td>
<td>Floating SUBtraction</td>
</tr>
<tr>
<td>FMPY</td>
<td>3000</td>
<td>Floating MULTIPLY</td>
</tr>
<tr>
<td>FDIV</td>
<td>4000</td>
<td>Floating DIVIDE</td>
</tr>
<tr>
<td>FGET</td>
<td>5000</td>
<td>Floating GET</td>
</tr>
<tr>
<td>FPUT</td>
<td>6000</td>
<td>Floating PUT</td>
</tr>
<tr>
<td>FNOR</td>
<td>7000</td>
<td>Floating NORmalize</td>
</tr>
<tr>
<td>FEXT</td>
<td>8000</td>
<td>Floating EXIT</td>
</tr>
</tbody>
</table>

When the Assembler has processed one of these symbols, the space acts as an address field delimiter:

```
*4100
JMP A
A, CLA
```

A has the value 4101, JMP has the value 5000, and the space acts as a field delimiter. These symbols are combined as follows:

```
A 100 001 000 001
JMP 101 000 000 000
```

The seven address bits of A are taken, i.e.:

```
000 001 000 001
```

The remaining bits of the address are tested to see if they are zero's (page zero reference); if they are not, the current page bit is set:

```
000 011 000 001
```

The operation code is then ORed into the expression to form:

```
101 011 000 001
```

or, written more concisely:

```
5301
```
In addition to the above outlined tests, the page bits of the address field are compared with the page bits of the current location counter. If the page bits of the address field are nonzero and do not equal the page bits of the current location counter, an out-of-page reference is being attempted and the Illegal Reference diagnostic is printed on PASS2 or PASS3.

For example:

*4100
   A,   CLA CLL
   :
*7200
   JMP A

The symbol in the address field of the jump instruction has a value of 4100 while the current location counter, i.e., the address where the instruction will be placed in memory, has a value of 7200. This instruction is illegal on the PDP-8 and will be flagged during PASS2 or PASS3 by the Illegal Reference diagnostic:

IR 4100 AT 7200

The value 5300 would be assembled at location 7200.

The symbol I caused the indirect bit (bit 3) to be set in a memory reference instruction: For example:

DCA I 10

would produce:

011 100 001 000

or:

3410

When a space occurs in an expression that does not contain a memory reference instruction op code, it means inclusive OR:

For example:

CLA CLL

the symbol CLA has a value of 7200 and the symbol CLL has a value of 7100; CLA CLL would produce 7300. User-defined symbols are treated as nonmemory reference instructions (see Pseudo-Instructions).
For example:

\[
\begin{align*}
    A &= 333 \\
    \times 222 \\
    B, \text{ CLA}
\end{align*}
\]

Then the expressions and their values are shown below:

\[
\begin{align*}
    A+B &\quad 0555 \\
    A-B &\quad 0111 \\
    A-B &\quad 0333 \\
    -A &\quad 7445 \\
    1-B &\quad 7557 \\
    B-1 &\quad 0221 \\
    -71 &\quad 7707 \\
    \text{etc.}
\end{align*}
\]

An expression is terminated by either a carriage-return (\textasciicircum) or a semicolon (;). If any information was generated to be loaded, the current location counter is incremented.

Example:

\[
\begin{align*}
    \text{RAR; RTR; CMA;}
\end{align*}
\]

Produces three registers of information and the current location counter is incremented after each expression. The statement:

\[
\begin{align*}
    \text{HALT=HLT CLA;}
\end{align*}
\]

produces no information to be loaded (it produces an association in the Assembler's symbol table) and hence does not increment the current location counter.

\[
\begin{align*}
    *4721 \\
    \text{TEMP, } \emptyset \\
    \text{TEM2, } \emptyset
\end{align*}
\]

The current location counter is not incremented after the line \text{TEMP, } \emptyset and hence the two symbols TEMP and TEM2 are assigned the same value, in this case 4721.

**CURRENT ADDRESS INDICATOR**

The single character period (.) has, at all times, a value equal to the value of the current location counter. It may be used as any number or symbol (except to the left of the equal sign).

Example:

\[
\begin{align*}
    *2000 \\
    \text{JMP } .+2
\end{align*}
\]
is equivalent to \texttt{JMP 202}.

\begin{verbatim}
*300
.2400
\end{verbatim}

would produce, in register 300, the quantity 2700.

Example:

\begin{verbatim}
*2200
CALL=JMS 27
\end{verbatim}

Since the second line, \texttt{CALL=JMS .27} does not increment the current location counter, 0027 would be placed in register 2200 and CALL would have the value of 100 110 0002 or 4608.

The properties of the character (.) have been slightly changed; so that, it now acts as a terminator. Previously, PAL III would neither diagnose nor correctly assemble expressions such as: \texttt{JMP .} (where there is no space between the P and the .) PAL III now treats this (\texttt{JMP .}) as if it were this (\texttt{JMP .}).

**COMMENTS**

A comment field is indicated by the slash (/) character. The Assembler will ignore everything from the slash to the next carriage return.

Example:

\begin{verbatim}
CLA /THIS IS A COMMENT
\end{verbatim}

**PSEUDO-INSTRUCTIONS**

There are several pseudo-instructions that are used to direct the Assembler. These are:

- **DECIMAL**: Set the current radix to decimal
- **OCTAL**: Set the current radix to octal
- **PAUSE**: Stop the Assembler. The current pass is not terminated. PAUSE must be at the physical end of the program tape segment as the reader routines are buffered and the buffer is emptied when PAUSE is detected. The assembly is continued by depressing CONTINUE.
- **FIELD EXPRESSION**: Causes a field setting to be punched during PASS2. This is recognized by the Extended Memory Loader (Digital-8-2A-U) and causes all subsequent information to be loaded into the field specified by the expression. The expression must be between 0 and 7, inclusive.
- **EXPUNGE**: Expunge the entire symbol table except for the pseudo-instructions.
- **FIXTAB**: Fix the current symbol table. Symbols that have been fixed are not printed in the symbol table at the end of PASS1 or PASS3.
FIXMRI  Fix memory reference instruction. This may be given only after EXPUNGE. It tells the Assembler that the following symbol definition is a memory reference instruction and is to be treated as described under Expressions.

Example:

EXPUNGE
FIXMRI TAD=1000
FIXMRI DCA=3000
CLA=7200
FIXTAB
PAUSE

When this program segment is read into the Assembler during PASS1, all symbol definitions are deleted and the three symbols listed are added to the table.

This process is often performed to alter the Assembler's symbol table so that it contains only those symbols that will be used. This may increase the Assembler's capacity for other user-defined symbols.
CHAPTER 4

PROGRAM PREPARATION AND ASSEMBLER OUTPUT

The source language tape (symbolic tape) is prepared in ASCII code on 8-channel punched paper tape using an off-line Teletype or the on-line Symbolic Tape Editor (Digital-8-1-S). In general, a program should begin with leader code which may be blank tape, code 200, or rubouts.

PROGRAM TAPE

Since the Assembler ignores certain codes, these may be used freely to produce a more readable symbolic source tape. These codes are tab, line-feed, and form-feed.

The Assembler will also ignore extraneous spaces, carriage-return/line-feed combinations, and blank tape.

The program body consists of statements and pseudo-instructions. The program is terminated by the dollar sign followed by some trailer code. If the program is large, it may be segmented by use of the pseudo-instruction PAUSE. This often facilitates the editing of the source program since each section will be physically smaller.

The Assembler initially sets its current location counter to 0200. This is reset whenever the asterisk is processed.

During PASS1, all illegal characters cause a diagnostic to be printed. The character is ignored.

The following two programs are identical:

```
*200
/EXAMPLE OF FORMAT
/GENERATOR
BEGIN, 0/START OF PROGRAM
KCC
KSF/WAIT FOR FLAG
JMP,-1/FLAG NOT SET YET
KR/READ IN CHARACTER
DCA CHAR
TAD CHAR
TAD MSPACE/IS IT A SPACE?
SNA CLA
HLT/YES
JMP BEGIN+2 /NO: INPUT AGAIN
CHAR, 0/TEMPORARY STORAGE
MSPACE, -248/-ASCII EQUIVALENT
/END OF EXAMPLE
```

$
Both of these programs are identical and produce the same binary code. The second, however, is easier to read.

During PASS1, the Assembler reads the source tape and defines all symbols used. The user's symbol table is printed (or punched) at the end of PASS1. If any symbols remain undefined, the UA diagnostic is printed. The symbol table is printed in alphabetic order. If the program listed above were assembled, the PASS1 output would be:

```
BEGIN, 0200 /START OF PROGRAM
  KCC
  KSF /WAIT FOR FLAG
  JMP,-1 /FLAG NOT SET YET
  KR8 /READ IN CHARACTER
  DCA CHAR
  TAD CHAR
  TAD MSPACE /IS IT A SPACE?
  SNA CLA
  HLT /YES
  JMP BEGIN+2 /NO: INPUT AGAIN
CHAR, 0 /TEMPORARY STORAGE
MSPACE, -240 /-ASCII EQUIVALENT
/END OF EXAMPLE
```

During PASS2, the Assembler reads the source tape and generates the binary code using the symbol table equivalences defined during PASS1. The binary tape that is punched may be loaded by the Binary Loader (Digital-S-2-U). This binary tape consists of leader code, an origin setting, and then data words. Every occurrence of an asterisk expression causes a new origin to be punched on the tape and resets the Assembler's current location counter. At the end of PASS2, the checksum is punched on the binary tape and trailer code is generated. During PASS2, the Assembler may diagnose an Illegal Reference. When using the 33 ASR Punch, the diagnostic will be both typed and punched and will be preceded and followed by rubouts. The Binary Loader will ignore everything that has been punched on a tape between rubouts.

During PASS3, the Assembler reads the source tape and generates the code from the source statements. The assembly listing is typed (or punched). It consists of the current location counter, the generated code in octal, and the source statement. The symbol table is typed at the end of the pass. If the program listed above were assembled, the PASS3 output would be:

```
4-2
```
*200

/EXAMPLE OF FORMAT
/GENERATOR

<table>
<thead>
<tr>
<th>Dec</th>
<th>Bin</th>
<th>Operation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0200</td>
<td>0000</td>
<td>BEGIN, 00</td>
<td>/START OF PROGRAM</td>
</tr>
<tr>
<td>0201</td>
<td>6032</td>
<td>KCC</td>
<td></td>
</tr>
<tr>
<td>0202</td>
<td>6031</td>
<td>KSF</td>
<td>/WAIT FOR FLAG</td>
</tr>
<tr>
<td>0203</td>
<td>5202</td>
<td>JMP -1</td>
<td>/FLAG NOT SET YET</td>
</tr>
<tr>
<td>0204</td>
<td>6036</td>
<td>KR</td>
<td>/READ IN CHARACTER</td>
</tr>
<tr>
<td>0205</td>
<td>3213</td>
<td>DCA CHAR</td>
<td></td>
</tr>
<tr>
<td>0206</td>
<td>1213</td>
<td>TAD CHAR</td>
<td></td>
</tr>
<tr>
<td>0207</td>
<td>1214</td>
<td>TAD MSPACE</td>
<td>/IS IT A SPACE?</td>
</tr>
<tr>
<td>0210</td>
<td>7650</td>
<td>SNA CLA</td>
<td></td>
</tr>
<tr>
<td>0211</td>
<td>7402</td>
<td>HLT</td>
<td>/YES</td>
</tr>
<tr>
<td>0212</td>
<td>5202</td>
<td>JMP BEGIN+2</td>
<td>/NO; INPUT AGAIN</td>
</tr>
<tr>
<td>0213</td>
<td>0000</td>
<td>CHAR, 00</td>
<td>/TEMPORARY STORAGE</td>
</tr>
<tr>
<td>0214</td>
<td>7540</td>
<td>MSPACE, -240</td>
<td>/-ASCII EQUIVALENT</td>
</tr>
</tbody>
</table>

BEGIN 0200
CHAR 0213
MSPACE 0214

/END OF EXAMPLE
CHAPTER 5

OPERATING INSTRUCTIONS

The PAL III Assembler is provided as a binary tape. This is loaded into the PDP-8 memory by means of the Binary Loader, using either the 33 ASR Reader or the 750C Photo-Electric Reader (see Digital-8-2-U). The Assembler will use either the 33 ASR Reader or the photo-electric reader to read the source language tape, and it will use either the 33 ASR Punch or the 75E Punch for output. The selection of I/O devices is made by the Assembler when it is started. The source language tape must be in the proper reader, with the reader and punch turned on. When using the high-speed punch, the symbol table will be typed on the 33 ASR if bit 11 of the switch register is 0 (down); it will be punched on the high-speed punch if bit 11 of the switch register is a 1 (up). When using the 33 ASR for symbol table output, the telepunch should be left on, since the symbol table produced may be read by DDT (see Digital-8-4-5). All diagnostics will be typed on the 33 ASR (except for the undefined address diagnostic when using the high-speed punch and the bit 11 switch option). The binary tape produced during PASS2 will be punched using the 33 ASR punch or the 75E Punch if it is included in the machine configuration and turned on. The only diagnostic in PASS2 will be Illegal Reference. Since this is typed on the 33 ASR, it may also be punched on the binary tape. It will, however, be ignored by the Binary Loader. The bit 11 switch option may be used during PASS3 also. If the machine is not equipped with the 75E High-Speed Punch, bit 11 will have no effect.

In addition to the binary tape of the Assembler, the user is provided with an ASCII tape containing symbol definitions for the instruction sets of the available options to the PDP-8 (i.e., card readers, magnetic tapes, A/D converters). Since there is only a finite amount of space available, expanding the number of permanent symbols that the Assembler recognizes decreases the maximum number of symbols the user may have available. For this reason, the ASCII Extended Definitions tape should be edited to contain definitions for only those options which the user has acquired. This tape should be read into the Assembler only on PASS1. Since it permanently fixes the symbols it contains, it should not be read again until PAL III is reloaded.

1. Load the Assembler using either the 33 ASR Reader or the 750C Photo-Electric reader.

2. Set $2000$ into the switch register; press LOAD ADDRESS.

3. Place the source language tape in the reader. Turn the reader on; turn the punch on. Be certain that leader code is in the reader.
4. Set Bits Ø and 1 of the switch register for the proper pass. These settings are:

<table>
<thead>
<tr>
<th>Bit Ø</th>
<th>Bit 1</th>
<th>Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ø</td>
<td>1</td>
<td>PASS1</td>
</tr>
<tr>
<td>1</td>
<td>Ø</td>
<td>PASS2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>PASS3</td>
</tr>
</tbody>
</table>

PASS1 is required so that the Assembler can initialize its symbol table and define all user symbols. After PASS1 has been made, either PASS2 or PASS3 may be made.

5. Bit 11 switch option

During PASS1

- Bit 11 = 1: Punch symbol table on high-speed punch if it is in the machine configuration.
- Bit 11 = Ø: Type (and punch) the symbol table on the 33 ASR.

During PASS2

- No effect

During PASS3

- Bit 11 = 1: Punch assembly listing tape, in ASCII, on high-speed punch.
- Bit 11 = Ø: Type assembly listing on 33 ASR.

6. Press START. The Assembler will halt at the end of each pass. Proceed from step 3.

If the Assembler has halted because of a PAUSE statement, put the next tape into the reader and press CONTINUE.

**SUMMARY**

PASS1

The Assembler reads the source tape, defines all user symbols, and outputs the user symbol table in alphabetic order. PASS1 diagnostics are:

IC dddd AT xxxx Illegal Character

where dddd is the value of the illegal character and xxxx is the value of the current location counter when the character was processed. The character is ignored.

RD XXXXXXX AT dddd ReDefinition

where XXXXXXX is the symbol being redefined and dddd is the value of the current location counter at the point of redefinition. The symbol is redefined.

DT XXXXXXX AT dddd Duplicate Tag
An attempt is being made to redefine a symbol using the comma. XXXXXX is the symbol and dddd is the value of the current location counter. The previous value of the symbol is retained and the symbol is not redefined.

ST XXXXXX AT dddd Symbol Table full

where XXXXXX is the symbol causing the overflow and dddd is the value of the Current Location Counter at the point of overflow. The Assembler halts and may not be restarted.

UA XXXXXX AT dddd Undefined Address

where XXXXXX is the symbol that was used, but never defined, and dddd is the value of the Current Location Counter when the symbol was first processed. This is typed with the symbol table at the end of PASS1. The symbol is assigned a value equal to the highest address on the memory page where it was first used.

The Assembler reads the source tape and using the symbol table defined during PASS1, generates and punches the binary code. This binary tape may then be loaded by the Binary Loader. The PASS2 diagnostic is:

IR dddd AT xxxx Illegal Reference

where dddd is the address being referenced and xxxx is the value of the Current Location Counter. The illegal address is then treated as if it were on the proper memory page.

Example:

*7306
JMP 307

would produce:

IR 0307 AT 7306

and would generate 5307 to be loaded into location 7306.
The Assembler reads the source tape and, using the symbol table defined during PASS1 generates and types the code represented by the source statements. The Current Location Counter, the contents, and the source statement are typed side by side on one line. If bit 11 of the switch register is a 1 and the machine configuration includes the high-speed punch, the assembly listing will be punched in ASCII. The PASS3 diagnostic is Illegal Reference.
PAL III contains a table of symbol definitions for the basic PDP-8 and its most common optional peripheral devices. These are the symbols such as TAD, RFC or SPA, which do not have to be defined in every program. This table is considered to be PAL III’s permanent symbol table. All the symbols it contains are listed under the heading BASIC SYMBOLS in Appendix 1 of this manual. If the user had purchased one or more of the optional devices whose instruction set is not defined among the BASIC SYMBOLS, for example, EAE or an A/D CONVERTER, it would be desirable if he could add the necessary symbol definitions to the permanent symbol table. This would eliminate the need for him to define these symbols in every program he writes. The opposite case would be the user who needs more space for his symbols. He would like to be able to delete all definitions except the ones he will actually use in his program.

For such purposes PAL III has three pseudo-instructions that may be used to alter its permanent symbol table. These pseudo-instructions are recognized by the Assembler only during PASS1. During either PASS2 or 3, they are ignored and have no effect.

The pseudo-instructions that alter the symbol table are:

EXPUNGE
EXPUNGE the entire permanent symbol table, except for the 9 pseudo-instructions listed in Appendix 1 under BASIC SYMBOLS.

FIXMRI
Fix Memory Reference Instructions. This must be followed on the same line by a symbol definition statement (parameter assignment) since the memory reference instructions are constructed in the symbol immediately following the pseudo-instructions. In other words the letters FIXMRI must be followed by one space, the symbol for the MRI to be defined, an equal sign, and the actual value of the symbol to the immediate left of the equal sign. The pseudo-instruction must be repeated for each MRI to be defined. All MRI’s must be defined before the definition of any other symbol.

EXAMPLE: EXPUNGE
FIX MRI TAD = 1000
FIX MRI DCA = 3000
FIXTAB

FIX the current symbol TABLE. All symbols that have been defined before the occurrence of this pseudo-instruction are made part of the permanent symbol table and will not be printed in the symbol table at the end of PASS1 or PASS3.

An actual tape to add two symbols to those already in PAL III's permanent symbol table would have punched on it in ASCII:

CDF=6201
CIF=6202
FIXTAB
PAUSE

To use such a tape the user would:

1. Read in PAL III with the Binary Loader.
2. Set 200 in the SWITCH REGISTER and press LOAD ADDRESS.
4. Put definitions tape (ASCII) in the proper reader.
5. Press START.

The PAUSE pseudo-instruction at the end of the tape indicates to the Assembler that the current PASS is not ended and another tape is to follow.

6. With switches still set to PASS1, put user's program in reader and press CONTINUE on the console.

The next program to be assembled should not be preceded by the definitions since they are already in the permanent symbol table and will be there until PAL III is reloaded.

After altering the symbol table to fit his needs the user might wish to keep PAL III in this state. This can be done by punching a binary of the section of core occupied by PAL with its new symbol table.

To do this:

1. Read in PAL III and modify symbol table as desired.
2. PAL III's symbol table begins at location 23508. Count all the symbols in the altered symbol table. Since each symbol and its value require four registers, multiply this number by 4. Convert this number to octal and add it to 23508. This number is the upper limit of PAL III. The lower limit is 0001.
3. Using the directions for Binary Punch Routine. (Digital-8-5-U) and the limits as stated in 2 above punch out the PAL III Assembler itself.

4. The output of the Binary Punch Routine is the Assembler with the modified Symbol Table and may be loaded with the binary loader.

EXAMPLE: PAL III is loaded.

The following ASCII tape is read in on PASS1:

CDF = 6201
CIF = 6202
RDF = 6214
RIF = 6224
RMF = 6244
RIB = 6234
FIXTAB
PAUSE

The Assembler now has in its symbol table the "MEMORY EXTENSION CONTROL" symbols and definitions. Six symbols were added and none removed. There were 84 symbols in the basic Assembler, there are now 90 symbols which require a total of $360 \times 10$ or $550_8$ locations. Since the symbol table starts at 2350, it extends to $2350_8 + 550_8$ or $3120_8$. The Binary Punch Routine is used to punch from 0001 through 3120_8 and the output is the Assembler with all the basic symbols plus memory extension symbols.
APPENDIX 1

SYMBOL LISTS

/PSEUDO INSTRUCTIONS
FIELD
EXPUNGE
FIXMRI
PAUSE
FIXTAB
DECIMAL
OCTAL
I
Z

/MEMORY REFERENCE INSTRUCTIONS
AND 0000
TAD 1000
ISZ 2000
DCA 3000
JMS 4000
JMP 5000

/FLOATING-POINT INSTRUCTIONS
FEXT 0000
FADD 1000
FSUB 2000
FMPY 3000
FDIV 4000
FGET 5000
FPUT 6000
FNOR 7000

/PROGRAM INTERRUPT
ION 6001
IOF 6002

/THELEPRINTER/PUNCH
TSF 6041
TCF 6042
TLS 6046
TPC 6044

/HIGH-SPEED READER
RSF 6011
RRB 6012
RFC 6014

/HIGH-SPEED PUNCH
PSF 6021
PCF 6022
PPC 6024
PLS 6026

/GROUP 1 OPERATES
NOP 7000
IAC 7001
RAL 7004
RTL 7006

/KEYBOARD/READER
KSF 6031
KCC 6032
KRS 6034
KRB 6036

/RAR 7010
RTR 7012
CML 7020
CMA 7040
CLL 7100
CLA 7200

/GROUP 2 OPERATES
HLT 7402
OSR 7404

/COMBINED OPERATES
CIA 7041
LAS 7604
SKP  7410  STL  7120
SNL  7420  GLK  7204
SZL  7430  STA  7240
SZA  7440
SNA  7450
SMA  7500
SPA  7510

/DECTAPE DUAL TRANSPORT TYPE 555 AND CONTROL TYPE 552
MMMM 6757  MMSF  6761
MMMF 6756  MMCF  6772
MMML 6766  MMSC  6771
MMLS 6751  MMRS  6774
MMLM 6752  MMCC  6762
MMLF 6754  MMLC  6764

/DECTAPE TRANSPORT TYPE TU55 AND CONTROL TYPE TC01
DTRA 6761  DTSF  6771
DTCA 6762  DTRB  6772
DTXA 6764  DTLB  6774

/MEMORY PARITY TYPE 188
SMP  6101
CMP  6104

EXTENDED SYMBOLS

/PDP -5 EAE SYMBOLS 153*
CAM  6101  SZO  6114
LMQ  6102  DIV  6121
LAR  6104  RDM  6122
MUL  6111  SAF  6124
RDA  6112

/PDP-8 EAE SYMBOLS 182
MUY  7405  ASR  7415
DVI  7407  LSR  7417
NMI  7411  MQL  7421
SHL  7413  SCA  7441
MQA  7501  CAM  7621

/MEMORY EXTENSION CONTROL TYPE 183
CDF  6201  RIF  6224
CIF  6202  RMF  6244
RDF  6214  RIB  6234

/AUTO RESTART TYPE KR01
SPL = 6102

* PDP-5 EAE symbol definitions do not appear on the actual tape due to a conflict in the CAM instructions of PDP-5 and PDP-8. PDP-8 EAE symbols should be deleted if those for PDP-5 are inserted in the extended symbols tape.
/AD CONVERTER TYPE 189
ADC 6004

/AD CONVERTER/MULTIPLEXER 137E/139E
ADSF 6531 ADCC 6541
ADCV 6532 ADSC 6542
ADR 6534 ADIC 6544

/OSCILLOSCOPE DISPLAY TYPE 34D
DCX 6051 DYL 6063
DXL 6053 DIX 6054
DCY 6061 DIY 6064
DXS 6057 DYS 6067

/SCOPE TYPE 30N
DLB 6074

/LIGHT PEN TYPE 370
DSF 6071 DCF 6072

/PLOTTER AND CONTROL TYPE 350B
PLSF 6501 PLCF 6502
PLPU 6504 PLPR 6511
PLPU 6512 PLDD 6514
PLPL 6521 PLUD 6522
PLPD 6524

/CARD READER AND CONTROL TYPE CR01C
RCSF 6631 RCSP 6671
RCRA 6632 RCSE 6671
RCRB 6634 RCRD 6674

/CARD READER TYPE 451
CRSF 6632 CERS 6634 /also services card punch 450
CRRB 6671 CRSA 6672
CRSB 6674

/CARD PUNCH AND CONTROL TYPE 450
CPSF 6631 CPSE 6642
CPBF 6644 /CERS as appears under card reader 451

/LINE PRINTER TYPE 645
LCF 6652 LPR 6655
LSF 6661 LCB 6662
LLB 6664
/SERIAL DRUM 25Ø AND 251

DRCR  6603     DRCW  6605
DRCF  6611     DREF  6612
DRTS  6615     DRSE  6621
DRC  6622      DRCN  6624

/MAGNETIC TAPE TYPE 57A

MSCR  6701     MCD  6702
MTS   6706     MSUR  6711
MNC   6712     MTC  6716
MSWF  6721     MDWF  6722
MCWF  6722     MEWF  6722
MIWF  6722     MSEF  6731
MDEF  6732     MCED  6732
MEEF  6732     MIEF  6732
MTRS  6734     MCC  6741
MRWC  6742     MRCA  6744
MCA  6745

/MAGNETIC TAPE TYPE 58Ø

TSRD  6715     TIFM  6707
TSWR  6716     TSDF  6721
TSRR  6722     TSST  6724
TWRT  6731     TCP1  6732
TSRS  6734

/EIGHT CHANNEL SAMPLE AND HOLD CONTROL TYPE ACØ1A

/OPTION TO TYPE 139E MULTIPLEXOR

HSC   6571
HAC   6572
SAC   6574

/DATA COMMUNICATION SYSTEMS TYPE 63Ø

TTINCR  6401     TTRL  6414
TTI    6402     TTSKP  6421
TTO    6404     TTXON  6422
TCL    6411     TTXOF  6424
TSL    6412
APPENDIX 2

ASCII CHARACTER SET

<table>
<thead>
<tr>
<th>Character</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>301</td>
<td>Ø</td>
</tr>
<tr>
<td>B</td>
<td>302</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>303</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>304</td>
<td>3</td>
</tr>
<tr>
<td>E</td>
<td>305</td>
<td>4</td>
</tr>
<tr>
<td>F</td>
<td>306</td>
<td>5</td>
</tr>
<tr>
<td>G</td>
<td>307</td>
<td>6</td>
</tr>
<tr>
<td>H</td>
<td>310</td>
<td>7</td>
</tr>
<tr>
<td>I</td>
<td>311</td>
<td>8</td>
</tr>
<tr>
<td>J</td>
<td>312</td>
<td>9</td>
</tr>
<tr>
<td>K</td>
<td>313</td>
<td>$</td>
</tr>
<tr>
<td>L</td>
<td>314</td>
<td>*</td>
</tr>
<tr>
<td>M</td>
<td>315</td>
<td>+</td>
</tr>
<tr>
<td>N</td>
<td>316</td>
<td>,</td>
</tr>
<tr>
<td>O</td>
<td>317</td>
<td>-</td>
</tr>
<tr>
<td>P</td>
<td>320</td>
<td>.</td>
</tr>
<tr>
<td>Q</td>
<td>321</td>
<td>/</td>
</tr>
<tr>
<td>R</td>
<td>322</td>
<td>;</td>
</tr>
<tr>
<td>S</td>
<td>323</td>
<td>=</td>
</tr>
<tr>
<td>T</td>
<td>324</td>
<td>Space</td>
</tr>
<tr>
<td>U</td>
<td>325</td>
<td>Tab</td>
</tr>
<tr>
<td>V</td>
<td>326</td>
<td>Line Feed</td>
</tr>
<tr>
<td>W</td>
<td>327</td>
<td>Form Feed</td>
</tr>
<tr>
<td>X</td>
<td>330</td>
<td>Carriage-Return</td>
</tr>
<tr>
<td>Y</td>
<td>331</td>
<td>Rubout</td>
</tr>
<tr>
<td>Z</td>
<td>332</td>
<td>Leader/Trailer</td>
</tr>
</tbody>
</table>

*Code 200 may be used as leader/trailer. It is generated by depressing:

Shift, CTRL, Repeat, @

Release the keys in reverse order.
NOTE 1: PAL III does not require the presence of Channel 8. Thus, 101 is considered equivalent to 301. This is useful if the paper tape is prepared on a Teletype that punches parity.

NOTE 2: All other characters are valid within comments.