# FORTRAN IV

## Part I. Language
## Part II. Object Time System
## Part III. Science Library

# ADVANCED SOFTWARE SYSTEM
# Programmer's Reference Manual

Order No. DEC-9A-AF4B-D from Program Library, Maynard, Mass. Price: $2.50

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# PREFACE

This manual describes the FORTRAN IV language and compiler system for the PDP-9 computer. It provides the user with the necessary information for writing FORTRAN programs for compilation and execution with the PDP-9 Advanced Software System. The manual is divided into three parts: Basic FORTRAN Language (Part I), FORTRAN Object Time System (Part II), and the FORTRAN Science Library (Part III).

Part I, Basic FORTRAN IV Language, is divided into chapters as follows:

Chapter 1. Introduction
Chapter 2. Elements of the FORTRAN Language
Chapter 3. Arithmetic Statements
Chapter 4. Control Statements
Chapter 5. Input/Output Statements
Chapter 6. Specification Statements
Chapter 7. Subprograms

Part I is intended to familiarize the user with specific PDP-9 FORTRAN coding procedures. Several excellent texts are available for a more elementary approach to FORTRAN programming. "A Guide to FORTRAN IV Programming," by Daniel D. McCracken (published by John Wiley and Sons, Inc.) is recommended.

Part II, FORTRAN IV Object Time System, describes the group of subprograms that process compiled FORTRAN statements, particularly I/O statements, at execution time.

Part III, PDP-9 Science Library, provides detailed descriptions of the intrinsic functions, external functions, subfunctions, and arithmetic routines in the PDP-9 Science Library.

PDP-9 FORTRAN IV is essentially the language specified by the United States of America Standards Institute (X3.9 - 1966) with the exceptions noted in Appendix 2 at the end of Part I of this manual.

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# CHAPTER 1
# INTRODUCTION

## 1.1 FORTRAN

Each type of digital computer is designed to respond to certain machine language codes. The codes are different for each type of computer. FORTRAN makes it unnecessary for the scientist or engineer to learn the machine language for specific computers. Using FORTRAN, he can write programs in a simple language that adapts easily to scientific usage. The FORTRAN language is composed of mathematical-like statements, constructed in accordance with precisely formulated rules. A FORTRAN program consists of meaningful sequences of FORTRAN statements that direct the computer to perform specific operations and calculations. A program written using FORTRAN statements is called a source program. It must be translated by the FORTRAN compiler program before execution. The translated version of the program is referred to as an object program. It is in a binary-coded form that the machine can understand.

## 1.2 SOURCE PROGRAM FORMAT

The FORTRAN character set consists of the 26 letters:

A, B, C, D, E, F, G, H, I, J, K, L, M,
N, O, P, Q, R, S, T, U, V, W, X, Y, Z.

the 10 digits:

0, 1, 2, 3, 4, 5, 6, 7, 8, 9

and 11 special characters:

| | |
|---|---|
| Blank | |
| Equals | = |
| Plus | + |
| Minus | - |
| Asterisk | * |
| Slash | / |
| Left Parenthesis | ( |
| Right Parenthesis | ) |
| Comma | , |
| Decimal Point | . |
| Dollar Sign | $ |

### 1.2.1 Card Format (IBM Model 029 Keypunch Codes)

The FORTRAN source program is written on a standard FORTRAN coding sheet (Figure 1-1) which consists of the following fields: statement number field, line continuation field, statement field, and identification field.

The FORTRAN statement is written in columns 7-72. If the statement is too long for one line, it can be continued in the statement field of as many lines as necessary if column 6 of each continuation line contains any character other than blank or zero. There are two exceptions to this rule: (1) the DO statement must be on one line; and (2) the equal sign (=) of an assignment statement must appear on the first line.

For one statement to be referenced by another, a statement number is placed in columns 1 through 5 of the first line of that statement. This number is made up of digits only, and may contain from one to five digits. Leading zeros and all blanks in this field are ignored. The statement numbers are used for identification only, and may be assigned in any order.

The FORTRAN compiler ignores the last eight columns (columns 73 through 80) which may be used for program identification, sequencing, or any other purpose desired by the user. Comments may be included in the program by putting a "C" in column 1 of each line containing a comment (or continuation of a comment). The compiler ignores these comments except for printing them.

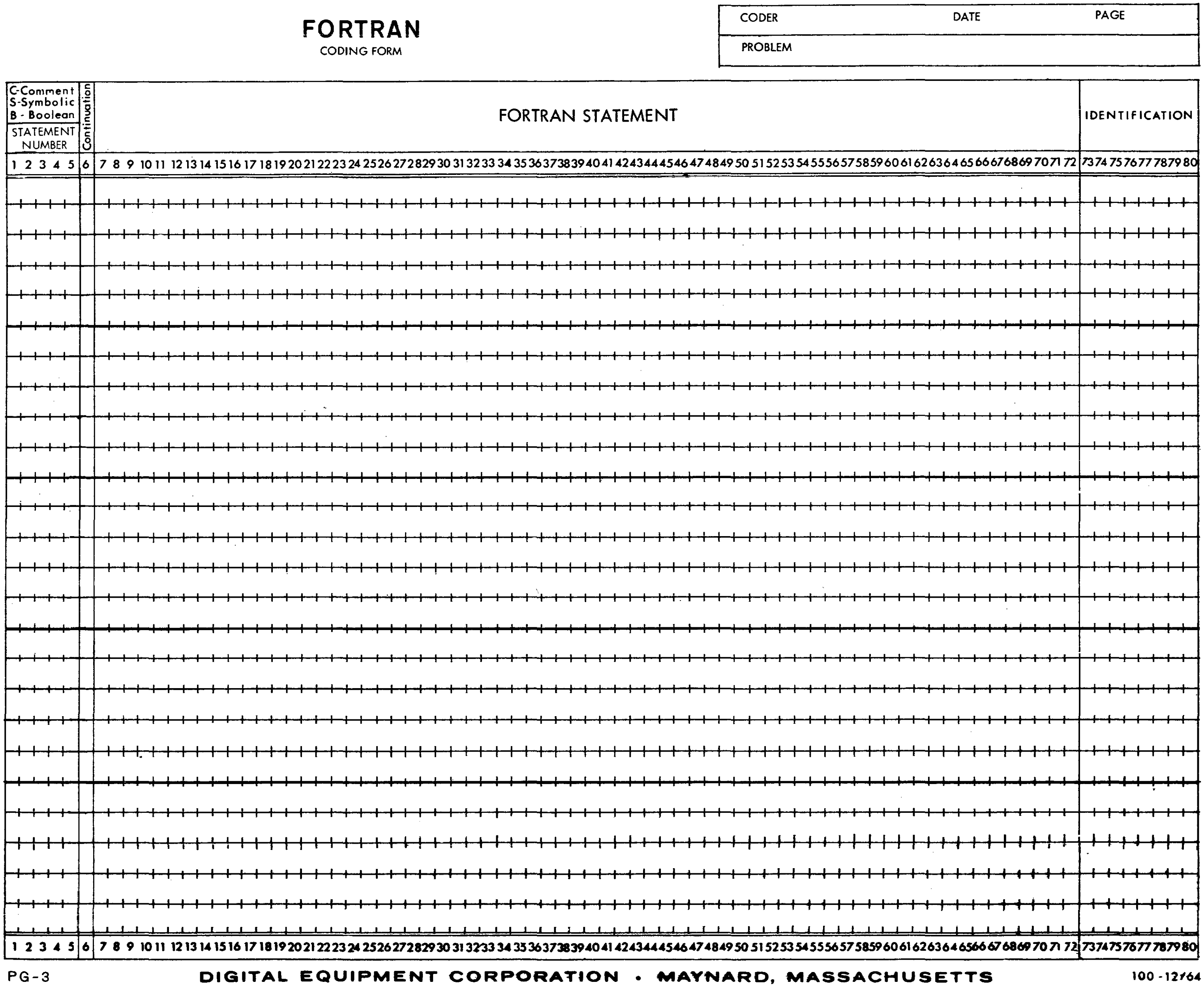
Blanks may be used to aid readability of a FORTRAN statement, except where indicated in this manual.

### 1.2.2 Paper Tape Format

When FORTRAN source program statements are prepared on paper tape, the sequence of characters is exactly the same as for card input, and each line is terminated with a carriage return, line feed sequence.

A statement number (all digits) may be written as the first five characters, or a "C" may be the first character to indicate a comment line or a continuation of a comment line. For statement continuation lines, any numeric character other than blank or zero is written as the sixth character. The seventh character begins the statement and must be alphabetic. Each line is terminated with a carriage return, line feed.

The TAB key can increase the speed of writing FORTRAN statements on paper tape. A TAB followed by an alphabetic character begins the statement in column 7. A TAB followed by a digit places the digit in column 6, indicating a statement continuation line. A statement number less than five digits, followed by a TAB, places the next character in column 6 if it is a digit, or in column 7 if it is a letter.



FORTRAN

CODING FORM

CODER DATE PAGE

PROBLEM

| C-Comment<br>S-Symbolic<br>B - Boolean<br>STATEMENT NUMBER | Continuation | FORTRAN STATEMENT | IDENTIFICATION |
|---|---|---|---|
| 1 2 3 4 5 | 6 | 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 | 73 74 75 76 77 78 79 80 |
| 1 2 3 4 5 | 6 | 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 | 73 74 75 76 77 78 79 80 |

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Figure I-1 FORTRAN Coding Form

If it is desired to have a title at the beginning of the tape for listing purposes, it must be entered as a comment line.

# CHAPTER 2
# ELEMENTS OF THE FORTRAN LANGUAGE

## 2.1 CONSTANTS

There are five types of constants allowed in the FORTRAN source program: integer, real, double-precision, logical, and Hollerith.

### 2.1.1 Integer Constants

An integer constant is a number written without a decimal point, consisting of one to six decimal digits. A + or - sign preceding the number is optional. The magnitude of the constant must be less than or equal to 131071 ($2^{17}-1$).

Example:

```
+97
0
-2176
576
```

If the magnitude $> 2^{17}-1$, an error message will be output. Negative numbers are represented in 2's complement notation.

### 2.1.2 Real Constants (6-decimal-digit accuracy)

A real constant is an integer, fraction, or mixed format number and may be written in the following forms:

a. A number consisting of one to six significant decimal digits with a decimal point included someplace within the constant. A + or - sign preceding the number is optional.

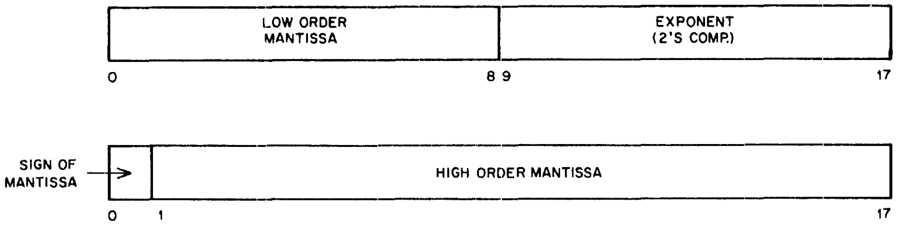
b. A number followed by the letter E, indicating a decimal exponent, and a 1- or 2-digit constant with magnitude less than 76* indicating the appropriate power of 10. A + or - sign may precede the scale factor. The decimal point is not necessary in real constants having a decimal exponent.

Example:

```
352.
+12.03
-.0054
5.E-3
+5E7
```

*If the adjusted magnitude exceeds 75, an error results. .999999E75 is legal, but 999.999E73 is illegal.

Real constants are stored in two words in the following format:



Negative mantissae are indicated with a change of sign.

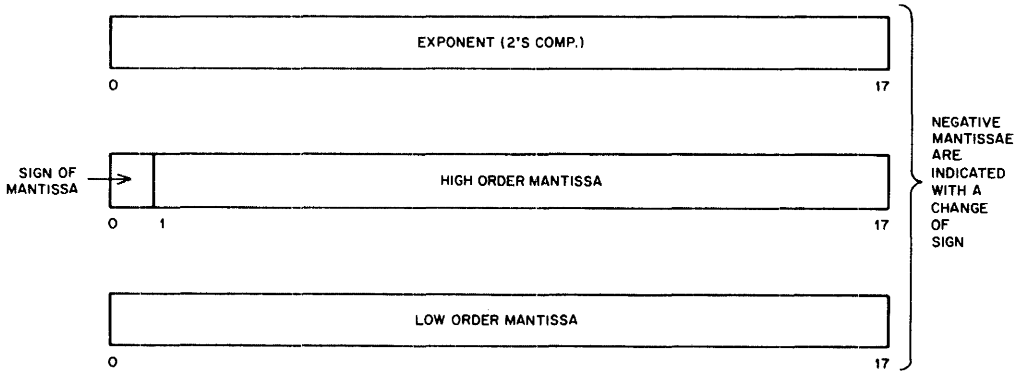
### 2.1.3 Double-Precision Constants (9-decimal-digit accuracy)

A double-precision constant is written as a real number followed by a decimal exponent, indicated by the letter D and a 1- or 2-digit constant with magnitude not greater than 76. A + or - sign may precede the constant and may also precede the scale factor. A decimal point within the constant is optional. A double-precision constant is interpreted identically to a real constant, the only difference being that the degree of accuracy is greater.

Example:

```
-3.0D0
987.6542D15
32.123D+7
```

Double-precision constants are stored in three PDP-9 words:



### 2.1.4 Logical Constants

The two logical constants are the words TRUE and FALSE, each both preceded and followed by a decimal point.

| | |
|---|---|
| .TRUE. | 777777 |
| .FALSE. | 0 |

### 2.1.5 Hollerith Constants

A Hollerith constant is written as an unsigned integer constant, whose value, n, must be equal to or greater than one and less than or equal to five, followed by the letter H, followed by exactly n characters, which are the Hollerith data. Any FORTRAN character, including blank, is acceptable. The Hollerith constants are used only in CALL and DATA statements and must be associated with real variable names. The Hollerith constants are packed in 7-bit ASCII, five, per two words of storage with the rightmost bit always zero.

Examples:

```
1HA
4HA$C
```

## 2.2 VARIABLES

A variable is a symbolic representation of a numeric quantity whose values may change during the execution of a program either by assignment or by computation. The symbol's representation, or name of the FORTRAN variable consists of from one to six alphanumeric (alphabetic and numeric) characters, the first of which must be alphabetic.

Example:

X = Y + 10. Both X and Y are variables; X by computation, and Y by assignment in some previous statement.

```
TEST
GAMMA
X12345
```

NOTE

If three or less characters are used for each symbol, considerable core space can be saved.

### 2.2.1 Variable Types

Variables in FORTRAN may represent one of the following types of quantities: integer, real, double-precision, or logical. This corresponds to the type of constant the variable is supposed to represent.

### 2.2.2 Integer Variables

Variable names beginning with the letters I, J, K, L, M, or N are considered to be integer variables. If the first letter is not one of the above letters, it is an integer variable only if it was named in a previous integer type specification statement.

### 2.2.3 Real Variables

Variable names beginning with letters other than I, J, K, L, M, or N are considered to be real variables. If the first character is one of the above letters, it is a real variable only if it was named in a previous real type specification statement.

### 2.2.4 Double-Precision and Logical Variables

A type specification statement is the only way to assign a variable value to one of these two types. This is done with either a double precision statement or a logical statement.

## 2.3 ARRAYS AND SUBSCRIPTS

An array is an ordered set of data identified by a symbolic name. Each individual quantity in this set of data is referred to in terms of its position within the array. This identifier is called a subscript. For example,

A (3)

represents the third element in a one-dimensional array named A. To generalize further, in an array A with n elements, A (I) represents the Ith element of the array A where I = 1, 2,...,n.

FORTRAN allows for one, two, and three-dimensional arrays, so there can be up to three subscripts for the array, each subscript separated from the next by a comma. For example,

B (1, 3)

represents the value located in the first row and the third column of a two-dimensional array named B. A dimension statement defining the size of the array (i.e., the maximum values each of its subscripts can attain) must precede the array in the source program.

### 2.3.1 Arrangement of Arrays in Storage

Arrays are stored in column order in ascending absolute storage locations. The array is stored with the first of its subscripts varying most rapidly and the last varying least rapidly. For example, a three-dimensional array A, defined in a DIMENSION statement as A (2,2,2) will be stored sequentially in this order:

```
A(1,1,1)  │
A(2,1,1)  │
A(1,2,1)  │
A(2,2,1)  │   ascending absolute
A(1,1,2)  │   storage locations
A(2,1,2)  │
A(1,2,2)  │
A(2,2,2)  ↓
```

### 2.3.2 Subscript Expressions

Subscripts may be written in any of the following forms:

```
V
C
V + k
V - k
C * V
C * V + k
C * V - k
```

where C and k represent unsigned integer constants and V represents an unsigned integer variable.

Example:

```
I
I3
IMOST + 3
ILAST - 1
5 * IFIRST
2 * J + 9
4 * M1 - 7
```

### 2.3.3 Subscripted Variables

A subscripted variable is a variable name followed by a pair of parentheses which contain one to three subscripts separated by commas.

Example:

```
A (I)
B (I, J - 3)
BETA (5 * J + 9, K + 7, 6 * JOB)
```

## 2.4 EXPRESSIONS

An expression is a combination of elements (constants, subscripted or nonsubscripted variables, and functions) each of which is related to another by operators and parentheses. An expression represents one single value which is the result of the calculations specified by the values and operators that make up the expression. The FORTRAN language provides two kinds of expressions: arithmetic and logical.

### 2.4.1 Arithmetic Expressions

An arithmetic expression consists of arithmetic elements joined by the arithmetic operators +, -, *, /, and **, which denote addition, subtraction, multiplication, division, and exponentiation, respectively. An expression may consist of a single element (meaning a constant, a variable, or a function name). An expression enclosed in parentheses is considered a single element. Compound expressions use arithmetic operators to combine single elements.

2.4.1.1 Mode of an Expression - The type of quantities making up an expression determines its mode; i.e., a simple expression consisting of an integer constant or an integer variable is said to be in the integer mode. Similarly, real constants or variables produce a real mode of expression, and double-precision constants or variables produce a double-precision mode. The mode of an arithmetic expression is important because it determines the accuracy of the expression.

In general, variables or constants of one mode cannot be combined with variables or constants of another mode in the same expression. There are, however, exceptions to this rule.

a. The following examples show the modes of the valid arithmetic expressions involving the use of the arithmetic operators +, -, *, and /. I, R, and D indicate integer, real, and double-precision variables or constants. A + is used to indicate any one of the four operators:

| | |
|---|---|
| I + I | Integer result |
| R + R | Real result |
| R + D | Double-precision result |
| D + R | |
| D + D | |

b. When raising a value to a power, the mode of the power may be different than that of the value being raised. The following examples show the modes of the valid arithmetic expressions using the arithmetic operator**. As above, I, R, and D indicate integer, real, and double-precision.

| | |
|---|---|
| I**I | Integer result |
| R**I | Real result |
| R**R | |
| R**D | Double-precision result |
| D**I | |
| D**R | |
| D**D | |

The subscript of a subscripted variable, which is always an integer quantity, does not affect the mode of the expression.

2.4.1.2 Hierarchy of Operations - The order in which the operations of an arithmetic expression are to be computed is based on a priority rating. The operator with the highest priority takes precedence over other operators in the expression. Parentheses may be used to determine the order of computation. If no parentheses are used, the order is understood to be as follows:

a. Function reference
b. **(Exponentiation)
c. Unary minus evaluation
d. * and/(multiplication and division)
e. + and -(addition and subtraction)

Within the same priority, operations are computed from left to right.

Example:

```
FUNC + A*B/C-D(I,J) + E**F*G-H
```

interpreted as,

$$\mathrm{FUNC} + ((A*B)/C) - D(I,J) + (E^{F} * G) - H$$

### 2.4.1.3 Rules for Constructing Arithmetic Expressions -

a. Any expression may be enclosed in parentheses.

b. Expressions may be preceded by a + or - sign.

c. Simple expressions may be connected to other simple expressions to form a compound expression, provided that:

(1) No two operators appear together.

(2) No operator is assumed to be present.

d. Only valid mode combinations may be used in an expression (described under Mode of an Expression, Section 2.4.1.1).

e. The expression must be constructed so that the priority scheme determines the order of operation desired (described in Section 2.4.1.2, Hierarchy of Operations).

Examples of arithmetic expressions follow:

```
3
A(I)
B + 7.3
C*D
A + (B*C) - D**2 + E/F
```

### 2.4.2 Relational Expressions

A relational expression is formed with the arithmetic expressions separated by a relational operator. The result value is either true or false depending upon whether the condition expressed by the relational operator is met or not met. The arithmetic expressions may both be of the integer mode or they may be a combination of real and/or double-precision. No other mode combinations are legal. The relational operators must be preceded by and followed by a decimal point. They are:

| | |
|---|---|
| .LT. | Less than (<) |
| .LE. | Less than or equal to (~~≮~~) ≤ |
| .EQ. | Equal to (=) |
| .NE. | Not equal to (≠) |
| .GT. | Greater than (>) |
| .GE. | Greater than or equal to (≥) |

Examples:

```
N .LT.5
DELTA + 7.3 .LE. B/3E7
(KAPPA + 7/5 .NE.IOTA
1.736D-4.GT.BETA
X.GE. Y*Z**2
```

### 2.4.3 Logical Expressions

A logical expression consists of logical elements joined by logical operators. The value is either true or false. The logical operator symbols must be preceded by and followed by a decimal point. They are:

.NOT. Logical negation. Reverses the state of the logical quantity that follows.

.AND. Logical AND generates a logical result (TRUE or FALSE) determined by two logical elements as follows:

T .AND. T generates T
T .AND. F generates F
F .AND. T generates F
F .AND. F generates F

.OR. Logical OR generates a logical result determined by two logical elements as follows:

T .OR. T generates T
T .OR. F generates T
F .OR. T generates T
F .OR. F generates F

#### 2.4.3.1 Rules for Construction Logical Expression -

a. A logical expression may consist of a logical constant, a logical variable, a reference to a logical function, a relational expression, or a complex logical expression enclosed in parentheses.

b. The logical operator .NOT. need only be followed by a logical expression, while the logical operators .AND. and .OR. must be both preceded by and followed by a logical expression for more complex logical expressions.

c. Any logical expression may be enclosed in parentheses. The logical expression following the logical operator .NOT. must be enclosed in parentheses if it contains more than one quantity.

d. No two logical operators may appear in sequence, not separated by a comma or parenthesis unless the second operator is .NOT. In addition, no two decimal points may appear together, not separated by a comma or parenthesis, unless one belongs to a constant and the other to a relational operator.

2.4.3.2 Hierarchy of Operations - Parentheses may be used as in normal mathematical notation to specify the order of operations. Within the parentheses, or where there are no parentheses, the order in which the operations are performed is as follows:

a. Evaluation of functions

b. **(Exponentiation)

c. Evaluation of unary minus quantities

d. * and/ (multiplication and division)

e. + and - (addition and subtraction)

f. .LT., .LE., .EQ., .NE., .GT., .GE.

g. .NOT.

h. .AND. and .OR.

i. = Replacement operator

Unlike an arithmetic expression where sequence of elements of the same priority (i.e., operations being performed from left to right) is important for the end result of the expression, the order of operation within the same priority in logical and relational expressions is unimportant.

## 2.5 STATEMENTS

Statements specify the computations required to carry out the processes of the FORTRAN program. There are four categories of statements provided for by the FORTRAN language:

a. Arithmetic statements define a numerical calculation.

b. Control statements determine the sequence of operation in the program.

c. Input/output statements are used to transmit information between the computer and related input/output devices.

d. Specification statements define the properties of variables, functions, and arrays appearing in the source program. They also enable the user to control the allocation of storage.

# CHAPTER 3
# ARITHMETIC STATEMENTS

An arithmetic statement is a mathematical equation written in the FORTRAN language which defines a numerical or logical calculation. It directs the assignment of a calculated quantity to a given variable. An arithmetic statement has the form

V = E

where V is a variable (integer, real, double-precision, or logical, subscripted or nonsubscripted) or any array element name; = means replacement rather than equivalence, as opposed to the conventional mathematical notation; and E is an expression.

In some cases, the mode of the variable may be different from that of the expression. In such cases an automatic conversion takes place. The rules for the assignment of an expression E to a variable V are as follows:

| V Mode | E Mode | Assignment Rule |
|---|---|---|
| Integer | Integer | Assign |
| Integer | Real | Fix and assign |
| Integer | Double-precision | Fix and assign |
| Real | Integer | Float and assign |
| Real | Real | Assign |
| Real | Double-precision | Double-precision evaluate and real assign |
| Double-precision | Integer | Double-precision float and assign |
| Double-precision | Real | Double-precision evaluate and assign |
| Double-precision | Double-precision | Assign |
| Logical | Logical | Assign |

Mode conversions involving logical quantities are illegal unless the mode of both V and E is logical. Examples of an assignment statement:

```
ITEM = ITEM + 1
A(I) = B(I) = ASSIN (C (I) )
V =  .FALSE.
X = A.GT.B.AND.C  .LE. G
A = B
```

# CHAPTER 4
# CONTROL STATEMENTS

The statements of a FORTRAN program normally are executed as written. However, it is frequently desirable to alter the normal order of execution. Control statements give the FORTRAN user this capability. This section discusses the reasons for control statements and the ways in which they may be used.

## 4.1 UNCONDITIONAL GO TO STATEMENTS

The form of the unconditional GO TO statement is

```
GO TO n
```

where n is a statement number. Upon the execution of this statement, control is transferred to the statement identified by the statement number, n, which is the next statement to be executed.
Example:

```
GO TO 17
```

## 4.2 ASSIGN STATEMENT

The general form of an ASSIGN statement is

```
ASSIGN n TO i
```

where n is a statement number and i is a nonsubscripted integer variable name which appears in a subsequently executed assigned GO TO statement. The statement number, n, is the statement to which control will be transferred after the execution of the assigned GO TO statement.
Example:

```
ASSIGN 27 TO ITEST
```

## 4.3 ASSIGNED GO TO STATEMENT

Assigned GO TO statements have the form

$$\text{GO TO i, } (n_1, n_2, \ldots., n_m)$$

where i is a nonsubscripted integer variable reference appearing in a previously executed ASSIGN statement, and $n_1$, $n_2$, ...., $n_m$ are the statement numbers which the ASSIGN statement may legally assign to i. Examples:

```
ASSIGN 13 TO KAPPA
GO TO KAPPA, (1, 13, 72, 100, 35)
```

There is no object time checking to ensure that the assignment is one of the legal statement numbers.

## 4.4 COMPUTED GO TO STATEMENT

The format of a computed GO TO statement is

GO TO $(n_1, n_2, \ldots., n_m)$, i

where $n_1, n_2, \ldots., n_m$ are statement numbers and i is an integer variable reference whose value is greater than or equal to 1 and less than or equal to the number of statement numbers enclosed in parentheses. If the value of i is out of this range, the statement is effectively a CONTINUE statement.

Example:

GO TO (3, 17, 25, 50, 66), ITEM

If the value of ITEM is 2 at the time this GO TO statement is executed, the statement to which control is transferred is the statement whose number is second in the series, i.e., statement number 17.

## 4.5 ARITHMETIC IF STATEMENT

The form of the arithmetic IF statement is

IF (e) $n_1, n_2, n_3$

where e is an arithmetic expression and $n_1, n_2, n_3$ are statement numbers. The IF statement evaluates the expression in parentheses and transfers control to one of the referenced statements. If the value of the expression (e) is less than, equal to, or greater than zero, control is transferred to $n_1$, $n_2$, or $n_3$ respectively.

Example:

IF (AUB (I) - B*D) 10, 7, 23

## 4.6 LOGICAL IF STATEMENT

The general format of a logical IF statement is

IF (e) s

where e is a logical expression and s is any executable statement other than a DO statement or another logical IF statement. The logical expression is evaluated, and different statements are executed depending upon whether the expression is true or false. If the logical expression e is true, statement s is executed and control is then transferred to the following statement (unless the statement is a GO TO statement or an arithmetic IF statement, in which cases control is transferred as indicated; or the statement s is a CALL statement, in which case control is transferred to the next statement after return from the subprogram). If the logical expression e is false, statement s is ignored and control is transferred to the statement following the IF statement.

Example:

```
IF (L1) I = I + 1
IF (L.LE.k) GO TO 17
IF (LOG.AND. (.NOT.LOG1) ) IF (X) 3,5,5
```

## 4.7 DO STATEMENT

The DO statement is a command used to execute repeatedly a specified series of statements. The general format of the DO statement is

$$\text{DO n i} = m_1, m_2, m_3$$

or

$$\text{DO n i} = m_1, m_2$$

where n is a statement number representing the terminal statement or the end of the "range"; i is a non-subscripted integer variable known as the "index"; and $m_1$, $m_2$, and $m_3$ are unsigned nonzero integer constants or nonsubscripted integer variables, which represent the "initial," "final," and "increment" values of the index. If $m_3$ is omitted, as in the second form of the DO statement, its value is assumed to be 1.

The DO statement is a command used to execute repeatedly a group of statements following it, up to and including statement n. The initial value of i is $m_1$ ($m_1$ must be less than or equal to $m_2$). Each succeeding time the statements are operated, i is increased by the value of $m_3$. When is is greater than $m_2$, control passes to the statement following statement number n.

The range of a DO statement is a series of statements to be executed repeatedly. It consists of all statements immediately following the DO, up to and including statement n. Any number of statements may appear between the DO and statement n. The terminal statement (statement n) may not be a GO TO (of any form), an arithmetic IF, a RETURN, a STOP, a PAUSE, or a DO statement, or a logical IF statement containing any of these forms.

The index of a DO is the integer variable i which is controlled by the DO statement in such a way that its initial value is set to $m_1$, and is increased each time the range of statements is executed by $m_3$, until a further incrementation would cause the value of $m_2$ to be exceeded. Throughout the range of the DO, the index is available for computation either as an ordinary integer variable or as the variable of a subscript. However, the index may not be changed by any statement within the DO range.

The initial value is the value of the index at the time the range is executed for the first time.

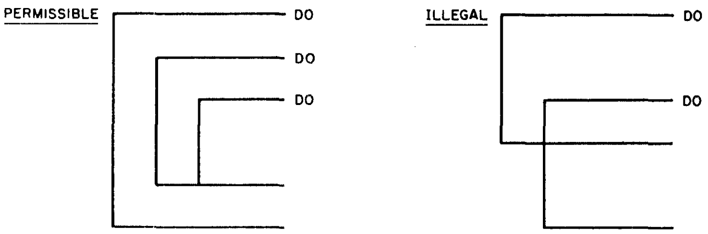
The final value is the value which the index must not exceed. When the condition is satisfied the DO is completed and control passes to the first executable statement following statement n.

The increment is the amount by which the index is to be increased after each execution of the range. If the increment is omitted, a value of 1 is implied.

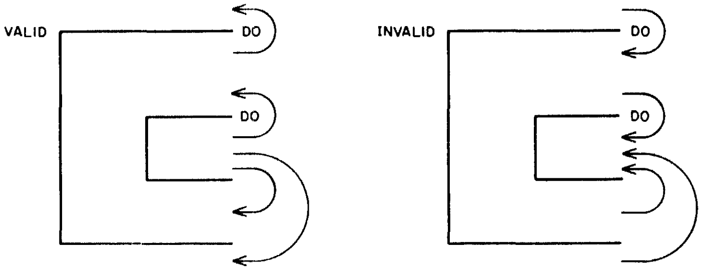
Example:

```
DO 72 I = 1, 10, 2
DO 15K = 1, 5
DO 23 I = 1, 11, 4
```

Any FORTRAN statement may appear within the range of a DO statement, including another DO statement. When such is the case, the range of the second DO must be contained entirely within the range of the first; i.e., it is not permissible for the ranges of DOs to overlap. A set of DOs satisfying this rule is called a nest of DOs. It is possible for a terminal statement to be the terminal statement for more than one DO statement. The following configuration, where brackets are used to represent the range of the DOs, indicates the permissible and illegal nesting procedures.



Transfer of control from within the range of a DO statement to outside its range is permitted at any time. However, the reverse is not true; i.e., control cannot be transferred from outside the range of a DO statement to inside its range. The following examples show both valid and invalid transfers.



## 4.8 CONTINUE STATEMENT

The CONTINUE statement causes no action and generates no machine coding. It is a dummy statement which is used for terminating DO loops when the last statement would otherwise be an illegal terminal statement (i.e., GO TO, arithmetic IF, RETURN, STOP, PAUSE, or DO, or a logical IF containing any of these forms). The form consists of the single word

CONTINUE

## 4.9 PAUSE STATEMENT

A PAUSE statement is a temporary halt of the program at run time. The PAUSE statement has one of the two forms

PAUSE

or

PAUSE n

where n is an octal integer whose value is less than $777777_8$. The integer n is typed out on the console Teletype for the purpose of determining which of several PAUSE statements was encountered. Program execution is resumed, by typing control P (↑P), starting with the first statement following the PAUSE statement.

## 4.10 STOP STATEMENT

The STOP statement is of one of the forms

STOP

or

STOP n

where n is an octal integer whose value is less than $7777777_8$. The STOP statement is placed at the logical end of a program and causes the computer to type out on the console Teletype, the integer n and then to exit back to the Monitor. There must be at least one STOP statement per main program, but none are allowed in subprograms.

## 4.11 END STATEMENT

The END statement is placed at the physical end of a program or subprogram. The form consists of the single word

END

The END statement is used by the compiler and generates no code. It signals the compiler that the processing of the source program is complete.

A control transfer type statement, a STOP statement, or a RETURN statement must immediately precede END. This will be checked by the compiler.

# CHAPTER 5
# INPUT/OUTPUT STATEMENTS

The input/output (I/O) statements direct the exchange of data between the computer and I/O devices. The information thus transmitted by an I/O statement is defined as a logical record, which may be formatted or unformatted. A logical record, or records, may be written on a device as one or more physical records. This is a function of the size of the logical record(s) and the physical device used.

The definition of the data which comprises a user's optimum physical record varies for each I/O device, as follows:

| Unit or Device | Formatted Physical Record Definition | Unformatted (Binary) Physical Record Definition |
|---|---|---|
| Typewriter (input and output) | One line of type is terminated by a carriage return. Maximum of 72 printing characters per line | Undefined |
| Line printer | One line of printing. Maximum of 120 characters per line | Undefined |
| Cards (input and output) | One card. Maximum of 80 characters | 50 words |
| Paper tape (input and output) | One line image of 72 printing characters | 50 words |
| Magnetic tape | One line image of 630 characters | 252 words |
| Disc/drum/ DECtape | One line image of 630 characters | 252 words |

Each I/O device is identified by an integer constant which is associated with a device assignment table in the PDP-9 Monitor. This table may be modified at system generation time, or just before run time. For example, the statement

```
READ (u,f) list
```

requests one logical record from the device associated with slot u in the device assignment table.

The statement descriptions in this section use u to identify a specific I/O unit, f as the statement number of the FORMAT statement describing the type of data conversion, and list as a list of arguments to be input or output.

## 5.1 GENERAL I/O STATEMENTS

These statements cause the transfer of data between the computer and I/O devices.

### 5.1.1 Input/Output Argument Lists

An I/O statement which calls for the transmission of information includes a list of quantities to be transmitted. In an input statement this list consists of the variables to which the incoming data is to be assigned; in an output statement the list consists of the variables whose values are to be transmitted to the given I/O device. The list is ordered, and the order must be that in which the data words exist (input) or are to exist (output) in the I/O device. Any number of items may appear in a single list. The same statement may transmit integer and real quantities. If the data to be transmitted exceeds the items in the list, only the number of quantities equal to the number of items in the list are transmitted. The remaining data is ignored. Conversely, if the items in the list exceed the data to be transmitted, succeeding superfluous records are transmitted until all items specified in the list have been transmitted.

5.1.1.1 Simple Lists - The list uses the form

$$C_1, C_2, \ldots, C_n$$

where each $C_i$ is a variable, a subscripted variable, or an array identifier. Constants are not allowed as list items. The list reads from left to right. When an array identifier appears in the list, the entire array is to be transmitted before the next item in the list. Examples of Simple Lists:

```
Y, Y, Z
A, B (3), C, D (I + 1, 4)
```

5.1.1.2 DO-Implied Lists - Indexing similar to that of the DO statement may be used to control the number of times a group of simple lists is to be repeated. The list elements thus controlled, and the index control itself, are enclosed in parentheses, and the contents of the parentheses are regarded as a single item of the I/O list.

Example:

```
W, X (3), (Y (I), Z (I,K), I = 1, 10)
```

### 5.1.2 READ Statement

The READ statement is used to transfer data from any input device to the computer. The general READ statement can be used to read either BCD or binary information. The form of the statement determines what kind of input will be performed.

5.1.2.1 Formatted READ - The formatted READ statements have the general form

```
READ (u,f) list
```

or

```
READ (u,f)
```

Execution of this statement causes input from device u to be converted as specified by format statement f, the resulting values to be assigned to the items specified by list, if any.

Examples:

```
READ (3,13) A,B,C
READ (2,10) A, (B (I), I = 1,5)
READ (1,3)
```

5.1.2.2 Unformatted READ - An unformatted READ statement has the general form

```
READ (u) list
```

or

```
READ (u)
```

Execution of this statement causes input from device u, in binary format, to be assigned to the items specified by list. If no list is given, one record will be read, but ignored. If the record contains more information words than the list requires, that part of the record is lost. If more elements are in the list than are in one record, additional records are read until the list is satisfied.

Example:

```
READ (5) I,J,K
READ (8)
```

### 5.1.3 WRITE Statement

The WRITE statement is used to transmit information from the computer to any I/O device. The WRITE statement closely parallels the READ statement in both format and operation.

5.1.3.1 Formatted WRITE - The formatted WRITE statement has the general form

```
WRITE (u,f) list
```

or

```
WRITE (u,f)
```

Execution of this statement causes the list elements, if any, to be converted according to format statement f, and output into device u.

5.1.3.2 Unformatted WRITE - The unformatted WRITE statement has the general form

WRITE (u) list

Execution of this statement causes output onto device u, in binary format, of all words specified by the list. If the list elements do not fill the record, the remaining part of the record is filled with blanks. If the list elements more than fill one record, successive records are written until all elements of the list are satisfied, the last record padded with blanks if necessary. Examples of WRITE:

```
WRITE (1,10) A, (B (I), (C (I,J), J=2,10,2), I=1,5)
WRITE (2,7) A,B,C
WRITE (5) W,X(3), Y(I + 1,4),Z
```

## 5.2 FORMAT STATEMENTS

These statements are used in conjunction with the general I/O statements. They specify the type of conversion which is to be performed between the internal machine language and the external notation. FORMAT statements are not executed. Their function is to supply information to the object program.

### 5.2.1 Specifying FORMAT

The general form of the FORMAT statement is

FORMAT $(S_1, S_2, \ldots., S_n)$

where $S_1 \ldots. S_n$ are data field descriptions. Breaking this format down further, the basic data field descriptor is written in the form

nkw.d

where n is a positive unsigned integer indicating the number of successive fields for which the data conversion will be performed according to the same specification. This is also known as the repeat count. If n is equal to 1, it may be omitted. The control character k indicates which type of conversion will be performed. This character may be I,E,F,D,P,L,A,H, or X. The nonzero integer constant w specifies the width of the field. The integer constant d indicates the number of digits to the right of the decimal point.

Six of the nine control characters listed above provide for data conversion between internal machine language and external notation.

| Internal | Type | External |
|---|---|---|
| Integer variable | I | Decimal integer |
| Real variable | E | Floating-point, scaled |
| Real variable | F | Floating-point, mixed |

| Internal | Type | External |
|---|---|---|
| Real variable | G | Floating-point, mixed/scaled |
| Double-precision variable | D | Floating-point, scaled |
| Logical variable | L | Letter T or F |
| Alphanumeric | A | Alphanumeric (BCD) characters |

The other three control types are special purpose control characters:

| Type | Purpose |
|---|---|
| P | Used to set a scale factor for use with E, F, and D conversions. |
| X | Provides for skipping characters in input or specifying blank characters in output. |
| H | Designates Hollerith fields. |

FORMAT statements are not executed and therefore may be placed anywhere in the source program. Because they are referenced by READ or WRITE statements, each FORMAT statement must be given a statement number.

Commas (,) and slashes (/) are used as field separators. The comma is used to separate field descriptors, with the exception that a comma need not follow a field specified by an H or X control character. The slash is used to specify the termination of formatted records. A series of slashes is also a field separator. Multiple slashes are the equivalent of blank records between output records, or records skipped for input records. If the series of n slashes occurs at the beginning or the end of the FORMAT specifications, the number of input records skipped or blank lines inserted in output is n. If the series of n slashes occurs in the middle of the FORMAT specifications, this number is n-1. A comma may precede and/or follow a slash, but is not necessary. An integer value cannot precede a slash.

For all field descriptors (with the exception of H and X), the field width must be specified. For those descriptors of the w.d type (see next page), the d must be specified even if it is zero. The field width should be large enough to provide for all characters (including decimal point and sign) necessary to constitute the data value as well as blank characters needed to separate it from other data values. Since the data value within a field is right justified, if the field specified is too small, the most significant characters of the value will be lost.

Successive items in the I/O list are transmitted according to successive descriptors in the FORMAT statement, until the entire I/O list is satisfied. If the list contains more items than descriptors in the FORMAT statement, a new record must be begun. Control is transferred to the preceding left parenthesis where the same specifications are used again until the list is complete.

Field descriptors (except H and X) are repeated by preceding the descriptor with an unsigned integer constant (the repeat count). A group repeat count is used to enable the repetition of a group of field descriptors or field separators enclosed in parentheses. The group count is placed to the left of the parenthesis. Two levels of parentheses (not including those enclosing the FORMAT specification) are permitted.

The field descriptors in the FORMAT must be the same type as the corresponding item in the I/O list; i.e., integer quantities require integer (I) conversion; real quantities require real (E or F) conversion, etc.

Example:

```
FORMAT (I7,F10.3)
FORMAT (I3, I7/E10.4,E10.4)
FORMAT (2I4, 3(I5,D10.3)
```

### 5.2.2 Conversion of Numeric Data

#### 5.2.2.1 I-Type Conversion - Field descriptor: Iw or nIw

The number of characters specified by w is converted as a decimal integer.

On input, the number in the input field by w is converted to a binary integer. A minus sign indicates a negative number. A plus sign, indicating a positive number, is optional. The decimal point is illegal. If there are blanks, they must precede the sign or first digit. All imbedded blanks are interpreted as zero digits.

On output, the converted number is right justified. If the number is smaller than the field w allows, the leftmost spaces are filled with blanks. If an integer is too large, the most significant digits are truncated and lost. Negative numbers have a minus sign just preceding their most significant digit if sufficient spaces have been reserved. No sign indicates a positive number.

Examples (b indicates blank):

| Format Descriptor | Input | Internal | Output |
|---|---|---|---|
| I5 | bbbbb | +00000 | bbbb0 |
| I3 | -b5 | -05 | b-5 |
| I8 | bbb12345 | +12345 | bbb12345 |

#### 5.2.2.2 E-Type Conversion - Field descriptor: Ew.d or nEw.d

The number of characters specified by w is converted to a floating-point number with d spaces reserved for the digits to the right of the decimal point. The w includes field d, spaces for a sign, the decimal point, plus four spaces for the exponent (written E ± XX) in addition to space for optional sign and one digit preceding the decimal point.

The input format of an E-type number consists of an optional sign, followed by a string of digits containing an optional decimal point, followed by an exponent. Input data can be any number of digits in length, although it must fall within the range of 0 to ± $10^{\pm 39}$.

E output consists of a minus sign if negative (blank if positive), the digit 0, a decimal point, a string of digits rounded to d significant digits, followed by an exponent of the form E ± XX.

Examples:

| Format Descriptor | Input | Internal | Output |
|---|---|---|---|
| E10.4 | 00.2134E03 | 213.4 | 0.2134E+03 |
| E9.4 | 0.2134E02 | 21.34 | .2134E+02 |
| E10.3 | bb-23.0321 | -23.0321 | -0.230E+02 |

5.2.2.3 F-Type Conversion - Field descriptor: Fw.d or nFw.d

The number of characters specified by w is converted as a floating-point mixed number with d spaces reserved for the digits to the right of the decimal point.

Input for F-type conversion is basically the same as that for E-type conversion, described above.

The output consists of a minus sign if the number is negative (blank if positive), the integer portion of the number, a decimal point, and the fractional part of the number rounded to d significant digits.

Examples:

| Format Descriptor | Input | Internal | Output |
|---|---|---|---|
| F6.3 | b13457 | 13.457 | 13.457 |
| F6.3 | 313457 | 313.457 | 13.457 |
| F9.2 | -21367. | -21367. | -21367.00 |
| F7.2 | -21367. | -21367- | 1367.00 |

5.2.2.4 G-Type Conversion - Field descriptor: Gw.d or nGw.d

The external field occupies w positions with d significant digits. The value of the list item appears, or is to appear, internally as a real number.

Input for G-type conversion is basically the same as that for E-type conversion, described in paragraph 5.2.2.2.

The form of the G-type output depends upon the magnitude of the internal floating-point number. Comparison is made between the exponent (e) of the internal value and the number of significant digits (d) specified by the format descriptor. If e is greater than d, the E-type conversion is used. If e is less than or equal to d, the F-type conversion is used, but modified by the following formula:

F (w-4).(d-e),4X

The 4X represents four blank spaces that are always appended to the value. If the value to be represented is less than .1 , the E-type conversion is always used.

Examples:

| Format Descriptor | Internal | Output |
|---|---|---|
| G14.6 | .12345678 x $10^{-1}$ | 0.12345678E-01 |
| G14.6 | .12345678 x $10^{0}$ | bb0.123456bbbb |
| G14.6 | .12345678 x $10^{4}$ | bbb1234.56bbbb |
| G14.6 | .12345678 x $10^{8}$ | bb0.123456E+08 |

5.2.2.5 D-Type Conversion - Field descriptor: Dw.d or nDw.d

The number of characters specified by w is converted as a double-precision floating-point number with the number of digits specified by d to the right of the decimal point.

The input and output are the same as those for E-type conversion except that a D is used in place of the E in the exponent.

Examples:

| Format Descriptor | Input | Internal | Output |
|---|---|---|---|
| D12.6 | bb+21345D 03 | 21.345 | 0.213450D+02 |
| D12.6 | b+3456789012 | 3456.789012 | 0.345678D+04 |
| D12.6 | -12345.6D-02 | -123.456 | 0.123456D+03 |

5.2.3 P-Scale Factor - Field descriptor: nP or -nP

This scale factor n is an integer constant. The scale factor has effect only on E,F,G, and D-type conversions. Initially, a scale factor of zero is implied. Once a P field descriptor has been processed, the scale factor established by n remains in effect for all subsequent E,F, and D descriptors within the same FORMAT statement until another scale factor is encountered.

For E, F, G, and D input conversions (when no exponent exists in the external field) the scale factor is defined as external quantity = internal quantity x $10^{n}$.

The scale factor has no effect if there is an exponent in the external field.

The definition of scale factor for F output conversion is the same as it is for F input. For E and D output, the fractional part is multiplied by $10^{n}$ and the exponent is reduced by n.

Examples:

| Format Descriptor | Input | Scale Factor | Internal | Output |
|---|---|---|---|---|
| -3PF6.3 | 123456 | -3 | +123456. | 23.456 |
| -3PE12.4 | 123456 | -3 | +12345.6 | bb0.0001E+08 |
| 1PD10.4 | 12.3456 | +1 | +1.23456 | 1.2345D+00 |

### 5.2.4 Conversion of Alphanumeric Data

5.2.4.1 A-Type Conversion (7-Bit ASCII, Handled As REAL Variables) - Field descriptor: Aw or nAw

The number of alphanumeric characters specified by w is transmitted according to list specifications.

If the field width specified for A input is greater than or equal to five (the number of characters representable in two machine words), the rightmost five characters are stored internally. If w is less than five, 5-w trailing blanks are added.

For A output, if w is greater than five, w-5 leading blanks are output followed by five alphanumeric characters. If w is less than or equal to five, the leftmost w characters are output.

5.2.4.2 H-Field Descriptor (7-Bit ASCII) - Field descriptor: $nHa_1 a_2a_3 \ldots a_n$

The number of characters specified by n immediately following the H descriptor are transmitted to or from the external device. Blanks may be included in the alphanumeric string. The value of n must be greater than 0.

On Hollerith input, n characters read from the external device replace the n characters following the letter H.

In output mode, the n characters following the letter H, including blanks, are output.

Examples:

```
3HABC
17H THIS IS AN ERROR
16H JANUARY 1, 1966
```

5.2.5 Logical Fields, L Conversion - Field descriptor: Lw or nLw

The external format of a logical quantity is T or F. The internal format of a logical quantity is T or F. The internal format is $777777_8$ for T or 0 for F.

On L input, the first nonblank character must be a T or F. Leading blanks are ignored. A nonblank character is illegal.

For L output, if the internal value is 0, an F is output. Otherwise a T is output. The F or T is preceded by w-1 leading blanks.

5.2.6 Blank Fields, X Conversion - Field descriptor: nX

The value of n is an integer number greater than 0. On X input, n characters are read but ignored. On X output, n spaces are output.

### 5.2.7 FORTRAN Statements Read in at Object Time

FORTRAN provides the facility of including the formatting data along with the input data. This is done by using an array name in place of the reference to a FORMAT statement label in any of the formatted I/O statements. For an array to be referenced in such a manner, the name of the variable FORMAT specification must appear in a DIMENSION statement, even if the size of the array is 1. The statements have the general form:

```
READ (u, name)
READ (u, name) list

WRITE (u, name)
WRITE (u, name) list
```

The form of the FORMAT specification which is to be inserted into the array is the same as the source program FORMAT statement, except that the word FORMAT is omitted and the nH field descriptor may not be used. The FORMAT specification may be inserted into the array by using a data initialization statement, or by using a READ statement together with an A format.

For example, this facility can be used to specify at object time, the format of a deck of cards to be read. The first card of the deck would contain the format statement,

```
1        10
(17,F10.3)
```

the subsequent cards would contain data in the general form,

```
      7        17
      xx       xxxx
```

```
   DIMENSION AA (10)
13 FORMAT (10A5)
   READ (3,13) (AA(I),I=1,10)
     :
   READ (3,AA) JJ, BOB
```

With the card reader assigned to device number 3, the first READ places the format statement from the first card into the array AA, and the second READ statement causes data from the subsequent cards to be read into JJ and BOB with format specifications I7 and F10.3, respectively.

### 5.2.8 Printing of a Formatted Record

When formatted records are prepared for printing, the first character of the record is not printed. The first character is used instead to determine vertical spacing as follows:

| Character | Vertical Spacing Before Printing |
|---|---|
| Blank | One line |
| 0 | Two lines |
| 1 | Skip to first line of next page |
| + | No advance |

Output of formatted records to other devices considers the first character as an ordinary character in the record.

## 5.3 AUXILIARY I/O STATEMENTS

These statements manipulate the I/O file oriented devices. The u is an unsigned integer constant or integer variable specifying the device.

### 5.3.1 BACKSPACE Statement

The BACKSPACE statement has the general form

BACKSPACE u

Execution of this statement causes the I/O device identified by u, to be positioned so that the record which had been the preceding record becomes the next record. If the unit u is positioned at its initial point, execution of this statement has no effect.

### 5.3.2 REWIND Statement

The REWIND statement has the general form

REWIND u

Execution of this statement causes the I/O device identified by u to be positioned at its initial point.

### 5.3.3 ENDFILE Statement

The ENDFILE statement has the general form

ENDFILE u

Execution of this statement causes an endfile record to be written on the I/O device identified by u.

and another program which is called later contains the statement,

```
COMMON/N/XX,YY,ZZ
```

the latter program will find the values 3, 4, and 5 in its variables XX, YY, and ZZ, respectively, since variables in the same relative positions in COMMON statements share the same registers in memory.

## 6.4 EQUIVALENCE STATEMENT

The EQUIVALENCE statement is used to permit two or more entities of the same size and type to share the same storage location. The general format of the EQUIVALENCE statement is:

$$\text{EQUIVALENCE } (k_1), (k_2), \ldots, (k_n)$$

where each k represents a list of two or more variables or subscripted variables separated by commas. Each element in the list is assigned the same memory storage location.

An EQUIVALENCE statement may lengthen the size of a COMMON block. The size can only be increased by extending the COMMON block beyond the last assignment for that block made directly by a COMMON statement. A variable cannot be made equivalent to an element of an array if it causes the array to extend past the beginning of the COMMON block.

When two variables or array elements share the same storage location because of the use of an EQUIVALENCE statement, they may not both appear in COMMON statements within the same program.

Example:

```
EQUIVALENCE (A,B), (C(10), D(10), E(15) )
```

## 6.5 EXTERNAL STATEMENT

An EXTERNAL statement is used to pass a subprogram name on to another subprogram. The general form of an EXTERNAL statement is:

```
EXTERNAL y,z,...
```

Example:

```
EXTERNAL ISUM, I SUB
      .
      .
      .
CALL DEBUG (ISUM, A, B)
      .
      .
      .
CALL DEBUG (ISUB, A, B)
      .
      .
      .
END
```

# CHAPTER 6
# SPECIFICATION STATEMENTS

Specification statements are nonexecutable because they do not generate instructions in the object program. They provide the compiler with information about the nature of the constants and variables used in the program. They also supply the information required to allocate locations in storage for certain variables and/or arrays. All SPECIFICATION statements must appear before any executable code generating statement. They must appear in this order: type statements, DIMENSION statements, COMMON statements, and EQUIVALENCE statements. EXTERNAL and DATA statements may appear anywhere after all type statements and before the executable code generating statements.

## 6.1 TYPE STATEMENTS

The type statements are of the forms

```
INTEGER a,b,c
REAL a,b,c
DOUBLE PRECISION a,b,c
LOGICAL a,b,c
```

where a, b, and c are variable names which may be dimensional or function names. A type statement is used to inform the compiler that the identifiers listed are variables or functions of a specified type, i.e., INTEGER, REAL, etc. It overrides any implicit typing; i.e., identifiers which begin with the letters I, J, K, L, M, or N are implicitly of the INTEGER mode; those beginning with any other letter are implicitly of the REAL mode. The type statement may be used to supply dimension information. The variable or function names in each type statement are defined to be of that specific type throughout the program; the type may not change.

Examples:

```
INTEGER ABC,IJK,XYZ
REAL A (2,4), I,J,K
DOUBLE PRECISION ITEM, GROUP
LOGICAL TRUE, FALSE
```

## 6.2 DIMENSION STATEMENT

The DIMENSION statement is used to declare arrays and to provide the necessary information to allocate storage for them in the object program.

The general form of the DIMENSION statement is:

$$\text{DIMENSION V }(i_1),\ V_2(i_2),\ \ldots V_n(i_n)$$

where each V is the name of an array and each i is composed of one, two, or three unsigned integer constants separated by commas. The number of constants represents the number of dimensions the array contains; the value of each constant represents the maximum size of each dimension. If the dimension information for the variable is given in a type statement or a COMMON statement, it must not be included in a DIMENSION statement.

Example:

```
DIMENSION ITEM (150), ARRAY (50,50)
```

When arrays are passed to subprograms, they must be redeclared in the subprogram. The mode, number of dimensions, and size of each dimension must be the same as that declared by the calling program.

## 6.3 COMMON STATEMENT

The COMMON statement provides a means of sharing memory storage between a program and its subprograms. The general form of the COMMON statement is:

$$\text{COMMON } /x_1/a_1/x_2/a_2/ \ldots /x_n/a_n$$

where each x is a variable which is a COMMON block name, or it can be blank. If $x_1$ is blank, the first two slashes are optional. Each a represents a list of variables and arrays separated by commas. The list of elements pertaining to a block name ends with a new block name, with a blank COMMON block designation (two slashes), or the end of the statement.

The elements of a COMMON block, which are listed following the COMMON block name (or the blank name), are located sequentially in order of their appearance in the COMMON statement. An entire array is assigned in sequence. Block names may be used more than once in a COMMON statement, or may be used in more than one COMMON statement within the program. The entries so assigned are strung together in the given COMMON block in order of their appearance. Labeled COMMON blocks with the same name appearing in several programs or subprograms executed together must contain the same number of total words. The elements within the blocks, however, need not agree in name, mode, or order. A blank COMMON may be any length.

Examples:

```
COMMON A,B,C/XX/X,Y,Z
COMMON/A/X(3,3), Y(2,5)//Z(5,10,15)
```

The COMMON statement is a means of transferring data between programs. If one program contains the statements,

```
COMMON/N/AA,BB,CC
AA=3
BB=4
CC=5
```

and another program which is called later contains the statement,

```
COMMON/N/XX,YY,ZZ
```

the latter program will find the values 3, 4, and 5 in its variables XX, YY, and ZZ, respectively, since variables in the same relative positions in COMMON statements share the same registers in memory.

## 6.4 EQUIVALENCE STATEMENT

The EQUIVALENCE statement is used to permit two or more entities of the same size and type to share the same storage location. The general format of the EQUIVALENCE statement is:

$$\text{EQUIVALENCE } (k_1), (k_2), \ldots, (k_n)$$

where each k represents a list of two or more variables or subscripted variables separated by commas. Each element in the list is assigned the same memory storage location.

An EQUIVALENCE statement may lengthen the size of a COMMON block. The size can only be increased by extending the COMMON block beyond the last assignment for that block made directly by a COMMON statement. A variable cannot be made equivalent to an element of an array if it causes the array to extend past the beginning of the COMMON block.

When two variables or array elements share the same storage location because of the use of an EQUIVALENCE statement, they may not both appear in COMMON statements within the same program.

Example:

```
EQUIVALENCE (A,B), (C(10), D(10), E(15) )
```

## 6.5 EXTERNAL STATEMENT

An EXTERNAL statement is used to pass a subprogram name on to another subprogram. The general form of an EXTERNAL statement is:

```
EXTERNAL y,z,...
```

Example:

```
EXTERNAL ISUM, ISUB
    .
    .
    .
CALL DEBUG (ISUM, A,B)
    .
    .
    .
CALL DEBUG (ISUB, A,B)
    .
    .
    .
END
```

```
SUBROUTINE DEBUG (X,Y,Z)
     .
     .
     .
RETURN
END
```

## 6.6 DATA STATEMENT

The DATA statement is used to set variables or array elements to initial values at the time the object program is loaded. The general form of the DATA initialization statement is:

$$\text{DATA } k_1/d_1/, k_2/d_2/, \ldots . k_n/d_n/$$

where each k is a list of variables or array elements (with constant subscripts) separated by commas, and each d is a corresponding list of constants with optional signs. The k list may not contain dummy arguments. There must be a one-to-one correspondence between the name list and the data list, except where the data list consists of a sequence of identical constants. In such a case, the constant need be written only once, preceded by an integer constant indicating the number of repeats and an asterisk. A Hollerith constant may appear in the data list.

Variable or array elements appearing in a DATA statement may not be in blank COMMON. They may be in a labeled COMMON block and initially defined only in a BLOCK DATA subprogram. Example:

```
   DATA A,B,C/3*2.0/
   DATA X(1), X(2), X(3), X(4)/0.0, 0.1, 0.2, 0.3/,Y(1), Y(2)
2  DATA Y(3), Y(4)/1.0E2, 1.0E-2, 1.0E4, 1.0E-4/
```

# CHAPTER 7 SUBPROGRAMS

A subprogram is a series of instructions which another program uses to perform complex or frequently used operations. Subprograms are stored only once in the computer, regardless how many times they are referred to by another program.

There are five categories of subprograms:

a. Statement Functions
b. Intrinsic or Library Functions
c. External Functions
d. External Subroutines
e. Block Data Subprograms

The first three categories of subprograms are referred to as functions. The fourth category is referred to as subroutines. Functions and subroutines differ in the following two respects. Functions can return only a single value to the calling program; subroutines can return more than one value. Functions are called by writing the name of the function and an argument list in a standard arithmetic expression; subroutines are called by using a CALL statement. The last category is a special purpose subprogram used for data initialization purposes.

## 7.1 STATEMENT FUNCTIONS

A statement function is defined by a single statement similar in form to that of an arithmetic assignment statement. It is defined internally to the program unit by which it is referenced. Statement functions must follow all specification statements and precede any executable statements of the program unit of which they are a part. The general format of a statement function is:

$$f(a_1, a_2, \ldots, a_n) = e$$

where f is a function name; the a's are nonsubscripted variables, known as dummy arguments, which are to be used in evaluating the function; and e is an expression.

The value of a function is a real quantity unless the name of the function begins with I, J, K, L, M, or N; in which case it is an integer quantity, or the function type may be defined by using the appropriate specification statement.

Since the arguments are dummy variables, their names are unimportant, except to indicate mode, and may be used elsewhere in the program, including within the expression on the right side of the statement function.

The expression of a statement function, in addition to containing nonsubscripted dummy arguments, may only contain:

a. Non-Hollerith constants
b. Variable references
c. Intrinsic function references
d. References to previously defined statement functions
e. External function references

A statement function is called any time the name of the function appears in any FORTRAN arithmetic expression. The actual arguments must agree in order, number, and type with the corresponding dummy arguments.

Execution of the statement function reference results in the computations indicated by the function definition. The resulting quantity is used in the expression which contains the function reference.

Examples:

```
A(X) = 3.2+SQRT (5.7* X**2)
SUM (A,B,C) = A+B+C
FUNC (A,B) = 2.*A/B**2.+Z
```

## 7.2 INTRINSIC OR LIBRARY FUNCTIONS

Intrinsic or library functions are predefined subprograms that are a part of the FORTRAN system library. The type of each intrinsic function and its arguments are predefined and cannot be changed.

An intrinsic function is referenced by using its function name with the appropriate arguments in an arithmetic statement. The arguments may be arithmetic expressions, subscripted or simple variables, constants, or other intrinsic functions (see table I-1).

Examples:

```
X = ABS (A)
I = INT (X)
J = IFIX (R)
```

Table I-1.
Intrinsic Functions

| Intrinsic Functions | Definition | No. of Arguments | Symbolic Name | Type of Argument | Type of Function |
|---|---|---|---|---|---|
| Absolute value | $\|a\|$ | 1 | ABS<br>IABS<br>DABS | Real<br>Integer<br>Double | Real<br>Integer<br>Double |
| Truncation | Sign of a times largest integer $\leq \|a\|$ | 1 | AINT<br>INT<br>IDINT | Real<br>Real<br>Double | Real<br>Integer<br>Integer |
| Remaindering* | $a_1 \pmod{a_2}$ | 2 | AMOD<br>MOD | Real<br>Integer | Real<br>Integer |
| Choosing largest value | Max $(a_1, a_2, \ldots)$ | 2 | AMAX0<br>AMAX1<br>MAX0<br>MAX1<br>DMAX1 | Integer<br>Real<br>Integer<br>Real<br>Double | Real<br>Real<br>Integer<br>Integer<br>Double |
| Choosing smallest value | Min $(a_1, a_2, \ldots)$ | 2 | AMIN0<br>AMIN1<br>MIN0<br>MIN1<br>DMIN1 | Integer<br>Real<br>Integer<br>Real<br>Double | Real<br>Real<br>Integer<br>Integer<br>Double |
| Float | Conversion from integer to real | 1 | FLOAT | Integer | Real |
| Fix | Conversion from real to integer | 1 | IFIX | Real | Integer |
| Transfer of sign | Sign of $a_2$ times $\|a_1\|$ | 2 | SIGN<br>ISIGN<br>DSIGN | Real<br>Integer<br>Double | Real<br>Integer<br>Double |
| Positive difference | $a_1$ - Min $(a_1, a_2)$ | 2 | DIM<br>IDIM | Real<br>Integer | Real<br>Integer |
| Obtain most significant part of double precision argument | | 1 | SNGL | Double | Real |
| Express single precision argument in double precision form | | 1 | DBLE | Real | Double |

*The function MOD or AMOD $(a_1, a_2)$ is defined as a $- [a_1/a_2]\, a_2$, where $[x]$ is the integer whose magnitude does not exceed the magnitude of x and whose sign is the same as x.

## 7.3 EXTERNAL FUNCTIONS

An external function is an independently written program which is executed whenever its name appears in another program. The general form in which an external function is written is:

```
t  FUNCTION NAME (a1,a2,...,an)
   (FORTRAN statements)
        :
        :
   NAME = final calculation
   RETURN
   END
```

where t is either INTEGER, REAL, DOUBLE PRECISION, LOGICAL, or is blank; NAME is the symbolic name of the function to be defined; and the a's are dummy arguments which are nonsubscripted variable names, array names, or other external function names.

The first letter of the function name implicitly determines the type of function. If that letter is I, J, K, L, M, or N, the value of the function is INTEGER. If it is any other letter, the value is REAL. This can be overridden by preceding the word FUNCTION with the specific type name.

The symbolic name of a function is one to six alphanumeric characters, the first of which must be the alphabetic name and must not appear in any nonexecutable statement of the function subprogram except in the FUNCTION statement where it is named. The function name must also appear at least once as a variable name within the subprogram. During every execution of the subprogram, the variable must be defined before leaving the function subprogram. Once defined, it may be referenced or redefined. The value of this variable at the time any RETURN statement in the subprogram is encountered is called the value of the function.

There must be at least one argument in the FUNCTION statement. There must be nonsubscripted variable names. If a dummy argument is an array name, an appropriate DIMENSION statement is necessary. The dummy argument names may not appear in an EQUIVALENCE, COMMON, or DATA statement in the function subprogram.

The function subprogram may contain any FORTRAN statements with the exception of a BLOCK DATA, SUBROUTINE, or another FUNCTION statement. It, of course, cannot contain any statement which references itself, either directly or indirectly.

A function subroutine must contain at least one RETURN statement. The general form is:

```
RETURN
```

This signifies the logical end of the subprogram and returns control and the computed value to the calling program.

An END statement, described in section 4.11, signals the compiler that the physical end of the subprogram has been reached.

An external function is called by using its function name, followed by an actual argument list enclosed in parentheses, in an arithmetic or logical expression. The actual arguments must correspond in number, order, and type to the dummy arguments. An actual argument may be one of the following:

a. A variable name
b. An array element name
c. An array name
d. Any other expression
e. The name of an external function or subroutine

Example:

```
DIMENSION A(100), B(100)
      .
      .
      .
RSLT = SUM (A,B)**2                 Main Program
      .
      .
      .
END

FUNCTION SUM (X,Y)
DIMENSION X (100), Y(100)
SUM = X(1) + Y(1)
DO 10 K = 2, 100                    Function Subprogram
SUM = SUM + X(K) + Y (K)
RETURN
END
```

Table I-2.
External Functions

| Basic External Function | Definition | No. of Arguments | Symbolic Name | Type of Argument | Type of Function |
|---|---|---|---|---|---|
| Exponential | $e^a$ | 1 | EXP | Real | Real |
| | | 1 | DEXP | Double | Double |
| Natural logarithm | $\log_e(a)$ | 1 | ALOG | Real | Real |
| | | 1 | DLOG | Double | Double |
| Common logarithm | $\log_{10}(a)$ | 1 | ALOG10 | Real | Real |
| | | 2 | DLOG10 | Double | Double |
| Trigonometric sine | sin (a) | 1 | SIN | Real | Real |
| | | 1 | DSIN | Double | Double |
| Trigonometric cosine | cos (a) | 1 | COS | Real | Real |
| | | 1 | DCOS | Double | Double |
| Hyperbolic tangent | tanh (a) | 1 | TANH | Real | Real |
| Square root | $(a)^{1/2}$ | 1 | SQRT | Real | Real |
| | | 1 | DSQRT | Double | Double |

Table 1-2. (Cont)
External Functions

| Basic External Function | Definition | No. of Arguments | Symbolic Name | Type of Argument | Type of Function |
|---|---|---|---|---|---|
| Arctangent | arctan (a) | 1 | ATAN | Real | Real |
| | | 1 | DATAN | Double | Double |
| | arctan $(a_1/a_2)$ | 2 | ATAN2 | Real | Real |
| | | 2 | DATAN2 | Double | Double |
| Remaindering* | $a_1$ (mod $a_2$) | 2 | DMOD | Double | Double |

*The function DMOD $(a_1,a_2)$ is defined as $a_1 - \left[a_1/a_2\right] a_2$, where $\left[x\right]$ is the integer whose magnitude does not exceed the magnitude of x and whose sign is the same as the sign of x.

## 7.4 SUBROUTINES

A subroutine is defined externally to the program unit which references it. It is similar to an external function in that both contain the same sort of dummy arguments, and both require at least one RETURN statement and an END statement. A subroutine, however, may have multiple outputs. The general form of a subroutine is:

SUBROUTINE NAME $(a_1,a_2, \ldots,a_n)$

or

SUBROUTINE NAME

where NAME is the symbolic name of the subroutine subprogram to be defined; and the a's are dummy arguments (there need not be any) which are nonsubscripted variable names, array names, or the dummy name of another subroutine or external function.

The name of a subroutine consists of one to six alphanumeric characters, the first of which is alphabetic. The symbolic names of the subroutines cannot appear in any statement of the subroutine except the SUBROUTINE statement itself.

The dummy variables represent input and output variables. Any arguments used as output variables must appear on the left side of an arithmetic statement or an input list within the subprogram. If an argument is the name of an array, it must appear in a DIMENSION statement within the subroutine. The dummy argument names may not appear in an EQUIVALENCE, COMMON, or DATA statement in the subprogram.

The subroutine subprogram may contain any FORTRAN subprograms with the exception of FUNCTION, BLOCK DATA, or another SUBROUTINE statement.

The logical termination of a subroutine is a RETURN statement. The physical end of the subroutine is an END statement.

A subroutine is referenced by a CALL statement, which has the general form

$$\text{CALL NAME } (a_1, a_2, \ldots, a_n)$$

or

CALL NAME

where NAME is the symbolic name of the subroutine subprogram being referenced, and the a's are the actual arguments that are being supplied to the subroutine. The actual arguments in the CALL statement must agree in number, order, and type with the corresponding arguments in the SUBROUTINE subprogram. The array sizes must be the same. An actual argument in the CALL statement may be one of the following:

a. A Hollerith constant
b. A variable name
c. An array element name
d. An array
e. Any other expression
f. The name of an external function or subroutine

## 7.5 BLOCK DATA SUBPROGRAM

The BLOCK DATA subprogram is a special subprogram used to enter data into a COMMON block during compilation. A BLOCK DATA statement takes the form

BLOCK DATA

This special subprogram contains only DATA, COMMON, EQUIVALENCE, DIMENSION, and TYPE statements. It cannot contain any executable statements. It can be used to initialize data only in a labeled COMMON block area; not in a blank COMMON block area.

All elements of a given COMMON block must be listed in the COMMON statement, even if they do not all appear in a DATA statement. Data may be entered in more than one COMMON block in a single BLOCK DATA subprogram.

An END statement signifies the termination of a BLOCK DATA subprogram.

### 7.5.1 Example of BLOCK DATA Subprogram

```
    BLOCK DATA
    DIMENSION X(4), Y(4)
    COMMON/NAME/A,B,C,I,J,X,Y
    DATA A,B,C/3*2.0/
    DATA X(1), X(2), X(3), X(4)/0.0, 0.1, 0.2, 0.3/Y(1), Y(2)
2   DATA Y(3), Y(4)/1.0E2, 1.0E-2, 1.0E4, 1.0E-4/
    END
```

# APPENDIX 1
# SUMMARY OF PDP-9 FORTRAN IV STATEMENTS

## CONTROL STATEMENTS

| | |
|---|---|
| ASSIGN n to i | I-15 |
| CALL name $(a_1,a_2,...)$ | I-42 |
| CONTINUE | I-19 |
| DO n $i=m_1,m_2,m_3$ | I-17 |
| GO TO n | I-15 |
| GO TO i, $(n_1,n_2,...)$ | I-15 |
| GO TO $(n_1,n_2,...)$,i | I-16 |
| IF $(e_1)$ $n_1,n_2,n_3$ | I-16 |
| IF (e) s | I-16 |
| PAUSE | I-19 |
| PAUSE n | I-19 |
| STOP | I-19 |
| STOP n | I-19 |
| END | I-19 |
| RETURN | I-39 |
| SUBROUTINE NAME $(a_1,a_2,...a_n)$ | I-41 |
| FUNCTION NAME $(a_1,a_2,...a_n)$ | I-39 |

## INPUT/OUTPUT STATEMENTS

| | |
|---|---|
| BACKSPACE u | I-31 |
| END FILE u | I-31 |
| FORMAT $(s_1,s_2,...,s_n)$ | I-24 |
| READ (u,f) | I-23 |
| READ (u,f) list | I-23 |
| READ (u) | I-23 |
| READ (u) list | I-23 |
| READ (u, name) | I-30 |
| READ (u,name) list | I-30 |
| REWIND u | I-31 |
| WRITE (u,f) list | I-23 |

SPECIFICATION STATEMENTS

## APPENDIX 2
## A NOTE ON PDP-9 FORTRAN IV

The FORTRAN language used in this manual is essentially the language of USASI Standard FORTRAN (X3.9-1966) with the exception of the following features which are modified to allow the compiler to operate in 8192 words of core storage:

a. All references to complex arithmetic are illegal.

b. The size of arrays in subprograms is not adjustable to the size specified by the calling program.

c. Blank COMMON is treated as name COMMON.

d. The implied DO feature is not legal in a DATA statement.

There are two versions of the FORTRAN IV compiler: F4 and F4A. F4 is the basic compiler, and F4A is an abbreviated version of the compiler that allows DECtape input and output in an 8K system. F4A operates under control of the Keyboard Monitor only, and is called by typing F4A rather than F4 on the Teletype. The F4A version does not provide for the following options available in the F4 version:

| | |
|---|---|
| O | Object code listing |
| S | Symbol table printout |
| L | Source listing |

In paper tape systems, the FORTRAN compiler along with necessary I/O device handlers and an appropriate version of the I/O Monitor are punched on a tape in absolute format, referred to as a "system tape." At the beginning of the system tape is a Bootstrap Loader. The system tape can be loaded by setting the starting address of the Loader (17720 for 8K systems, 37720 for 16K) on the console address switches, pressing I/O RESET, and then pressing the READIN switch. (Refer to the I/O Monitor Guide for Paper Tape Systems, DEC-9A-NGAA-D.)

In larger systems with a bulk storage device such as DECtape, the Keyboard Monitor accepts direct keyboard commands to load the compiler in a device-independent environment. (Refer to Keyboard Monitor Guide, DEC-9U-NGAA-D.) This feature enables use of READ (I,f) or READ (I) statements where the value of I is undefined at compile and load times. If such statements are used, it is important to clear unused positive .DAT slots before loading to avoid loading device handlers that are not required.

Either DDT-9 or the Linking Loader must be used to load user object programs for execution. Refer to the appropriate Monitor Guide (I/O Monitor of Keyboard Monitor) for operating procedures.

Since A is a single-precision, floating-point number, two machine words are required and must be accounted for in the subprogram. Thus MIN1 and MIN2 (which contain the addresses of A and B) must be incremented to get to the second word of each number. FORTRAN expands the CALL statement as follows:

```
      CALL MIN (A,B)
00013        JMS*       MIN        (Exit to MACRO-9 subprogram)
00014        JMP        $00014     (Entry from MACRO subprogram)
00015        .DSA       A
00016        .DSA       B
$00014=00017
```

When the program is loaded, the address (plus relocation factor) of A is stored in location 00015 (plus relocation factor) and the address of B in 00016 (plus relocation factor). When .DA is called from the MACRO-9 subprogram, it stores these addresses in MIN1 and MIN2 (plus relocation factor). Thus MIN1 must be referenced indirectly to get the value of A (a direct reference would get the address of A).

2. Linking MACRO-9 Programs With FORTRAN IV Subprograms:

There are two forms of FORTRAN IV subprograms: subroutines and external functions. The main difference between the two is the method of returning arguments to the calling program: subroutines return the argument directly to the calling program, while functions return arguments through accumulators.

The MACRO-9 program set-up for a FORTRAN IV subroutine is basically that described in Part III of this manual for FORTRAN IV Science Library routines. The name of the subroutine to be called must be declared as a global, there must be a jump around the argument addresses, and the number and type (integer, real, double precision) of arguments must agree from the calling program to the subroutine.

An example of a calling routine:

```
TITLE
.GLOBL      SUBROT
JMS*        SUBROT
JMP         .+N+1
.DSA        ADDR OF ARG1       /+400000 if indirect
.DSA        ADDR OF ARG2       /+400000 if indirect
  .
  .
  .
.DSA        ADDR OF ARGN       /+400000 if indirect
  .
  .
  .
```

# APPENDIX 3
# FORTRAN IV AND MACRO-9 LINKAGE

## 1. Linking FORTRAN IV Programs With MACRO-9 Subprograms

There are two essential elements of a MACRO subprogram that is linked to FORTRAN IV. One is the declaration of the name of the subprogram (as used in the F4 program) in a .GLOBL statement within the subprogram. The second is leaving open registers in the subprogram for the transfer vectors of the arguments used in the FORTRAN calling sequence. The number of open registers must agree with the number of arguments given in the calling sequence.

As an illustrative example, consider a FORTRAN program and a MACRO-9 subprogram which read, negate, and write a number. One positive, single-precision floating-point number is read by the FORTRAN program, negated in the MACRO-9 subprogram, and written out from the FORTRAN program.

FORTRAN IV PROGRAM:

```
C           TEST MACRO SUBPROGRAM
C           READ A NUMBER (A)
1           READ (1,100)  (A)
100         FORMAT (E12.4)
C           NEGATE THE NUMBER AND PUT IT IN B
            CALL MIN (A,B)
C           WRITE OUT THE NUMBER (B)
            WRITE (2,100) B
            STOP
            END
```

MACRO-9 SUBPROGRAM:

```
            .TITLE MIN
            .GLOBL MIN,.DA
MIN         0                   /ENTRY/EXIT
            JMS*      .DA       /USE THE F4 GENERAL GET ARGUMENT
                                /SUBPROGRAM TO LOAD THE ARGUMENTS
            JMP       .+3       /JUMP AROUND REGISTERS LEFT FOR
                                /ARGUMENT ADDRESSES
MIN1        .DSA      0         /ARG 1
MIN2        .DSA      0         /ARG2
            LAC*      MIN1      /PICK UP FIRST WORD OF A
            DAC*      MIN2      /STORE IN FIRST WORD OF B
            ISZ       MIN1      /BUMP THE POINTER TO SECOND WORD
            ISZ       MIN2      /OF A AND B
            LAC*      MIN1      /PICK UP SECOND WORD OF A
            TAD       (400000   /SIGN BIT = 1
            DAC*      MIN2      /STORE IN SECOND WORD OF B
            JMP*      MIN       /EXIT
            .END
```

When the FORTRAN IV subroutine is compiled, the compiler will generate code for .DA, the General Get Argument Routine, which will transfer the arguments from the MACRO-9 calling program to the FORTRAN IV subroutine. .DA expects to find the calling sequence just described for the calling program. The following is an example of an expansion of the beginning of a FORTRAN IV subroutine.

```
      C                      TITLE SUBROT
                             SUBROUTINE SUBROT (A, B)
000000                          CAL          0
000001                          JMS*         .DA
000002                          JMP          $000002
000003                          .DSA         A
00004                           .DSA         B
$000002=000005
```

The simplest method of passing arguments between the main program and the subroutine is to use one of the calling arguments as output. For example, if the value of D is to be calculated in the subroutine, use D as one of the calling arguments. "D=" will generate a "DAC* D", which will store the value calculated for D by the subroutine in location D in the calling program.

The MACRO-9 program set-up for a FORTRAN IV External Function is identical to that for linkage with subroutines, except that some provision must be made for storage of the values calculated and stored in the accumulator. In the case of integers, the value is returned in the A-register, and in the floating accumulator for real and double precision numbers. The simplest method of storing the values is to use the FORTRAN IV routines furnished in the library for this purpose. .AH store real values, and .AP stores double precision values. Since the A-register is the standard hardware accumulator, a DAC instruction will store integer values.

## 3. Linking MACRO-9 Programs With FORTRAN IV Library Routines

Refer to Part III of this manual , PDP-9 Science Library, for a complete description of the linkage to library routines.

## APPENDIX 4
## CHAINING FORTRAN IV PROGRAMS

Chaining is a method of program segmentation that allows for multiple core overlap of executable code and certain types of data areas. FORTRAN programs can thus be divided into segments and executed separately, with intersegment communication of data accomplished through common storage. Common areas of core are reserved by means of the blank COMMON statement.

Transfer of control from one chain segment to another can be specified in a FORTRAN source program with the statement

CALL CHAIN (N)

where N is the segment number to be called. The chain number (N) is established at chain-build time (refer to the CHAIN section of the Keyboard Monitor Guide, DEC-9U-NGAA-D). N can be greater than or less than but not equal to the current chain number. A STOP statement must immediately precede the END statement in the main program for each chain. Only variables and arrays named in blank COMMON statements are retained from one chain segment to another. Blank common size should be the same for all chain segments.

```
C          TEST CHAIN PROGRAM
C
C          CHAIN JOB SEGMENT 1
           COMMON A,B,C
           DIMENSION ARRAY (10,10)
           READ (4,5) ARRAY
                      .
                      .
                      .
           CALL CHAIN (2)
           STOP
           END
C          CHAIN JOB SEGMENT 2
           COMMON A,B,C
           DIMENSION TABLE (30)
                      .
                      .
                      .
           CALL CHAIN (3)
                      .
                      .
                      .
           STOP
           END
C          CHAIN JOB SEGMENT 3
           COMMON A,B,C
           DIMENSION A LIST (5,5)
                      .
                      .
                      .
```

```
WRITE (4,6) ALIST
6 FORMAT (E10.3)
STOP
END
```

# APPENDIX 5
# FORTRAN IV ERROR LIST

These letter-coded error messages apply to F4 V2A and all versions of F4 thereafter and all versions of F4A. Refer to page II-2 of this manual for a list of object-time errors.

| | Error Code | Cause |
|---|---|---|
| X | Syntax error | Statement cannot be recognized as a properly constructed FORTRAN IV statement. |
| V | Variable/constant mode error | Illegal mode mixing. Missing constant, variable or exponent, or illegal matching of constants or variables in a DATA statement. |
| N | Statement number error | Phase error, number more than 5 digits, no statement number where one is required, statement shouldn't be labeled or doubly defined statement numbers. |
| S | Argument/subscript error | Missing argument or subscript, illegal use of subscripts, illegal construction of subscripted variable, more than 3 subscripts or stated number of subscripts does not agree with declared number. |
| F | FORMAT statement error | Illegal FORMAT specification or illegal construction of FORMAT statement. |
| I | Character/statement/ term error | Illegal character, unrecognizable statement, illegal statement for program type, statement out of order or improper statement preceding END statement. |
| D | DO loop error | Illegal DO construction or illegal statement terminating DO LOOP. |
| T | Table overflow | Symbol/constant/arg (I)/OP(I) table limits exceeded. |
| L | Nesting error | Illegal nesting or DO nesting too deep. |
| M | Magnitude error | Program exceeds 8190 words, maximum number of dummy arguments or EQUIVALENCE classes exceeded, or constant/variable exceeds specified limits. |
| C | COMMON/EQUIVALENCE/ DIMENSION/DATA statement error | Illegal construction of statement, illegal EQUIVALENCE relationships, illegal COMMON declaration or non-common storage declared in BLOCK DATA subprogram. |
| E | FUNCTION/SUBROUTINE/ EXTERNAL/CALL statement error | Illegal use of FUNCTION/SUBROUTINE name, out of order, or illegal variable for EXTERNAL declaration. |
| H | Hollerith error | Hollerith data illegal in this statement or illegal of Hollerith constant. |

# APPENDIX 5A
# FORTRAN IV ERROR LIST

This list of error messages applies of all versions of F4 prior of V2A.

| Error Code | Cause |
|---|---|
| 001 | Improper statement preceding END statement. |
| 002 | FUNCTION/SUBROUTINE name not used or used improperly in a subprogram. |
| 003 | Variable required. |
| 004 | Positive non-zero constant required. |
| 005 | Symbol-constant table limits exceeded. |
| 006 | Statement number has more than 5 digits. |
| 007 | Unsigned simple integer argument required. |
| 008 | Integer value greater than ($2^{17}$ -1). |
| 009 | Magnitude of number (ignoring decimal point and/or exponent) greater than ($2^{35}$ - 1). |
| 010 | Array element (function reference) and next argument not separated by comma. |
| 012 | Exponent missing from numeric field. |
| 014 | Open parenthesis in subscript. |
| 015 | Binary operator used in unary sense or missing argument. |
| 016 | Additional grouping parenthesis not allowed. |
| 017 | Subscript list terminated before last argument obtained. |
| 018 | Too many right parenthesis. |
| 019 | Argument follows converted argument (no operator separating them). |
| 021 | E or D in numeric field after exponent has been processed. |
| 023 | Format descriptor character used in non-format statement. |
| 024 | Hollerith data illegal this statement. |
| 025 | Non-integer constant precedes Hollerith constant. |
| 026 | Length of Hollerith constant exceeds range ($0<x<6$). |
| 027 | Hollerith constant contains statement termination character. |
| 030 | Symbolic name exceeds 6 characters. |
| 031 | Limit on number of nested functions exceeded. |
| 032 | Simple variable delineated by left parenthesis. |
| 033 | Subscripted variable used as subscript. |
| 034 | Unrecognizable logic term. |
| 036 | Logical .NOT. used as binary operator or logical constant used as a binary operator. |
| 037 | Illegal character. |

| Error Code | Cause |
|---|---|
| 040 | Adjusted floating point exponent exceeds 76. |
| 045 | Subscript expression not delimited by "," or ")". |
| 050 | Arg (I), op (I) table overflow. |
| 051 | Unsubscripted array reference used as a variable. |
| 052 | Function name used as a variable. |
| 053 | Comma used other than as parameter separator. |
| 054 | Function or array name used in an expression representing a function parameter. |
| 055 | Expression used as an assignment variable. |
| 056 | Expression contains uneven number of parenthesis. |
| 060 | Illegal mode mixing. |
| 063 | Signed assignment variable. |
| 069 | Doubly defined statement numbers or phase error. |
| 070 | Illegal statement for BLOCK DATA program. |
| 071 | Statement not a DO or DO illegal as True statement for logical IF. |
| 072 | Illegal logical IF true statement. |
| 074 | Unrecognizable statement (first 3 characters). |
| 075 | Unrecognizable statement (4-n characters). |
| 076 | Statement out of order. |
| 077 | Statement shouldn't be labeled. |
| 078 | First character following READ or WRITE not a left parenthesis. |
| 079 | Illegal format specification in READ or WRITE. |
| 080 | Binary WRITE has no list. |
| 081 | Illegal list element separator. |
| 082 | Illegal implied DO construction. |
| 086 | DO nesting too deep. |
| 087 | Missing DO parameter. |
| 088 | Illegal DO parameter construction. |
| 089 | Illegal statement type terminated DO. |
| 090 | Improper DO nesting. |
| 091 | Illegal character following I/O unit specification. |
| 092 | Illegal character following FORMAT specification. |
| 095 | Name previously appeared in a specification statement. |
| 096 | Statement improperly delimited. |
| 097 | Illegal array declaration - DIMENSION statement. |

| Error Code | Cause |
|---|---|
| 098 | Array size greater than 78192 - DATA specification statement. |
| 100 | Improper subscript list delimiter in a DIMENSION statement. |
| 101 | More than 3 subscripts (dimensions). |
| 102 | Integer argument not a constant. |
| 103 | Integer constant not less than 8192. |
| 104 | Integer constant negative. |
| 105 | FORMAT statement has no statement number. |
| 106 | Illegal FORMAT specification. |
| 114 | COMMON block name has illegal delimiter (not /). |
| 115 | Name declared as COMMON Block name previously declared otherwise. |
| 116 | COMMON block size exceeds 8190 words. |
| 117 | Declared COMMON variable is a dummy, function, or already in COMMON. |
| 118 | ASSIGN statement missing "TO". |
| 120 | Computed GOTO statement number list members not delimited. |
| 121 | Computed GOTO statement number list not delimited. |
| 123 | Assigned GOTO statement number list no preceded by left parenthesis. |
| 124 | Assigned GOTO statement number list not delimited. |
| 126 | DATA/EQUIVALENCE variable is a dummy variable. |
| 127 | DATA/EQUIVALENCE variable is a function name. |
| 128 | DATA/EQUIVALENCE simple variable subscripted by more than one number. |
| 129 | DATA/EQUIVALENCE array element greater than 8192. |
| 130 | Missing right or redundant left parenthesis in FORMAT statement. |
| 131 | Stated number of subscripts does not agree with declared number. |
| 132 | EQUIVALENCE class not started with left parenthesis. |
| 136 | EQUIVALENCE class improperly delimited (no right parenthesis). |
| 137 | Maximum number of EQUIVALENCE classes exceeded. |
| 138 | Illegal EQUIVALENCE relationships. |
| 139 | Illegal extension of common block caused by EQUIVALENCE relationship. |
| 140 | Illegal variable for EXTERNAL declaration. |
| 142 | Program size exceeds 8190 words. |
| 143 | Non-common storage declared in BLOCK DATA subroutine. |
| 144 | IF expression not terminated by closing parenthesis. |
| 145 | No comma separating statement numbers - IF statement. |
| 147 | No statement number where one is required. |

| Error Code | Cause |
|---|---|
| 148 | Referenced statement number does not appear as a statement label. |
| 149 | Illegal statement function name (used twice or is external). |
| 150 | Delimiter following statement function dummy argument list not "=". |
| 151 | Function statement out of order (or more than one). |
| 152 | FUNCTION name not followed by argument list. |
| 153 | Dummy variable previously declared as something else. |
| 154 | Dummy argument list not enclosed in parenthesis. |
| 155 | Maximum number of dummy arguments exceeded. |
| 156 | STOP/PAUSE statement constant contains a non-octal digit. |
| 157 | STOP/PAUSE statement constant contains too many digits. |
| 158 | DATA statement variable is "common" but data not "block data". |
| 159 | DATA statement is "block data" but variable is not "common". |
| 160 | DATA statement variables not delimited by a slash. |
| 161 | DATA statement argument not a constant. |
| 162 | Mode of variable and corresponding constant disagree in a DATA statement. |
| 163 | DATA statement constants not separated by a comma (may indicate more variables than constants). |
| 164 | Two successive asterisks used as operators in a DATA statement. |
| 165 | Constant preceding asterisk is not integer in a DATA statement. |
| 167 | More constants than variables in a DATA statement. |
| 168 | RETURN statement in main-body program unit (not subroutine). |
| 169 | CALL statement - name is not a function name. |

# FORTRAN IV OBJECT - TIME SYSTEM

## INTRODUCTION

Part II describes the subprograms included in the PDP-9 FORTRAN IV Object Time System. The Object Time System is a group of subprograms that process compiled FORTRAN IV statements, particularly I/O statements, at execution time. The compiler outputs calls in the form of globals to various subprograms, depending upon the content of the FORTRAN program. When the compiled program is loaded via the Linking Loader, the Loader attempts to satisfy these globals by searching the FORTRAN library. As it finds the required object time subprograms, it brings them into core and sets up the necessary linkages.

Included in the package are programs for processing formatted and unformatted READ and WRITE statements, BACKSPACE, REWIND and ENDFILE statements, the index of computed GO TO statements, STOP and PAUSE statements, and File commands. There are eight error messages output by the object time system which are described in Table II-1.

The following information is given for each program:

a. Class
b. Purpose
c. Calling sequence
d. External calls
e. Size
f. Error conditions

Table II-1.
OTS Errors

| Error Number | Error Description | Library Routines* That May Cause Error |
|---|---|---|
| ØØ-Ø4 | Not used | |
| Ø5 | Negative REAL Square Root Argument | SQRT |
| Ø6 | Negative DOUBLE PRECISION Square Root Argument | DSQRT |
| Ø7 | Illegal Index in Computed GO TO | .GO |
| 1Ø | Illegal I/O Device Number | .FR,.FW,.FS,.FX,<br>.FR,.FA,.FE,.FF,.FS, |
| 11 | Bad input data - IOPS Mode Incorrect | .FR,.FA,.FE,.FF,.FS, |
| 12 | Bad FORMAT | .FA,.FE,.FF |
| 13 | Negative or Zero REAL Logarithmic Argument | .BC,.BE,ALOG |
| 14 | Negative or Zero DOUBLE PRECISION Logarithmic Argument | .BD,.BF,.BG,.BH,<br>DLOG,DLOG1Ø |

*Only those routines whose calls are generated by the compiler are listed.

## BCDIO

1. Class: Object - Time System

2. Purpose: The BCD input/output object-time package is designed to process the formatted READ and WRITE statements in FORTRAN IV programs and subprograms. The FORTRAN IV compiler generates all the necessary object-time subroutine calls to perform input and output operations on a character-to-character basis under the control of a FORMAT statement. To permit FORMAT statements to be altered or read at execution time, the FORMAT statements are interpreted by BCDIO at execution time rather than at compile-time. This has two advantages:

   1) It provides a greater flexibility to the FORTRAN programmer,

   2) It provides the ability to utilize fully the capabilities of BCDIO in machine-language programs.

   In demonstrating this capability, an illustrative MACRO-9 language program is given below, which reads 8 floating point numbers into memory with F-conversion and writes them on an output device using the E-conversion.

   Example:

```
         .TITLE
         .GLOBL    .FP,.FR,.FE,.EE,.FW
         .IODEV    3,4
ENTRY    JMS*      .FP        /Initialize I/O device status table.
         JMS*      .FR        /Initialize device 3 for input
         .DSA      (3)        /under control of FORMAT statement
         .DSA      FRMT1      /FRMT1 and read first record into line
                              /buffer.
         LAW       -1Ø        /Set loop counter to 8.
         DAC       COUNT
         LAC       (ARRAY)    /Set element address to first word
         DAC       ARG1       /in the array.

LOOP1    JMS*      .FE        /Convert next line buffer field from
ARG1     Ø                    /BCD to floating point binary and
                              /store in ARRAY.
         ISZ       ARG1       /Increment ARRAY address by two.
         ISZ       ARG1
         ISZ       COUNT      /Check the counter and
         JMP       LOOP1      /if not done, repeat loop.
         JMS*      .FF        /Otherwise, terminates reading.

         JMS*      .FW        /Initialize device 4 for output
         .DSA      (4)        /under control of FORMAT
         .DSA      FRMT2      /statement FRMT2.
         LAW       -1Ø        /Set loop counter to 8.
         DAC       COUNT
         LAC      (ARRAY)  /Set element address to first
         DAC      ARG2     /word in the array.
LOOP2    JMS*     .FE      /Convert floating-point binary word
ARG2     Ø                 /pair to BCD and store in line-buffer.
         ISZ      ARG2     /Increment ARRAY address by 2.
         ISZ      ARG2     /
         ISZ      COUNT    /Check count.
         JMP      LOOP2    /If not done, go to LOOP 2.
         JMS*     .FE      /if done, output last line-buffer
                           /and terminates writing.
         HLT
ARRAY    .BLOCK   2Ø
FRMT1    .ASCII   '(8F10.5)'
FRMT2    .ASCII   '(8E12.5)'
COUNT    Ø
         .END
```

3. Calling Sequences:

a. To initialize a device for BCD input (output):

```
JMS*     .FR (.FW)
.DSA     address of slot number.
.DSA     address of first word of FORMAT statement or array.
```

b. To input (output) a data element:

```
JMS*     .FE
.DSA     address of element (first word)
```

c. To input (output) an entire FORTRAN array:

```
JMS*     .FA
.DSA     address of last word in the Array Descriptor Block.
```

d. To terminate the current logical record:

```
JMS*     .FF
```

All BCDIO routines utilize the FIOPS object-time package to perform all I/O data transfers between devices and the FIOPS line buffer. Device level communication is never employed.

e. External Calls:

FIOPS, OTSER, REAL ARITHMETIC

f. Size: 2773 octal locations

g. Error Conditions:

OTS ERROR 1∅ - Illegal I/O Device Number
OTS ERROR 11 - Bad Input Data (IOPS Mode Incorrect)
OTS ERROR 12 - Illegal FORMAT

## BINIO

1. Class: Object - Time System

2. Purpose: The Binary Input/Output Object-Time package is designed to process the unformatted READ and WRITE statements in FORTRAN IV programs and subprograms. A FORMAT statement is not required and the data transfer is on a word-to-word basis instead of on character-to-character basis, regardless of data type.

The size of the physical data record is always the standard line buffer size provided by IOPS.

Logical data records are comprised of one or more physical records, the number of which is determined by the length of the I/O list associated with the WRITE statements that generates the logical record.

Each WRITE statement generates one logical record.

Each READ statement reads one logical record, regardless of the length of its I/O list. For this reason, it is the responsibility of the FORTRAN programmer to ensure that I/O lists for WRITE and READ statements are compatible.

3. Calling Sequences:

a. To initialize a device for binary input (output):

```
JMS*        .FS (.FW)
.DSA        DEVICE
```

b. To input (or output) an integer data element:

```
JMS*        .FI
.DSA        address of the element
```

c. To input (or output) an integer data element:

```
JMS*        .FJ
.DSA        address of the element (first word)
```

d. To input (or output) a double precision data element:

```
JMS*        .FK
.DSA        address of the element (first word)
```

e. To input (or output) a logical data element:

```
JMS*        .FL
.DSA        address of the element
```

f. To input (or output) an entire FORTRAN array:

```
JMS*        .FB
.DSA        address of the last word in the Array Descriptor Block.
```

g. To terminate the current logical record:

```
JMS*        .FG
```

The third word of each physical record contains a record of ID numbers starting with ZERO for the first record. Then ID is incremented by one as each physical record is generated until the last record in the logical record has bit Ø set.

A typical WRITE statement may generate the following record for ID:

```
            ØØØØØØ
            ØØØØØ1
LOGICAL     ØØØØØ2              PHYSICAL RECORD
RECORD      ØØØØØ3              FOR ID (OCTAL)
            ØØØØØ4
```

4. External Calls:

   FIOPS, OTSER

5. Size: 244 octal locations

6. Error Conditions:

   OTS ERROR 1Ø - Illegal I/O Device Number
   OTS ERROR 11 - Illegal Input Data (IOPS Mode Incorrect)

## AUXIO

1. Class: Object - Time System

2. Purpose: Auxiliary Input/Output consists of the processors for the three auxiliary I/O statements in FORTRAN IV: BACKSPACE, REWIND, and ENDFILE.

These statements are normally used to control Magnetic Tape Transports which are being used by unformatted READ and WRITE statements (BINIO).

1) BACKSPACE (.FT):

Repositions the tape at a point just prior to the first physical record associated with the current logical record.

Example:

```
WRITE (7) A,B,C
BACKSPACE (7)
READ (7) D,E,F
```

These three instructions as shown in the above order cause the data of A, B, and C to be transferred to D, E, and F.

2) REWIND (.FU)

Causes the specified device to be positioned at its initial (load) point.

3) ENDFILE (.FV)

Issues an IOPS command to close the current file on the specified device.

In the case of Magnetic Tape, this writes a file mark.

3. Calling Sequences:

a. To backspace one logical record:

```
JMS*     .FT
.DSA     DEVICE
```

b. To position a device at its initial point:

```
JMS*     .FU
.DSA     DEVICE
```

c. To end (close) a file:

```
JMS*     .FV
.DSA     DEVICE
```

4. External Calls:

FIOPS

5. Size: 64 octal locations

6. Error Conditions:

   OTS ERROR 1Ø - Illegal I/O Device Number

## FIOPS

1. Class: Object - Time System

2. Purpose: FIOPS provides the necessary calls to IOPS required by all FORTRAN input and output statements.

Slot numbers are initialized by the .FC routine (Initialize I/O Device). Initialization of all slots is maintained in the device status table. The first time that .FC is called for any device, the appropriate .INIT call is made to IOPS. The buffer size and input/output flag are stored in the status word table. Then all subsequent calls to .FC for the same device suppress another .INIT unless the input/output flag has changed.

One life buffer is used by all FORTRAN programs. Data transfers between the line buffer and I/O devices are performed by the .FQ routine, which performs a .READ if the input/output flag (.FH) is "ZERO" or a .WRITE if .FH is "ONE." A .WAIT is always performed.

The .FP routine is called at the beginning of all FORTRAN main programs. This routine sets all words in the device status table to zero, indicating that all devices are uninitialized.

3. Calling Sequences:

a. To initialize the I/O device status table:

```
JMS*         .FP
```

b. To specify input:

```
DZM*         .FH
```

c. To specify output:

```
LAC          (1)
DAC*         .FH
```

d. To select device:

```
LAC          DEVICE (address of slot number)
JMS*         .FC
```

e. To input or output the line buffer:

```
LAC          address of .DAT slot number (bits 9-17) and IOPS mode (bits 6-8)
JMS*         .FQ
```

f. Notes:

1) DEVICE is a cell containing the slot number.
2) The line buffer is in locations .FN to .FN+$377_8$.

3) The standard line buffer size (for the device currently selected) is in location .FM.
4) On output, IOPS header words (.FN and .FN + 1) must be prepared by the user.

4. External Calls:

OTSER

5. Size: 530 octal locations

6. Error Conditions:

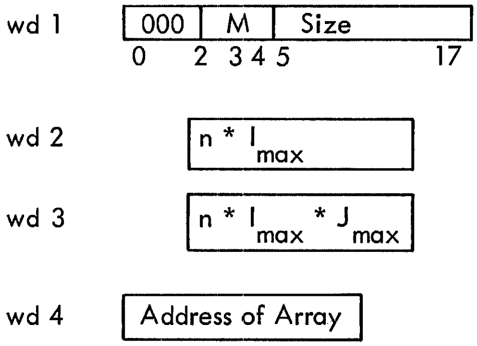
OTS ERROR 1Ø - Illegal I/O Device Number

OTS Calculate Array Element Address

## .SS

1. Class: Object - Time System

2. Purpose: To calculate the array element address. The Array Descriptor Block is constructed as follows:



M: data type - translates to number of words per array element (n)

| M | N | Type |
|---|---|---|
| 00 | 01 | integer |
| 01 | 02 | real |
| 10 | 03 | double precision |
| 11 | 01 | logical |

Subscript calculation formula (for declared A (I,J,K) and specified A (i,j,k) )

Addr of A (i,j,k) =

$$\underbrace{\underbrace{\underbrace{\underbrace{A}_{\text{wd 4}} + (i-1) * n}_{\text{1-dimension array}} + (j-1) * \underbrace{I * n}_{\text{wd 2}}}_{\text{2-dimension array}} + (k+1) * \underbrace{I * J * n}_{\text{wd 3}}}_{\text{3-dimension array}}$$

3. Calling Sequence:

```
JMS*     .SS
.DSA     ARRAY     /Address (indirect) of array
                   /Descriptor Block
LAC      S1        /Subscript 1 (I)
LAC      S2        /Subscript 2 (J)
LAC      S3        /Subscript 3 (K)
DAC                /Store array element address
```

4. External Calls:

   INTEGER and REAL ARITHMETIC

5. Size: 57 octal locations

6. Error Conditions:

   None.

## GOTO (.GO)

1. Class: Object - Time System

2. Purpose: To compute the index of a computed GO TO

3. Calling Sequence:

```
LAC             V            /Index value in A-register
JMS*            .GO
-N                           /Number of statement addresses
STMT ADDR (1)
STMT ADDR (2)
      .
      .
      .
STMT ADDR (N)
```

4. External Calls:

   OTSER

5. Size: 26 octal locations

6. Error Conditions:

   OTS ERROR 7 if the index is illegal (equal to or less than zero).

STOP (.ST)

1. Class: Object - Time System

2. Purpose: To process the STOP statement and return control to the monitor.

3. Calling Sequence:

```
LAC         (Octal number to be printed)
JMS*        .ST
```

4. External Calls:

   SPMSG (.SP)

5. Size: 13 octal locations

6. Error Conditions:

   None

PAUSE (.PA)

1. Class: Object - Time System

2. Purpose: To process the PAUSE statement. After receiving a ↑P (Control P) from the keyboard, control is returned to the program.

3. Calling Sequence:

```
LAC       (Octal number to be printed)
JMS*      .PA
```

4. External Calls:

   SPMSG (.SP)

5. Size: 14 octal locations

6. Error Conditions:

   None

SPMSG (.SP)

1. Class: Object - Time System

2. Purpose: To print the octal number coded with STOP and PAUSE. If no number is given, zero (Ø) is assumed.

3. Calling Sequence:

```
LAC      (Octal integer to be printed)
JMS*     .SP
.DSA     (Control return)  /pause only
LAC      1st Character
LAC      2nd Character
LAC      3rd Character
LAC      4th Character
LAC      5th Character
LAC      6th Character
```

4. External Calls:

   None

5. Size: 74 octal locations

6. Error Conditions:

   None

## OTSER (.ER)

1. Class: Object - Time System

2. Purpose:

   a. To announce an error on the teletype:

```
          JMS*          .ER
         .DSA           Error number
```

   b. If bit Ø of the error number is a 1, the error is recoverable and program control is returned to the calling program at the first location following the error number.

   c. If bit Ø of the error number is a Ø, the error is unrecoverable and program control is transferred to the monitor by means of the .EXIT function.

   d. In the case of recoverable errors, the AC and link are restored to their original contents prior to returning control to the caller.

   e. If the error is a bad format statement (unrecoverable), the current 5/7 ASCII word pair of the erroneous format statement is printed in addition to the error number.

3. Calling Sequence:

```
                JMS*          .ER
                .DSA          Error number,  octal
ERROR #12       LAC           Note word 1
  only          LAC           Note word 2
```

   Words 1 and 2 are the current 5 characters (in 5/7 ASCII of the bad format statement (ERROR #12)

4. External Calls:

   None

5. Size: 117 octal locations

6. Error Conditions:

   None

## FILE

1. Class: External Subroutine

2. Purpose: To provide the device-independent .IOPS commands SEEK, ENTER, and CLOSE. These commands are used to allow the FORTRAN IV Object Time System to communicate with .IOPS file-oriented devices.

   a. SEEK finds and opens a named input file.

   b. ENTER initiates and opens a named output file.

   c. CLOSE terminates an input or an output file and must be used if SEEK or ENTER has been used.

   NOTE

   BACKSPACE, REWIND, and ENDFILE commands should never be used with a device that is operating in the file-oriented mode using the above subroutines.

3. Calling Sequences:

   a. To seek a named file:

   ```
   CALL  SEEK  (N,A)
   ```

   where N = device number
   A = array name containing the 9-character 5/7 ASCII file name and extension.

   b. To enter a named file:

   ```
   CALL ENTER (N,A)
   ```

   where N and A are the same as for SEEK.

   c. To close a named file:

   ```
   CALL CLOSE (N)
   ```

   where N is the same as for SEEK.

4. External Calls:

   FIOPS, .DA, .SS.

5. Size: 174 octal locations

6. Error Conditions:

   OTS Error 10 if I/O device number is illegal.

# PDP-9 SCIENCE LIBRARY

## INTRODUCTION

All mathematical routines in the PDP-9 Science Library are described in Part III. Most of the descriptive material is listed in Table III-1; in cases where detailed calculations or algorithms are involved, a reference (Δ) is made in column 1 to detailed descriptions following the table. Information given in Table III-1 for each routine includes the routine name, mnemonic, calling sequence, function, mode, errors, accuracy and timing (where available), storage requirements, and external calls. Routines are categorized by Intrinsic Functions, External Functions, Sub-Functions, or part of the Arithmetic Package and are listed in the table accordingly.

### Intrinsic Functions

Intrinsic Functions are predefined subprograms that are part of the FORTRAN library. The type of each Intrinsic Function and its arguments is predefined and cannot be changed. Intrinsic Functions are referenced in a FORTRAN program by writing the function name along with the desired arguments in an appropriate FORTRAN statement.

Example:

```
        X = ABS (A)
```

### External Functions

External Functions are independently written programs that are executed each time their name appears in a FORTRAN program. Each External Function accepts one or more numerical arguments and computes a single result. SIN, COS, and ALOG are examples of external functions. All basic External Functions supplied with the FORTRAN system are described in Table III-1.

### Sub-Functions

Sub-Functions are called by Intrinsic and External Functions, but are not directly accessible to the user via FORTRAN. For example, the Sub-Function .EB is called by the External Function SIN, and performs the actual computation of the sine.

### The Arithmetic Package

The Arithmetic Package contains all arithmetic routines required for integer, real, and double precision arithmetic. Both EAE and non-EAE versions are available, depending upon the hardware.

## Accumulators

There are three accumulators referred to in the CALLING SEQUENCE column of the table. These include the A-register, the floating accumulator, and the held accumulator.

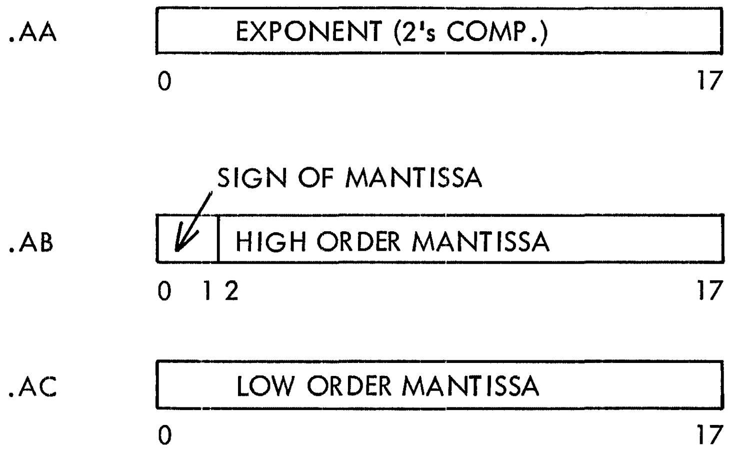
## A-Register

The A-register is the standard hardware accumulator and is used in some of the computations that involve integer values.

occasionally

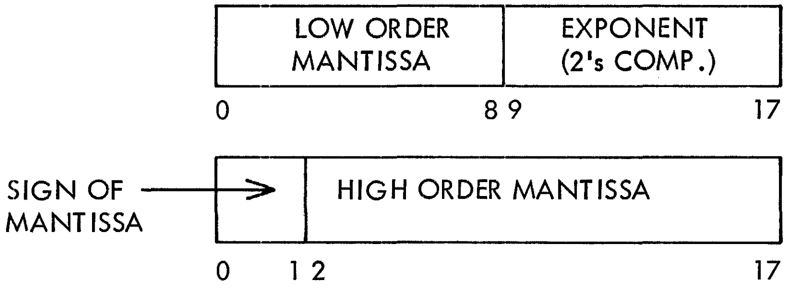
## Floating Accumulator

The floating accumulator is a software accumulator that is included in the REAL ARITHMETIC package. It is a 3-word accumulator, .AA being the label of the first word, .AB the second, and .AC the third. Numbers are stored in this accumulator in the following format:



Negative mantissae are indicated with a change of sign.

Used by both the single and double precision routines, this format is also that of double precision numbers. Single precision numbers have a different format and must be converted before and after use in the floating accumulator. The format of single precision numbers is:



## Held Accumulator

The held accumulator has the same format as the floating accumulator and is used as temporary storage by some routines. The labels of the three words are CE01, CE02, and CE03.

are not global
BUT = .CE-1, .CE-2, .CE-3

## Calling Sequences

The MACRO-9 calling sequences, given in the third column of Table 3-1, assume in some cases where there are two arguments, that the appropriate accumulator has been loaded with the first argument. If the first argument is an integer value, it can be loaded into the A-register with a LAC instruction. If the first argument is a real or double precision value, the routines .AG and .AO, respectively, should be used to load the floating accumulator. The DAC instruction may be used to store the result of routines that return with an integer value in the A-register. The routines .AH and .AP should be used to store the result of routines that return with real or double precision values in the floating accumulator.

In calling sequences that use the .DSA pseudo operation to define the symbolic address of arguments, 400000 must be added to the address field if indirect addressing is involved.

FORTRAN library routines that are used in MACRO-9 programs must be declared with a .GLOBL pseudo operation in the MACRO-9 program. There must be agreement in the number and type of arguments between the calling program and the FORTRAN library routine.

The following example shows a section of a MACRO-9 main program that uses the FORTRAN External Function SIN.

```
        .TITLE
        .GLOBL     SIN, .AH
           .
           .
           .
        JMS*       SIN
        JMP        .+2          /JUMP AROUND ARGUMENT
        .DSA       A            /+400000 IF INDIRECT
        JMS*       .AH          /STORE IN REAL FORMAT AT X
        .DSA       X
           .
           .
           .
X       .DSA       0
        .DSA       0
```

When the above MACRO-9 program is loaded, the Linking Loader will attempt to satisfy the globals by searching the Science Library. The External Function SIN and the REAL ARITHMETIC package will be loaded. The references to these routines in the MACRO-9 program must be indirect (as indicated in the example) since only the transfer vectors are given in the main program.

## Table III-1
## PDP-9 Science Library

| | | | | | | | Timing † | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ROUTINE NAME | Mnemonic | Calling Sequence | Function | Mode | Errors | Accur. Bits | Non-EAE | EAE | Storage (Octal) | External Calls |
| INTRINSIC FUNCTIONS | | | | | | | | | | |
| Exponentiation: | | | | | | | | | | |
| Integer Base, Integer Exponent | .BB | LAC ARG1 (base)<br>JMS* .BB<br>LAC ARG2 (exp) | I**K | I=I**I | None | N.A. | Note 1 | | 45 | INTEGER |
| Real Base, Integer Exponent | .BC | | A**K | R=R**I | #13, if base ≤0 | 26 | 23.2 ms | | 44 | .EE,.EF, REAL |
| DP Base, Integer Exponent | .BD | | A**K | D=D**I | #14, if base ≤0 | 32 | 27.8 ms | | 46 | .DE,.DF,DOUBLE |
| Real Base, Real Exponent | .BE | | A**B | R=R**R | #13, if base ≤0 | 26 | 23.0 ms | | 20 | .EE,.EF,REAL |
| Real Base, DP Exponent | .BF | JMS* SUBR<br>.DSA ADDR of ARG2 (exp.) | A**B | D=R**D | #13, if base ≤0 | 26 | 27.6 ms | | 21 | .EE,.DF,DOUBLE |
| DP Base, Real Exponent | .BG | | A**B | D=D**R | #14, if base ≤0 | 32 | 27.6 ms | | 22 | .DE,.DF,DOUBLE |
| DP Base, DP Exponent | .BH | | A**B | D=D**D | #14, if base ≤0 | 32 | 26.6 ms | | 21 | .DE,.DF,DOUBLE |
| Absolute Value: | | | | | | | | | | |
| Real Absolute Value | ABS | | \| A \| | R=ABS(R) | None | N.A. | 120 µs | | 16 | .DA,REAL |
| Integer Absolute Value | IABS | | \| I \| | I=IABS(I) | None | N.A. | 64 µs | | 14 | .DA |
| DP Absolute Value | DABS | JMS* SUBR<br>JMP .+2<br>.DSA ADDR of ARG | \| A \| | D=DABS(D) | None | N.A. | 120 µs | | 16 | .DA, DOUBLE |
| Truncation: | | | | | | | | | | |
| Real to Real Truncation | AINT | | Sign of A times largest integer ≤A | R=AINT(R) | None | N.A. | 365 µs | | 15 | .DA,REAL |
| Real to Integer Truncation | INT | | | I=INT(R) | None | N.A. | 180 µs | | 13 | .DA,REAL |
| DP to Integer Truncation | IDINT | | | I=IDINT(D) | None | N.A. | 180 µs | | 13 | .DA,REAL,DOUBLE |
| Remaindering: | | | | | | | | | | |
| Real Remaindering | AMOD | | Note 2 | R=AMOD(R,R) | None | N.A. | 3015 µs | | 27 | .DA,REAL |
| Integer Remaindering | MOD | | Note 2 | I=MOD(I, I) | None | N.A. | 477 µs | | 24 | .DA, INTEGER |
| DP Remaindering | DMOD | | Note 2 | D=DMOD(D, D) | None | N.A. | 3335 µs | | 30 | .DA, DOUBLE |
| Transfer of Sign: | | JMS* SUBR<br>JMP .+3<br>.DSA ADDR of ARG1<br>.DSA ADDR of ARG2 | | | | | | | | |
| Real Transfer of Sign | SIGN | | Sign of A1<br>↓<br>Sign of A2 | R=SIGN(R,R) | None | N.A. | 198 µs | | 26 | .DA,REAL |
| Integer Transfer of Sign | ISIGN | | | I=SIGN(I,I) | None | N.A. | 81 µs | | 20 | .DA |
| DP Transfer of Sign | DSIGN | | | D=SIGN(D,D) | None | N.A. | 192 µs | | 26 | .DA,DOUBLE |
| Positive Difference: | | | | | | | | | | |
| Real Positive Difference | DIM | | A1-MIN(A1,A2) | R=DIM(R,R) | None | N.A. | 794 µs | | 22 | .DA,REAL |
| Integer Positive Difference | IDIM | | I1-MIN(I1, I2) | I=IDIM(I, I) | None | N.A. | 85 µs | | 15 | .DA, INTEGER |
| Conversion: | | | | | | | | | | |
| Integer to Real Conversion | FLOAT | | A←I | R=FLOAT(I) | None | N.A. | 246 µs | | 11 | .DA,REAL |
| Real to Integer Conversion | IFIX | JMS* SUBR<br>JMP .+2<br>.DSA ADDR of ARG | I A | I=IFIX(R) | None | N.A. | 180 µs | | 13 | .DA,REAL |
| DP to Real Conversion | SNGL | | A←B | R=SNGL(D) | None | N.A. | 144 µs | | 27 | .DA,DOUBLE |
| Real to DP Conversion | DBLE | | A←B | D=DBLE(R) | None | N.A. | 115 µs | | 11 | .DA,REAL |

NOTES: † Timing indicated in this column is estimated unless indicated to be otherwise with a dagger (†). The dagger indicates actual, average-to-worst-case times based on arbitrarily chosen values.

1. Timing is dependent upon the size of the exponent, but is approximately equal to 335 µs times n, where n is the largest powe· of 2 in the exponent.
2. Remaindering is defined as A1 - [A1/A2] A2, where [A1/A2] is the integer whose magnitude does not exceed the magnitude of A1/A2 and whose sign is the same as A1/A2.

## Table III-1 (cont)
## PDP-9 Science Library

| ROUTINE NAME | Mnemonic | Calling Sequence | Function | Mode | Errors | Accur. Bits | Timing † |  | Storage (Octal) | External Calls |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  | Non-EAE | EAE |  |  |
| INTRINSIC FUNCTIONS (Cont) |  |  |  |  |  |  |  |  |  |  |
| Maximum/Minimum Value: |  |  |  |  |  |  |  |  |  |  |
| Integer Maximum/Minimum | IMNMX | JMS* MAX0,MIN0, AMAX0, or AMIN0<br>JMP .+n+1<br>.DSA ADDR of ARG1<br>.DSA ADDR of ARG2<br>: :<br>.DSA ADDR of ARGn |  |  |  |  |  |  | 106 | INTEGER, REAL |
| Integer to Integer Max. | MAX0 |  | Max. Value | I=MAX0(I1, . . . , In) | None | N.A. | Note 3 |  |  |  |
| Integer to Integer Min. | MIN0 |  | Min. Value | I=MIN0(I1, . . . , In) | None | N.A. | Note 3 |  |  |  |
| Integer to Real Max. | AMAX0 |  | Max. Value | R=AMAX0(I1,... In) | None | N.A. | Note 4 |  |  |  |
| Integer to Real Min. | AMIN0 |  | Min. Value | R=AMIN0(I1,... In) | None | N.A. | Note 4 |  |  |  |
| Real Maximum/Minimum | RMNMX | JMS* AMAX1,AMIN1, MAX1, or MIN2<br>JMP .+n+1<br>.DSA ADDR of ARG1<br>.DSA ADDR of ARG2<br>:<br>.DSA ADDR of ARGn |  |  |  |  |  |  | 117 | INTEGER, REAL |
| Real to Real Max | AMAX1 |  | Max. Value | R=AMAX1(R1, ...Rn) | None | N.A. | Note 5 |  |  |  |
| Real to Real Min. | AMIN1 |  | Min. Value | R=AMIN1(R1,...Rn) | None | N.A. | Note 5 |  |  |  |
| Real to Integer Max. | MAX1 |  | Max. Value | I=MAX1(R1, ...Rn) | None | N.A. | Note 6 |  |  |  |
| Real to Integer Min. | MIN1 |  | Min. Value | I=MIN1(R1,...Rn) | None | N.A. | Note 6 |  |  |  |
| DP Maximum/Minimum | DMNMX | JMS* DMAX1 or DMIN1<br>JMP .+n+1<br>.DSA ADDR of ARG1<br>: :<br>.DSA ADDR of ARGn |  |  |  |  |  |  | 105 | DOUBLE |
| DP Maximum | DMAX1 |  | Max. Value | D=DMAX1(D1,... Dn) | None | N.A. | Note 7 |  |  |  |
| DP Minimum | DMIN1 |  | Min. Value | D=DMIN1(D1,... Dn) | None | N.A. | Note 7 |  |  |  |
| EXTERNAL FUNCTIONS |  |  |  |  |  |  |  |  |  |  |
| Square Root: |  |  |  |  |  |  |  |  |  |  |
| Real Square Root △1 | SQRT | JMS* SUBR<br>JMP .+2<br>.DSA ADDR of ARG | $X^{1/2}$ | R=SQRT(R) | #5,ARG < 0 | 26 | †6.657ms | †3.584 ms | 66 | .DA,.ER,REAL |
| DP Square Root △1 | DSQRT |  | $X^{1/2}$ | D=DSQRT(D) | #6,ARG < 0 | 34 | †8.191 ms | †4.094 ms | 66 | .DA,.ER,DOUBLE |
| Exponential: |  |  |  |  |  |  |  |  |  |  |
| Real Exponential △2 | EXP |  | $e^X$ | R=EXP(R) | #13, ARG ≤0 | 26 | †15.489 ms | †4.672 ms | 13 | .DA,.EF,.ER,REAL |
| DP Exponential △2 | DEXP |  | $e^X$ | D=DEXP(D) | #14, ARG ≤0 | 34 | †17.664 ms | †7.223 ms | 13 | .DA,DF,.ER, DOUBLE |
| Natural Logarithm: |  |  |  |  |  |  |  |  |  |  |
| Real Natural Logarithm △3 | ALOG |  | $\text{Log}_e$ X | R=ALOG(R) | #13, ARG <0 | 26 | †8.197 ms | †4.092 ms | 20 | .DA,.EE,.ER,REAL |
| DP Natural Logarithm △3 | DLOG |  | $\text{Log}_e$ X | D=DLOG(D) | #14, ARG <0 | 32 | †15.489 ms | †4.095 ms | 21 | .DA,.DE,.ER, DOUBLE |
| Common Logarithm: |  |  |  |  |  |  |  |  |  |  |
| Real Common Logarithm △3 | ALOG10 |  | $\text{Log}_{10}$ X | R=ALOG10(R) | #13, ARG <0 | 26 | †8.197 ms | †4.094 ms | 20 | .DA,.EE,.ER,REAL |
| DP Common Logarithm △3 | DLOG10 |  | $\text{Log}_{10}$ X | D=DLOG10(D) | #14, ARG <0 | 32 | †11.7 ms |  | 21 | .DA,.DE,.ER, DOUBLE |
| Sine: |  |  |  |  |  |  |  |  |  |  |
| Real Sine △4 | SIN |  | Sin (X) | R=SIN(R) | None | 26 | †10.368 ms | †4.094 ms | 13 | .DA,.EB,REAL |
| DP Sine △4 | DSIN |  | Sin (X) | D=SIN(D) | None | 34 | †16.383 ms | †5.632 ms | 13 | .DA,DB,DOUBLE |
| Cosine: |  |  |  |  |  |  |  |  |  |  |
| Real Cosine △4 | COS |  | Cos (X) | R=COS(R) | None | 26 | †11.025 ms | †4.901 ms | 20 | .DA,.EB,REAL |
| DP Cosine △4 | DCOS |  | Cos (X) | D=COS(D) | None | 34 | †16.383 ms | †6.145 ms | 21 | .DA,.DB,DOUBLE |

NOTES:
3. 57 μs + 40 μs for each argument.
4. 242 μs + 40 μs for each argument.
5. 168 μs + 624 μs for each argument.
6. 233 μs + 624 μs for each argument.
7. 163 μs + 607 μs for each argument.

## Table III-1 (cont)
## PDP=9 Science Library

| ROUTINE NAME | Mnemonic | Calling Sequence | Function | Mode | Errors | Accur. (Bits) | Timing | | Storage (Octal) | External Calls |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Non-EAE | EAE | | |
| EXTERNAL FUNCTIONS (Cont) | | | | | | | | | | |
| Arctangent: | | | | | | | | | | |
| Real Arctangent [5] | ATAN | JMS* ATAN or DATAN<br>JMP<br>.DSA ADDR or ARG | $\tan^{-1}$ (a) | R=ATAN(2) | None | 26 | 16.352 ms | 5.632 ms | 13 | .DA, .ED, REAL |
| DP Arctangent [5] | DATAN | | $\tan^{-1}$ (a) | D=DATAN(D) | None | 34 | 14.6 ms | | 13 | .DA, .DD, DOUBLE |
| Real Arctangent (x/y) [5] | ATAN2 | JMS* ATAN2 or DATAN2<br>JMP .+3<br>.DSA ADDR of ARG1<br>.DSA ADDR of ARG2 | $\tan^{-1}$(x/y) | R=ATAN2(R, R) | None | 26 | 12.4 ms | | 17 | .DA, .ED, REAL |
| DP Arctangent (x/y) [5] | DATAN2 | | $\tan^{-1}$ (x/y) | D=DATAN2(D, D) | None | 34 | 16.2 ms | | 17 | .DA, .DD, DOUBLE |
| Hyperbolic Tangent [6] | TANH | JMS* TANH<br>JMP .+2<br>.DSA ADDR OF ARG | tanh (a) | R=TANH(R) | None | 26 | 16.383 ms | 7.233 ms | 47 | .DA, .EF, REAL |
| SUB-FUNCTIONS | | JMS* SUBR<br>NOTE<br>Enter with argument in floating accumulator. Returns with result in floating accumulator. | | | | | | | | |
| Sine Computation: | | | | | | | | | | |
| Real Sine [4] | .EB | | Sin (a) | R=.EB(R) | None | 19 | 9.3 ms | | 100 | .EC, .REAL |
| DP Sine [4] | .DB | | Sin (a) | D=.DB(D) | None | 28 | 10.8 ms | | 116 | .DC, .DOUBLE |
| Arctangent Computation: | | | | | | | | | | |
| Real Arctangent [5] | .ED | | $\tan^{-1}$ (a) | R=.ED(R) | None | 26 | 11.0 ms | | 65 | .EC, .REAL |
| DP Arctangent [5] | .DD | | $\tan^{-1}$ (a) | D=.DD(D) | None | 34 | 14.5 ms | | 144 | .DC, .DOUBLE |
| Logarithm (Base 2) Computation: | | | | | | | | | | |
| Real Log [7] | .EE | | $\log_2$ a | R=.EE(R) | #13, ARG ≤ 0 | 26 | 9.0 ms | | 71 | .ER, .REAL |
| DP Log | | | $\log_2$ a | D=.DE(D) | #14, ARG ≤ 0 | 32 | 10.7 ms | | 101 | .ER, .DOUBLE |
| Exponential Computation: | | | | | | | | | | |
| Real Exponential [2] | .EF | | $e^X$ | R=.EF(R) | None | 26 | 12.2 ms | | 116 | REAL |
| DP Exponential [2] | .DF | | $e^X$ | D=.DF(D) | None | 34 | 15.0 ms | | 137 | DOUBLE |
| Polynomial Evaluation: | | JMS* .EC or .DC<br>CAL PLIST<br>: :<br>PLIST -N /-No. of terms +1<br>$C_n$ /last term<br>$C_{n-1}$ /next to last<br>:<br>$C_1$ /2nd term<br>$C_0$ /1st term | | | | | | | | |
| Real Polynomial Evaluation [8] | .EC | | $x= \sum_{i=0}^{n} C_{2i+1} Z^{2i+1}$ | R=.EC($R_2$, $R_1$, ... $R_n$) | None | N.A. | Note 8 | | 44 | REAL |
| DP Polynomial Evaluation [8] | .DC | | $x= \sum_{i=0}^{n} C_{2i+1} Z^{2i+1}$ | D=.DC($D_2$, $D_1$, ... $D_n$) | None | N.A. | Note 8 | | 47 | DOUBLE |

NOTES: 8. 2.0 ms + 1.3 ms for each coefficient.

## Table III-1 (cont)
## PDP-9 Science Library

| ROUTINE NAME | Mnemonic | Calling Sequence | | | Function | Mode | Errors | Accur. Bits | Timing† | | Storage (Octal) | External Calls |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Non-EAE | EAE | | |
| SUB-FUNCTIONS (Cont) | | | | | | | | | | | | |
| General Get Argument | .DA | Routine that calls Calling Routine<br>JMS* SUBR<br>JMP .+n+1<br>.DSA ARG1<br>.DSA ARG2<br>⋮ ⋮<br>DSA ARGn | Calling Routine<br>SUBR CAL 0<br>JMS* .DA<br>JMP .+n+1<br>(address of ARG1)<br>(address of ARG2)<br>⋮<br>(address of ARGn) | | N.A. | N.A. | None | N.A. | Note 9 | | 46 | None |
| ARITHMETIC PACKAGE | | | | | | | | | | | | |
| Integer Arithmetic: | INTEGE | ARG1<br>A-Register | ARG2 | | | | | | | | Note 11 | |
| Multiplication | .AD | Multiplicand | Multiplier | | I*J | I=I*I | None | | †281 µs | † 48 µs | | |
| Division | .AE | Dividend | Divisor | | I/J | I=I/I | None | | †352 µs | † 55 µs | | |
| Reverse Division | .AF | Divisor | Dividend | JMS* SUBR | J/I | I=I/I | None | | | | | |
| Subtraction | .AY | Minuend | Subtrahend | LAC ARG2 | I-J | I=I-I | None | | | | | |
| Reverse Subtraction | .AZ | Subtrahend | Minuend | | J-I | I=I-I | None | | | | | |
| Double Precision Arithmetic: | DOUBLE | ARG1<br>FL.ACC. | ARG2 | | | | | | | | 142 | REAL |
| Load | .AO | | Address | | N.A. | D=.AO(D) | None | N.A. | †70 µs | | | |
| Store | .AP | Value | Address | | N.A. | D=.AP(D) | None | N.A. | †72 µs | | | |
| Add | .AQ | Augend | Addend | | A+B | D=D-D | None | | †255 µs | | | |
| Subtract | .AR | Minuend | Subtrahend | JMS* SUBR<br>.DSA ARG2 | A-B | D=D-D | None | | † 324 µs | | | |
| Reverse Subtract | .AU | Subtrahend | Minuend | | B-A | D=D-D | None | | | | | |
| Multiply | .AS | Multiplicand | Multiplier | | A*B | D=D*D | None | | †1.937 ms | † 264 µs | | |
| Divide | .AT | Dividend | Divisor | | A/B | D=D/D | None | | †1.327 ms | † 324 µs | | |
| Reverse Divide | .AV | Divisor | Dividend | | B/A | D=D/D | None | | | | | |
| Real Arithmetic (Includes Floating): | REAL | ARG1<br>FL.ACC. | ARG2 | | | | | | | | Note 12 | |
| Load | .AG | | Address | | N.A. | R=.AG(R) | None | N.A. | † 67 µs | | | |
| Store | .AH | Value | Address | | N.A. | R=.AH(R) | None | N.A. | † 70 µs | | | |
| Add | .AI | Augend | Addend | | A+B | R=R+R | None | | †280 µs | | | |
| Subtract | .AJ | Minuend | Subtrahend | JMS* SUBR<br>.DSA ARG2 | A-B | R=R-R | None | | †385 µs | | | |
| Reverse Subtract | .AM | Subtrahend | Minuend | | B-A | R=R-R | None | | | | | |
| Multiply | .AK | Multiplicand | Multiplier | | A*B | R=R*R | None | | †2.047 ms | † 272 µs | | |
| Divide | .AL | Dividend | Divisor | | A/B | R=R/R | None | | †1.537 ms | † 352 µs | | |
| Reverse Divide | .AN | Divisor | Dividend | | B/A | R=R/R | None | | | | | |

NOTES: 9. 37 µs + 15 µs for each argument.

10. The sign of the result (the exclusive OR of the sign bits of .AB and CE02) is stored in .CE. The sign of .AB is saved in CE05.

11. $130_8$ for EAE, $164_8$ for non EAE.

12. $764_8$ for EAE, 733 for non EAE.

## Table III-1 (cont)
## PDP-9 Science Library

| | Mnemonic | Calling Sequence | | | Function | Mode | Errors | Accur. Bits | Timing | | Storage (Octal) | External Calls |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Non-EAE | EAE | | |
| ARITHMETIC PACKAGE (Cont) | | | | | | | | | | | | |
| Floating Arithmetic | | A-Register | FL.ACC. | | | | | | | | | |
| Float | .AW | Integer | F.P. No. | JMS* SUBR | A← I | R=.AW(I) | None | N.A. | 185 µs | | | |
| Fix | .AX | | F.P. No. | | I ←A | I=.AX(R) | None | N.A. | 65 µs | | | |
| Negate | .BA | | | | A← -A | R=.BA(R) | None | N.A. | 10 µs | | | |
| | | FL.ACC. | HELD ACC. | | | | | | | | | |
| Multiply | .CA | Multiplicand | Multiplier | | A*B | R=R*R | None | | 774 µs (avg) | | | |
| Divide | .CI | Divisor | Dividend | | A/B | R=R/R | None | | 1124 µs (real)<br>1444 µs (DP) | | | |
| Add | .CC | Augend | Addend | JMS* SUBR | A+B | R=R+R | None | | 300 µs (avg) | | | |
| Normalize | .CD | Value | | | N.A. | R=.CD(R) | None | N.A. | 160 µs (avg) | | | |
| Hold | .CF | Value | | | N.A. | R=.CF(R) | None | N.A. | 16 µs | | | |
| Round & Sign | .CH | Value | | | N.A. | R=.CH(R) | None | N.A. | 30 µs | | | |
| Sign Control | .CG | Value | Value | | Note 10 | R=.CG(R) | None | N.A. | 30 µs | | | |
| Short Get Argument | .CB | CAL 0<br>JMS* .CB<br>CAL 0<br>.DSA 0 | | | N.A. | R=.CB(R) | None | N.A. | 28 µs | | | |

# PDP-9 SCIENCE LIBRARY ALGORITHM DESCRIPTIONS

## 1. SQUARE ROOT (SQRT, DSQRT)

A first-guess approximation of the square root of the argument is obtained as follows.

If the exponent (EXP) of the argument is odd:

$$P_0 = .5^{\left(\frac{EXP-1}{2}\right)} + ARG^{\left(\frac{EXP-1}{2}\right)}$$

If the exponent (EXP) of the argument is even:

$$P_0 = .5^{\left(\frac{EXP}{2}\right)} + ARG^{\left(\frac{EXP}{2} -1\right)}$$

Newton's iterative approximation is then applied three times.

$$P_{i+1} = \frac{1}{2} \left(\pi + \frac{ARG}{\pi}\right)$$

buncha damn morons!

$$P_{i+1} = \frac{1}{2} \left(P_i + \frac{ARG}{P_i}\right)$$

## 2. EXPONENTIAL (EXP, DEXP, .EF, .DF)

$e^x$ is calculated as

THIS $= e^x$

$$\left(2^{x \log_2 e}\right)\left(x \log_2 e\right)$$

WHAT'S THIS ?

and will have an integral portion (I) and a fractional portion (F). Then

$$e^x = (2^I)(2^F)$$

where $2^F = \left(\sum_{i-0}^{n} C_i F^i\right)^2$ and $n = 6$.

The values of C are:

$C_0 = 1.0$

$C_1 = 0.34657359$

$C_2 = 0.06005663$

$C_3 = 0.00693801$

$C_4 = 0.00060113$

$C_5 = 0.00004167$

$C_6 = 0.00000241$

## 3. NATURAL AND COMMON LOGARITHMS (ALOG, ALOG10, DLOG, DLOG10)

The exponent of the argument is saved as one greater than the integral portion of the result. The fractional portion of the argument is considered to be a number between 1 and 2. Z is computed as follows.

$$Z = \frac{X - \sqrt{2}}{X + \sqrt{2}}$$

Then $$\log_2 X = \frac{1}{2} + \left( \sum_{i=0}^{n} C_{2i+1} Z^{2i+1} \right)$$

where n = 2 for ALOG, and n = 3 for DLOG. The values of C are as follows.

| ALOG & ALOG10 | DLOG & DLOG10 |
|---|---|
| $C_1$ = 2.8853913 | $C_1$ = 2.8853900 |
| $C_3$ = 0.96147063 | $C_3$ = 0.96180076 |
| $C_5$ = 0.59897865 | $C_5$ = 0.57658434 |
| | $C_7$ = 0.43425975 |

Finally,

$$\log_e X = (\log_2 X)(\log_e 2), \text{ for ALOG \& DLOG}$$

and

$$\log_{10} X = (\log_2 X)(\log_{10} 2), \text{ for ALOG10 \& DLOG10.}$$

## 4. SINE AND COSINE (SIN, COS, DSIN, DCOS, .EB, .DB)

The argument is converted to quarter circles by multiplying by $2/\pi$. The low two bits of the integral portion determine the quadrant of the argument and produce a modified value of the fractional portion (Z) as follows.

| Low 2 Bits | Quadrant | Modified Value (Z) |
|---|---|---|
| 00 | I | F |
| 01 | II | 1-F |
| 10 | III | -F |
| 11 | IV | -(1-F) |

Z is then applied to the following polynomial expression.

$$\sin X = \left( \sum_{i=0}^{n} C_{2i+1} Z^{2i+1} \right)$$

where n=4 for REAL routines and n=6 for DP routines. The values of C are as follows.

| REAL ROUTINES | DP ROUTINES |
|---|---|
| $C_1 = 1.570796318$ | $C_1 = 1.5707932680$ |
| $C_3 = -0.6459637111$ | $C_3 = -0.6459640975$ |
| $C_5 = 0.7968967928$ | $C_5 = 0.06969262601$ |
| $C_7 = -0.00467376557$ | $C_7 = -0.004681752998$ |
| $C_9 = 0.00015148419$ | $C_9 = 0.00016043839964$ |
| | $C_{11} = -0.000003595184353$ |
| | $C_{13} = 0.00000005446285$ |

The argument for COS and DCOS routines is adjusted by adding $\pi/2$. The sin subfunction is then used to compute the cosine according to the following relationship:

$$\cos x = \sin \left(\frac{\pi}{2} + x\right)$$

5. ARCTANGENT (ATAN, DATAN, ATAN2, DATAN2, .ED, .DD)

For X less than or equal to 1, Z = X, and:

$$\text{arctangent } X = \left( \sum_{i=0}^{n} C_{2i+1} \; Z^{2i+1} \right)$$

where n = 8 for REAL routines and n = 3 for DP routines. For X greater than 1, Z = 1/X, and:

$$\text{arctangent } X = \frac{\pi}{2} - \left( \sum_{i=0}^{n} C_{2i+1} \; Z^{2i+1} \right)$$

where n = 8 for REAL routines and n = 3 for DP routines. The values of C are as follows.

| REAL ROUTINES | DP ROUTINES |
|---|---|
| $C_1 = 1.570796327$ | $C_1 = 0.9992150$ |
| $C_3 = 0.9999993329$ | $C_3 = -0.3211819$ |
| $C_5 = -0.3332985605$ | $C_5 = 0.1462766$ |
| $C_7 = 0.1994653599$ | $C_7 = -0.0389929$ |
| $C_9 = -0.1390853351$ | |
| $C_{11} = 0.0964200441$ | |
| $C_{13} = -0.0559098861$ | |
| $C_{15} = 0.0218612288$ | |
| $C_{17} = -0.0040540580$ | |

## 6. HYPERBOLIC TANGENT (TANH)

$$\tanh |X| = \left(1 - \frac{2}{1+e^{2|X|}}\right)$$

$e^X$, calculated as $\left(2^{X \log_2 e} \quad X \log_2 e\right)$ will have an integral portion (I) and a fractional portion (F), then:

$$e^X = (2^I)\ (2^F)$$

where

$$2^F = \left(\sum_{i=0}^{n} C_i F^i\right)^2 \quad \text{and } n = 6$$

The values of C are as follows.

$$\begin{aligned}
C_1 &= 1.0 \\
C_2 &= 0.34657359 \\
C_3 &= 0.06005663 \\
C_4 &= 0.00693801 \\
C_5 &= 0.00060113 \\
C_6 &= 0.00004167 \\
C_7 &= 0.00000241
\end{aligned}$$

## 7. LOGARITHM, BASE 2 (.EE,.DE)

The exponent of the argument is saved as one greater than the integer portion of the result. The fractional portion of the argument is considered to be a number between 1 and 2. Z is computed as follows.

$$Z = \frac{X - \sqrt{2}}{X + \sqrt{2}}$$

Then

$$\log_2 X = \frac{1}{2} + \left(\sum_{i=0}^{n} C_{2i+1} Z^{2i+1}\right)$$

where n = 2 for .EE and n = 3 for .DE. The values of C are as follows.

| .EE | .DE |
|---|---|
| $C_1 = 2.8853913$ | $C_1 = 2.8853900$ |
| $C_3 = 0.96147063$ | $C_3 = 0.96180076$ |
| $C_5 = 0.59897865$ | $C_5 = 0.57658434$ |
| | $C_7 = 0.43425975$ |

## 8. POLYNOMIAL EVALUATOR (.EC, .DC)

The polynomial is evaluated as follows.

$$X = Z\,(C_0 + Z^2\,(C_1\ \ldots\ + Z^2\,(C_n Z^2 + C_{n-1})\,)\,)$$