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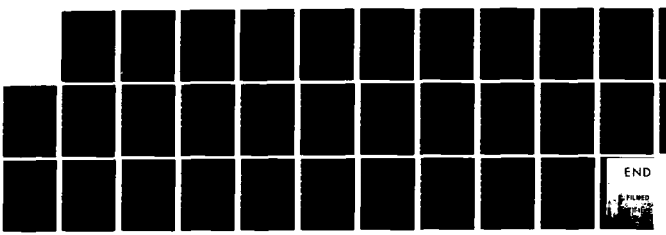

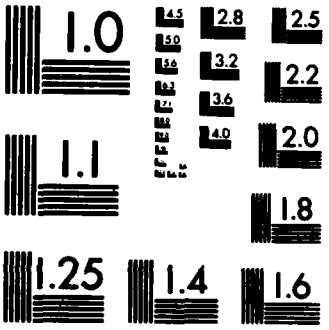

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FPP1, A FLOATING POINT PACKAGE FOR PDP-8 COMPUTERS

CHRISTOPHER B. WALKER
METALS RESEARCH DIVISION

August 1983

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report describes a 23-bit floating point package for PDP-8 computers developed from the DEC YQ4B package that retains most of the capabilities of YQ4B while requiring only 1101 words storage.

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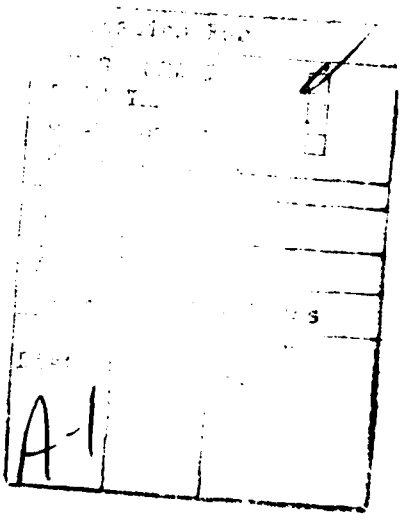

INTRODUCTION

The AMMRC floating point (FP) package, FPP1, for PDP-8 computers was developed from the Digital Equipment Corporation (DEC) package, YQ4B (4/70), with the primary aim of reducing its size, so that an adequate calculation and control software package could be fit into the 4K memory of a PDP-8 that was used to control an X-ray diffractometer in a wide variety of experiments in the AMMRC program of materials research. It should be particularly useful for systems with memory size limitations, as in the older PDP-8's or as part of an arithmetic package committed to ROM in modern units. It follows essentially the same approach and basic procedures as YQ4B, the major changes being the exclusion of E-format input and output (I/O) and the use of a different square-root algorithm, and it retains the same accuracy, generally six decimal digits in normal computations. It has the same mnemonic and numerical codes for the basic FP instructions and function subroutines and many of the same page 0 locations and address tags as the DEC package, so it should be compatible with minimal changes with many programs using a 4K memory. The linkages for multiple-field operations are left to those users to supply.

FPP1 includes all the operations of YQ4B, excluding E-format I/O, plus two-word fix and float routines and an improved output roundoff. It occupies locations 0007, 0015, 0040 through 0064, and 5512 through 7577, for a total of 1101 words, 26% less than the 1492 words of YQ4B, the saving being approximately 10% of a 4K memory. It is not easily relocatable; a number of subroutines, constants, and storage registers are positioned so that their indirect addresses occur as regular program words (e.g., JMP I XXX) to reduce storage requirements. Its data I/O to the outside world is handled by two subroutines, READIN and TYPOUT, coded here for a teletype (TTY).

FPP1 is a package of 41 subroutines, ranging from simple register shifts to function series expansions involving other subroutines including the FP system itself, which allows the user to program mathematical computations in FP arithmetic through a set of simple block instructions, each of which calls up the detailed programming necessary for that complete operation. We shall first outline the general features of the package and discuss how to use it. At the end we add a few general comments and give a complete PAL III pass 3 listing of the assembled package for those interested in the programming details.

GENERAL

In the FPP1/YQ4B convention a normalized FP number has the form,

$$X = \text{Mantissa} \cdot 2^{\text{Exponent}} ,$$

where the Mantissa, a signed fraction with $0.5 \leq |\text{Mantissa}| < 1.0$, is specified in two words by a sign and 23 significant binary bits, and the Exponent, a signed binary integer with $|\text{Exponent}| < 2048$, is specified in two's-complement form in one word. It is stored as three consecutive words: the Exponent, then the high-order (more significant) and the low-order Mantissa words. The Exponent address serves as the address of that FP number.

To work with these three-word FP numbers, FPP1/YQ4B uses a three-word 'pseudo' floating accumulator (FAC), consisting of locations 0044, 0045, and 0046, labelled EXP, HORD, and LORD, respectively. To maintain accuracy, some operations include at intermediate stages a third word for still lower order Mantissa bits 24 thru 35; that third Mantissa word for FAC is location 0047, labelled OVER2.

FP operations generally involve doing something to or with FAC. (A reference to manipulation of a register or address simply means a manipulation of its contents.) When the operation involves another FP quantity, e.g., adding Y to FAC, that quantity is first brought to the operand register (OP), and then the operation is carried out between OP and FAC. The OP consists of locations 0040, 0041, and 0042, labelled EX1, AC1H, and AC1L, respectively, with a third word available for OP Mantissa bits 24 through 35 at location 0043, labelled OVER1.

To carry out FP operations at some point in a program, the first step is a jump to the FP Interpreter subroutine. Each succeeding word in the program is then interpreted as a FP instruction, and this mode continues until the FP Exit instruction is reached, which returns the computer to normal interpretation/operation at the next program word.

The FP Interpreter subroutine begins at location 7000. That address is stored at location 0007, so the usual jump entry to the Interpreter is obtained by the instruction: JMS I 0007 . Entrance to the FP mode clears the computer AC, but it does not affect FAC.

FP INSTRUCTIONS

There are seven FP instructions that carry out the basic add/subtract/multiply/divide/get/put/normalize operations. They are written in the usual PDP-8 memory reference instruction format: bits 0, 1, and 2 contain a non-zero operation code, and the remaining bits specify the relevant address in the standard manner (bit 3 for indirect address, bit 4 for current page vs page 0, and bits 5 through 11 for the page address). These basic FP instructions, referencing an address Y, are:

Mnemonic	Op Code	Operation
FADD Y	1	Y is added to FAC, and the result left in FAC.
FSUB Y	2	Y is subtracted from FAC, and the result left in FAC.
FMPY Y	3	FAC is multiplied by Y, and the result left in FAC.
FDIV Y	4	FAC is divided by Y, and the result left in FAC.
FGET Y	5	Y is loaded into FAC.
FPUT Y	6	FAC is stored in Y.
FNOR	7	FAC is adjusted to normalized FP form.

Operations 1 through 5 leave Y unchanged, and operation 6 leaves FAC unchanged. Operation 7 involves only FAC; the address part of this instruction is irrelevant.

A set of other instructions provide mathematical functions, input, output, and other manipulative operations that deal primarily with FAC and do not require a coded address. The complete octal code for these 'subroutine' instructions has the form, 00XY, where XY locates the appropriate entry in a table of subroutine addresses. These other FP instructions are:

Mnemonic		Octal Code	Operation
SQUARE	=	0001	FAC is squared, and the result left in FAC.
SQROOT	=	0002	The square-root of FAC is calculated, and the result left in FAC. A negative or zero FAC causes a program halt.
SIN	=	0003	The sine of FAC (assumed in radians) is calculated, and the result left in FAC.
COS	=	0004	The cosine of FAC (assumed in radians) is calculated, and the result left in FAC.
ARCTAN	=	0005	The arctangent of FAC is calculated, and the result (in radians, limited to the range, $\pm \pi/2$) left in FAC.
EXP1	=	0006	The exponentiation, e^{FAC}, is calculated, and the result left in FAC.
LOG	=	0007	The natural logarithm of FAC is calculated, and the result left in FAC. A negative or zero FAC causes a program halt.
INPUT	=	0010	A numerical quantity is entered on the TTY and converted to normalized FP form, and the result left in FAC. A detailed discussion of the input process is given in the next section.
OUTPUT	=	0011	FAC is output in decimal format on the TTY, with FAC lost afterwards. A detailed discussion of the output process is given in a later section.
NEGATE	=	0012	FAC is negated, and the result left in FAC.
FLOAT	=	0013	The two-word binary integer in locations 0057, 0060 is converted to normalized FP form, and the result left in FAC.
INVERT	=	0014	The reciprocal of FAC is calculated, and the result left in FAC. A zero FAC causes a program halt.
FIX	=	0015	FAC is converted and rounded off to a two-word binary integer, and the result left in HORD, LORD.

The addition of further FP instructions is discussed in a later section.

Finally, there is the FP Exit instruction:

FEXT	=	0000	Exit FP mode, return to normal word interpretation.

This exit clears the computer AC, but it does not affect FAC.

These mnemonics of course must either be defined in the program or included in the PAL Assembler symbol table if a program using them is to assemble properly.

The use of these FP instructions is illustrated by a PAL III pass 3 listing of a program to read in two sides of a right triangle and output its hypotenuse:

```
                *0400
0400   4407             JMS I 0007
0401   0010             INPUT          /INPUT A
0402   0001             SQUARE
0403   6213             FPUT X
0404   0010             INPUT          /INPUT B
0405   0001             SQUARE
0406   1213             FADD X
0407   0002             SQROOT
0410   0011             OUTPUT         /OUTPUT C
0411   0000             FEXT
0412   7402             HLT
0413   0000   X,        0              /THREE-WORD STORAGE
0414   0000             0
0415   0000             0
```

For other examples, see FPP1 subroutines such as SQARE (6772) and SQROT (7156).

INPUT

The FP instruction, INPUT, causes a program jump to the subroutine, INPVT (7400), which accepts and converts a numerical value entered on the TTY. That numerical value must be entered in fixed-point or integer format; E-format is not accepted. An input character string then has the general form: optional initial spaces (ignored); a possible sign (+ is not needed and is ignored); the decimal digits of the value being entered, with appropriately positioned decimal point (e.g., 123.45); and, finally, a terminator, which is any character except initial spaces, an initial sign, a decimal digit, or a decimal point. The TTY input routine, READIN, echoes each character as printed output, giving a visual advantage to non-printing terminators such as a following space, or a carriage return (which is automatically followed by an output line feed). The terminator stops the input cycle, and the accumulated value is converted to a properly signed, normalized FP number in FAC.

Several aspects of this routine should be noted:

1. Input of a terminator before input of any decimal digits yields zero in FAC. Input of a misplaced terminator yields an incorrect value in FAC; recovery may require restarting from the previous FP Interpreter entry in the program.

2. Input of a wrong number can be corrected easily if recognized before input of a terminator; typing a 'rub-out' restarts the input cycle, erasing all prior input for that quantity.

3. A decimal point is never a terminator. Input of a second decimal point in a character string simply redefines the position of the decimal point in that number. If no decimal point is included in the character string, it is assumed to follow the last decimal digit (i.e., integer format).

4. The number entered, disregarding decimal points and initial zeroes, must be less than $2^{31} \approx 2 \cdot 10^9$ (i.e., crudely, no more than nine significant digits), or a program halt occurs. This limit, which appreciably exceeds the 23 bit precision of the FP Mantissa, defines the magnitude of the largest number that can be entered directly without program interruption. There is no corresponding smallest number limit, so one method for entering a number $\geq 2^{31}$ is to enter its inverse and then invert the result.

OUTPUT

The FP instruction, OUTPUT, causes a jump to the subroutine, OUTPVT (7200), which converts FAC to a decimal representation that is output on the TTY. The output can be in either fixed-point or integer format, but not in E-format. The format specifications are stored beforehand as two numbers: NDEC (0054), the number of digits to the right of the decimal point; and NDIG (0055), the total number of characters to be output (not counting the sign or decimal point). The string of characters output then has the general form: initial spaces, as needed to fill the format; the sign (if positive, a space); and then the decimal digits and decimal point for the FAC value, out through NDEC digits beyond the decimal point. If the output is in integer format (NDEC = 0), the decimal point is not output. The precision of the FP Mantissa allows only six significant decimal digits, so zeroes are output for any further digits required by the format. The last significant digit to be output, a function usually of the format, is rounded off approximately to the nearest integer. If FAC = $0.X \cdot 10^N$ is too large to fit the given format but could fit it if NDEC were smaller (NDIG $\geq$ N > NDIG - NDEC), then NDEC is reduced until the output can fit (i.e., NDEC = NDIG - N), and output continues in this left-shifted format until NDIG and NDEC are redefined. If FAC is too large to fit any shifted format (i.e., N > NDIG), then NDIG decimal points are output instead.

Two points should be noted:

1. A carriage return/line feed sequence is automatically sent to the TTY after each output if SWIT1 (0061) is non-zero. That sequence can be obtained in normal mode programming by the instruction, JMS I CRLF , where CRLF = 0064.

2. FAC must be stored if it is needed for later steps, since FAC is obliterated by the output process.

OTHER COMMENTS

If improper operations are encountered, a program halt occurs. There are five such halts in FPP1, as follows:

Address	Error
5562	FAC is too large to be fixed as a two-word integer.
5700	The logarithm argument is zero or negative.
6304	The divisor is zero.
7125	The FP instruction, 00XY, is not a valid code.
7445	The input number exceeds the limiting size.

Easy recovery is possible only for the last of these, where actuating CONTINUE and then entering a terminator will still yield proper input conversion.

Input and output of ASCII characters to the external world are handled by subroutines READIN (7370) and TYPOUT (7172), respectively, coded here for a TTY. Other serial I/O devices could be used by recoding these two routines.

Other address-less FP instructions allowing the coded form, 00XY, such as functions and manipulations of FAC or conditional skips, can easily be added to the present set. The necessary steps are:

1. Enter the subroutine to carry out the operation in an arbitrary, convenient region of memory.

2. Enter ADDRESS-1 of this subroutine in the first empty space in the subroutine address table - here, 5776. The position of the entry in the table defines its octal code - here, 0016.

3. Decrement MNSBR (7142) and increment TABL2 (7057).

4. Add the mnemonic code for the operation to the PAL symbol table.

The added subroutine may itself make routine use of the FP mode and the basic FP instructions, but if it is also to use FP 'subroutine' instructions (00XY codes) care must be taken to save pointers [see, e.g., the square-root subroutine, SQROT (7156)] and to avoid overlapping use of storage registers. The subroutine address table, TABLE2 (5761 ff), presently has room for two more entries, but it can be moved to allow room for many more; the FP Interpreter is capable of identifying codes up to 0177.

Finally, it is not necessary to enter the FP mode to use these subroutines; any of them can be accessed by a normal indirect jump subroutine instruction, JMS I YYY. Only one caution is needed: if the double precision binary multiplication routine, DMULT (6200), is used, its preset return address, 7153, should be restored afterwards for possible use by a FP divide instruction.

DISCUSSION

FPP1 was developed from the DEC package, YQ4B, with the primary objective of reducing its size while retaining most of its capabilities. The effort centered on eliminating duplication and wasted space and tightening up the programming, while retaining essentially the same basic procedures and algorithms and the same computational accuracy. This compaction has been surprisingly successful; the final package, including several extra routines, requires 391 fewer words of storage, a savings of almost 10% of a 4K memory.

There are a few differences about FPP1 that should be noted:

1. E-format I/O is not available. This could present a problem for some types of calculations, but it was not at all restrictive when FPP1 was used as part of the calculation and control software for a wide range of X-ray diffraction experiments, and it saved space.

2. The square-root is calculated by the sequence of operations, logarithm/divide by two/exponentiation, which involves working in the FP mode to depth two. This may be somewhat slower than the Newton iteration approach, but it saves significant space.

3. Arctan (x), for $0.5 \leq x < 2.0$, is calculated from the expansion,

$$\tan^{-1}x = \frac{\pi}{4} + \left\{ y - \frac{1}{3}y^3 + \frac{1}{5}y^5 \ldots . \right\} \quad , \text{ where } y = \frac{x - 1}{x + 1} \quad ,$$

which converges more rapidly in this range than do the usual expansions for the small x and large x ranges, and which did not require many extra words.

4. The output is rounded off [subroutine RNDOUT (5512)] by adding $0.5 \cdot 10^N$ to FAC, where $X \cdot 10^N$ is the last significant digit to be typed, which works quite well except when all six significant digits are output and the number is large. This is a cosmetic extravagance, using 33 words, which is easily deleted.

A complete PAL III pass 3 listing and symbols follow. It includes many comments to help in understanding the general FP approach and procedures and in following the detailed programming. Its listed date marks the recent revision in preparation for this documentation that added the cosmetic output roundoff and modified slightly the I/O routines; the basic package was developed several years ago and has been heavily used. The user is urged to add other changes, as time permits, as an educational exercise.

It is hoped that both the FPP1 package and its documentation will be useful to the community of PDP-8 users.

```
                /FLOATING POINT PACKAGE - AMMRC FPP1
                /
                /           24 FEBRUARY 1983
                /
                /THIS PACKAGE WAS DEVELOPED FROM THE DEC Y04B
                /VERSION (APRIL, 1970) AND REQUIRES 26% LESS
                /STORAGE.  THE MAJOR ADDED RESTRICTION IS THAT
                /E-FORMAT INPUT AND OUTPUT ARE NOT PERMITTED.
                /MODIFIED ALGORITHMS ARE USED FOR SOME FUNCTIONS.
                /BASIC INSTRUCTION MNEMONICS AND CODES ARE
                /UNCHANGED.  SUBROUTINES INCLUDED ARE:
                /  SQUARE=0001
                /  SQROOT=0002
                /  SIN=0003
                /  COS=0004
                /  ARCTAN=0005
                /  EXPT=0006
                /  LOG=0007
                /  INPUT=0010
                /  OUTPUT=0011
                /  NORATE=0012
                /  FLOAT=0013           [FLOAT INTEGER IN (57,60)]
                /  INVERT=0014
                /  FIX=0015
                /
                /
                *0007
0007  7000              7000
                *0015
0015  0000    AUT1,     0
                *0040
0040  0000    EX1,      0                   /OP
0041  0000    AC1H,     0
0042  0000    AC1L,     0
0043  0000    OVER1,    0
0044  0000    EXP,      0                   /FAC
0045  0000    HORD,     0
0046  0000    LORD,     0
0047  0000    OVER2,    0
0050  0000    QUOL,     0
0051  0000    LOC1,     0
0052  0000    LOC2,     0
0053  0000    LOC3,     0
0054  0010    NDEC,     0010
0055  0020    NDIG,     0020
0056  0027    NBRX,     0027
0057  0000    NBRHI,    0
0060  0000    NBRLO,    0
0061  7777    SWIT1,    7777
0062  7370    READ,     READIN
0063  7172    TYPE,     TYPOUT
0064  5724    CRLF,     CRLFRT
```

```
                *5512
5512  0000  RNDOUT, 0                    /ROUNDOFF OUTPUT
5513  1462           TAD I READ           /ADDS 0.5*(10**-N) TO FAC
5514  1054           TAD NDEC
5515  7510  DVTEN2, SPA
5516  5346           JMP OUT0
5517  1350           TAD M6
5520  7500           SMA
5521  7200           CLA                  /ROUNDOFF SIXTH DIGIT
5522  7040           CMA                  /ROUNDOFF TO FORMAT
5523  1350           TAD M6
5524  3463           DCA I TYPE
5525  4407           JMS I 0007
5526  6752           FPUT I XXX
5527  5751           FGET I ONE
5530  0000           FEXT
5531  3044           DCA EXP
5532  7410           SKP
5533  4715           JMS I DVTEN2
5534  2463           ISZ I TYPE
5535  5333           JMP .-2
5536  4407           JMS I 0007
5537  1752           FADD I XXX
5540  0000           FEXT
5541  1044           TAD EXP
5542  7750           SPA SNA CLA
5543  5712           JMP I RNDOUT
5544  4715           JMS I DVTEN2
5545  2462           ISZ I READ
5546  7200  OUT0,    CLA
5547  5712           JMP I RNDOUT
5550  7772  M6,      -6
5551  5666  ONE,     5666
5552  5734  XXX,     5734
5553  0000  FIXX,    0                    /FIX FAC
5554  1044           TAD EXP              /EXIT WITH INTEGER IN (HORD,LORD)
5555  7510           SPA
5556  7240           CLA CMA              /[FAC] < 0.5: SHIFT 30(8)
5557  7041           CMA IAC
5560  1056           TAD NBRX             /[FAC] > 0.5: SHIFT [27(8)-EXP]
5561  7510           SPA
5562  7402           HLT                  /[FAC] > 2**23: TOO LARGE
5563  7160           CLL CML CMA
5564  3776           DCA I AMNT5
5565  2776           ISZ I AMNT5          /WAS EXP = 27(8)?
5566  4777           JMS I RSHFT3         /NO: RIGHT SHIFT MANTISSA
5567  1047           TAD OVER2            /ROUND OFF TO NEAREST INTEGER
5570  7710           SPA CLA
5571  2046           ISZ LORD
5572  5753           JMP I FIXX
5573  2045           ISZ HORD
5574  7000           NOP
5575  5753           JMP I FIXX
5576  6655  AMNT5,    AMOUNT
5577  6670  RSHFT3,   RSHFT
```

```
5600  0000  ACNEG,    0                   /NEGATE FAC
5601  7300            CLA CLL
5602  1047            TAD OVER2
5603  7041            CMA IAC
5604  3047            DCA OVER2
5605  1046            TAD LORD
5606  7040            CMA
5607  7430            SZL
5610  7101            CLL IAC
5611  3046            DCA LORD
5612  1045            TAD HORD
5613  7040            CMA
5614  7430            SZL
5615  7101            CLL IAC
5616  3045            DCA HORD
5617  5600            JMP I ACNEG
5620  0000  FEXP,     0                   /F.P. EXPONENTIAL
5621  1045            TAD HORD
5622  7510            SPA
5623  4200            JMS ACNEG           /MAKE FAC POSITIVE
5624  3275            DCA FLOG            /NON-ZERO IF FAC WAS > 0
5625  4252            JMS SETODD
5626  4641            JMS I SETEV
5627  3252            DCA SETODD
5630  3664            DCA I SERSV
5631  7350            CLL CLA CMA RAR
5632  4674            JMS I SERIEZ
5633  1225            TAD FEXP+5
5634  3664            DCA I SERSV
5635  1275            TAD FLOG
5636  7650            SNA CLA             /WAS FAC NEGATIVE?
5637  4665            JMS I INVRT1        /YES, INVERT RESULT
5640  5620            JMP I FEXP          /NO
5641  6042  SETEV,    SETEVN
5642  0000  XMP1,     0                   /MAKES (X-1)/(X+1)
5643  4407            JMS I 0007
5644  1266            FADD ONE
5645  6334            FPUT X
5646  2673            FSUB I DEUX
5647  4334            FDIV X
5650  0000            FEXT
5651  5642            JMP I XMP1
5652  0000  SETODD,   0                   /SETS TERMS FOR SERIES
5653  4407            JMS I 0007          /BEGINNING WITH X
5654  6334            FPUT X
5655  6337            FPUT TR1
5656  6345            FPUT TR3
5657  5266            FGET ONE
5660  6342            FPUT TR2
5661  6350            FPUT TR4
5662  0000            FEXT
5663  5652            JMP I SETODD
5664  6150  SERSV,    SERIES+3
5665  6137  INVRT1,   INVRT
```

```
5666  0001  ONE,      0001
5667  2000            2000
5670  0000  LOGG2,    0000            /LOG 2
5671  2613            2613
5672  4414            4414
5673  6134  DEUX,     TWO
5674  6145  SERIEZ,   SERIES
5675  0000  FLOG,     0               /F.P. LOGARITHM
5676  1045            TAD HORD
5677  7750            SPA SNA CLA
5700  7402            HLT             /NEGATIVE ARGUMENT
5701  1044            TAD EXP
5702  3060            DCA NBRLO
5703  3044            DCA EXP         /0.5 < X < 1.0
5704  4242            JMS XMP1
5705  4252            JMS SETODD
5706  3252            DCA SETODD
5707  1007            TAD 0007
5710  4674            JMS I SERIEZ
5711  1060            TAD NBRLO
5712  7710            SPA CLA
5713  7040            CMA
5714  3057            DCA NBRHI
5715  4353            JMS FLOWT
5716  4407            JMS I 0007
5717  3270            FMPY LOGG2
5720  1345            FADD TR3
5721  1345            FADD TR3
5722  0000            FEXT
5723  5675            JMP I FLOG
5724  0000  CRLFRT,   0
5725  1332            TAD C215
5726  4463            JMS I TYPE
5727  1333            TAD C212
5730  4463            JMS I TYPE
5731  5724            JMP I CRLFRT
5732  0215  C215,     0215
5733  0212  C212,     0212            /DO NOT RELOCATE
5734  0000  X,        0
5735  0000            0
5736  0000            0
5737  0000  TR1,      0               /OUTPUT BUFFER
5740  0000            0
5741  0000            0
5742  0000  TR2,      0
5743  0000            0
5744  0000            0
5745  0000  TR3,      0
5746  0000            0
5747  0000            0
5750  0000  TR4,      0
5751  0000            0
5752  0000            0
5753  0000  FLOWT,    0               /TWO WORD INTEGER FLOAT
5754  4407            JMS I 0007
5755  5056            FGET NBRX
```

```
5756  7000            FNOR
5757  0000            FEXT
5760  5753            JMP I FLOAT
5761  6771  TABLE2,    SQARE-1          /SUBROUTINE ADDRESS TABLE
5762  7155            SQROT-1
5763  5777            FSIN-1
5764  6033            FCOS-1
5765  6065            ARCTN-1
5766  5617            FEXP-1
5767  5674            FLOG-1
5770  7377            INPUT-1
5771  7177            OUTPUT-1
5772  5577            ACNEG-1
5773  5752            FLOAT-1
5774  6136            INVRT-1
5775  5552            FIXX-1
5776  0000            0
5777  0000            0

              *6000
6000  0000  FSIN,     0                /F.P. SINE
6001  1045            TAD HORD
6002  7700            SMA CLA
6003  5206            JMP .+3
6004  4633            JMS I ACNEG1
6005  7126            CLL CML RTL
6006  3266            DCA ARCTN
6007  1044            TAD EXP
6010  7750            SPA SNA CLA      /IS MAG. FAC < 1?
6011  5217            JMP .+6          /YES
6012  4407            JMS I 0007       /NO, REDUCE BY PI/2.
6013  2372            FSUB HALFPI
6014  0000            FEXT
6015  2266            ISZ ARCTN
6016  5207            JMP .-7
6017  4665            JMS I SETOD      /SET FOR SINE SERIES
6020  1266            TAD ARCTN
6021  7010            RAR
6022  3266            DCA ARCTN
6023  7430            SZL              /ODD MULTIPLE OF PI/2 SUBTRACTED?
6024  4242            JMS SETEVN       /YES, SET FOR COSINE SERIES
6025  7350            CLL CLA CMA RAR
6026  4345            JMS SERIES
6027  1266            TAD ARCTN
6030  7010            RAR
6031  7630            SZL CLA          /SIGN REVERSAL REQUIRED?
6032  4633            JMS I ACNEG1     /YES
6033  5600  ACNEG1,    JMP I FSIN
6034  0000  FCOS,      0                /F.P. COSINE
6035  4407            JMS I 0007
6036  1372            FADD HALFPI
6037  0000            FEXT
6040  4200            JMS FSIN
6041  5634            JMP I FCOS
6042  0000  SETEVN,    0                /SETS TERMS FOR SERIES
6043  4407            JMS I 0007       /BEGINNING WITH 1
```

```
6044  6744          FPUT I TS1      /USE AFTER JMS SETOD
6045  6771          FPUT I TS3
6046  2771          FSUB I TS3
6047  6776          FPUT I TS4
6050  0000          FEXT
6051  5642  XXMP1,   JMP I SETEVN
6052  0000  TERM,    0               /INCREMENTS TS4, MAKES TS4! IN TS2
6053  4407          JMS I 0007      /AND MAKES X**TS4 IN TS1
6054  5776          FGET I TS4
6055  1733          FADD I UNO
6056  6776          FPUT I TS4
6057  3777  TRMSW,  FMPY I TS2
6060  6777          FPUT I TS2
6061  5744          FGET I TS1
6062  3775          FMPY I XX
6063  6744          FPUT I TS1
6064  0000          FEXT
6065  5652  SETOD,   JMP I TERM
6066  0000  ARCTN,   0               /F.P. ARCTANGENT
6067  1045          TAD HORD
6070  7450          SNA
6071  5666          JMP I ARCTN
6072  7510          SPA
6073  4633          JMS I ACNEG1
6074  3234          DCA FCOS
6075  1044          TAD EXP
6076  7500          SMA
6077  5302          JMP .+3
6100  4665          JMS I SETOD     /CASE I: FAC < 0.5
6101  5326          JMP READY
6102  7110          CLL RAR
6103  7640          SZA CLA
6104  5316          JMP BIGG
6105  4651          JMS I XXMP1     /CASE II: 0.5 < FAC < 2.0
6106  4665          JMS I SETOD
6107  4407          JMS I 0007
6110  5372          FGET HALFPI
6111  4334          FDIV TWO
6112  1771          FADD I TS3
6113  6771          FPUT I TS3
6114  0000          FEXT
6115  5326          JMP READY
6116  4337  BIGG,    JMS INVRT       /CASE III: 2.0 < FAC
6117  4633          JMS I ACNEG1
6120  4665          JMS I SETOD
6121  4407          JMS I 0007
6122  5372          FGET HALFPI
6123  1771          FADD I TS3
6124  6771          FPUT I TS3
6125  0000          FEXT
6126  1007  READY,   TAD 0007
6127  4345          JMS SERIES
6130  1234          TAD FCOS
6131  7650          SNA CLA
6132  4633          JMS I ACNEG1
6133  5666  UNO,     JMP I ARCTN
```

```
6134  0002  TWO,      0002
6135  2000            2000
6136  0000            0000
6137  0000  INVRT,    0                 /MAKES RECIPROCAL OF FAC
6140  4665            JMS I SETOD
6141  4407            JMS I 0007
6142  4775            FDIV I XX
6143  0000            FEXT
6144  5737  TS1,      JMP I INVRT
6145  0000  SERIES,   0                 /FORMS POWER SERIES
6146  3257            DCA TRMSW         /ENTER WITH SWITCH SETTING IN AC
6147  3242            DCA SETEVN        /(3777: TS4! IN TS2: 7000: TS4)
6150  4252            JMS TERM          /OVERLAY HERE WITH 0 IF SERIES HAS
6151  4252            JMS TERM          /ALL TERMS INSTEAD OF ALTERNATE
6152  1665            TAD I SETOD       /TERMS
6153  7650            SNA CLA           /NON-ZERO SETODD: SIGN ALTERNATES
6154  5362            JMP .+6
6155  2242            ISZ SETEVN
6156  1242            TAD SETEVN
6157  7010            RAR
6160  7630            SZL CLA
6161  4633            JMS I ACNEG1
6162  4407            JMS I 0007
6163  4777            FDIV I TS2
6164  1771            FADD I TS3
6165  6771            FPUT I TS3
6166  0000            FEXT
6167  2050            ISZ QUOL
6170  5350            JMP SERIES+3
6171  5745  TS3,      JMP I SERIES
6172  0001  HALFPI,   0001              /0.5 * PI
6173  3110            3110
6174  3755            3755
6175  5734  XX,       X
6176  5750  TS4,      TR4
6177  5742  TS2,      TR2

              *6200
6200  7153  DMULT,    MUL+2             /MULTIPLY FAC BY OP
6201  4775            JMS I AMNT1       /IS FAC = 0?
6202  5370            JMP EXIT1         /YES
6203  1265            TAD MULSW
6204  3272            DCA SNSW
6205  4261            JMS SIGN
6206  1042            TAD AC1L
6207  3051            DCA LOC1
6210  1046            TAD LORD
6211  4657            JMS I MULT        /AC1L * LORD
6212  7200            CLA
6213  1052            TAD LOC2
6214  3047            DCA OVER2
6215  1045            TAD HORD
6216  4657            JMS I MULT        /AC1L * HORD
6217  1047            TAD OVER2
6220  3047            DCA OVER2
```

```
6221  7004            RAL
6222  1052            TAD LOC2
6223  3053            DCA LOC3
6224  7004            RAL
6225  3015            DCA AUT1
6226  1041            TAD AC1H
6227  3051            DCA LOC1
6230  1046            TAD LORD
6231  4657            JMS I MULT        /AC1H * LORD
6232  1047            TAD OVER2
6233  3047            DCA OVER2
6234  7004            RAL
6235  1052            TAD LOC2
6236  1053            TAD LOC3
6237  3053            DCA LOC3
6240  7004            RAL
6241  1015            TAD AUT1
6242  3015            DCA AUT1
6243  1045            TAD HORD
6244  4657            JMS I MULT        /AC1H * HORD
6245  1053            TAD LOC3
6246  3046            DCA LORD
6247  7004            RAL
6250  1052            TAD LOC2
6251  1015            TAD AUT1
6252  3045            DCA HORD
6253  4660            JMS I DNORM1
6254  2300            ISZ SNREG
6255  5600  ACNEG2,   JMP I DMULT
6256  5372            JMP FACNEG
6257  6743  MULT,     DMPY
6260  6400  DNORM1,   DNORM
6261  0000  SIGN,     0                 /SET SIGNS OF FAC AND OP
6262  7144            CLL CMA RAL
6263  3300            DCA SNREG
6264  1045            TAD HORD
6265  7700  MULSW,    SMA CLA
6266  5271            JMP .+3
6267  4655            JMS I ACNEG2      /MAKE FAC POSITIVE
6270  2300            ISZ SNREG
6271  1041            TAD AC1H
6272  0000  SNSW,     0                 /MAKE OP POSITIVE FOR MULTIPLY
6273  5661            JMP I SIGN        /MAKE OP NEGATIVE FOR DIVIDE
6274  4701            JMS I NEGOP
6275  2300            ISZ SNREG
6276  5661            JMP I SIGN
6277  5661            JMP I SIGN
6300  0000  SNREG,    0
6301  7060  NEGOP,    NEG
6302  1051  DIV,      TAD LOC1          /OPCODE 4
6303  7650            SNA CLA
6304  7402            HLT               /OP IS ZERO
6305  1040            TAD EX1
6306  7041            CMA IAC
6307  3040            DCA EX1
6310  4774            JMS I UNFLW1      /UNDERFLOW?
```

```
6311  4775          JMS I AMNT1     /IS FAC = 0?
6312  5370          JMP EXIT1       /YES, UNDERFLOW OR ZERO FAC
6313  1376          TAD DIVSW
6314  3272          DCA SNSW
6315  4261          JMS SIGN
6316  7300          CLA CLL
6317  3052          DCA LOC2
6320  3050          DCA QUOL
6321  1377          TAD CN23
6322  3053          DCA LOC3
6323  1042  DVX,    TAD AC1L        /SUBTRACT DIVISOR FROM DIVIDEND
6324  1046          TAD LORD
6325  3051          DCA LOC1
6326  7004          RAL
6327  1041          TAD AC1H
6330  1045          TAD HORD
6331  7420          SNL             /WAS DIVIDEND LARGER THAN DIVISOR?
6332  5336          JMP .+4
6333  3045          DCA HORD        /YES: DIFFERENCE IS NEW DIVIDEND
6334  1051          TAD LOC1
6335  3046          DCA LORD
6336  7200          CLA
6337  1050          TAD QUOL        /ROTATE (LOC2,QUOL) LEFT ONE
6340  7004          RAL
6341  3050          DCA QUOL
6342  1052          TAD LOC2
6343  7004          RAL
6344  3052          DCA LOC2
6345  1046          TAD LORD        /SHIFT DIVIDEND LEFT ONE
6346  7004          RAL
6347  3046          DCA LORD
6350  1045          TAD HORD
6351  7004          RAL
6352  3045          DCA HORD
6353  2053          ISZ LOC3
6354  5323          JMP DVX
6355  1042          TAD AC1L        /SET UP ROUNDOFF
6356  1046          TAD LORD
6357  7204          CLA RAL
6360  1041          TAD AC1H
6361  1045          TAD HORD
6362  7210          CLA RAR
6363  3047          DCA OVER2
6364  1050          TAD QUOL
6365  3046          DCA LORD
6366  1052          TAD LOC2
6367  3045          DCA HORD
6370  4660  EXIT1,  JMS I DNORM1
6371  2300          ISZ SNREG
6372  4655  FACNEG, JMS I ACNEG2
6373  5600          JMP I DMULT
6374  6511  UNFLW1, UNFLW
6375  6655  AMNT1,  AMOUNT
6376  7710  DIVSW,  SPA CLA
6377  7751  CN23,   7751
```

```
                *6400
6400  0000  DVORM,     0                   /NORMALIZE FAC
6401  4653            JMS I AMNT2         /IS FAC = 0?
6402  5245            JMP EXIT0           /YES
6403  1046            TAD LORD            /IS FAC APPARENT -0?
6404  7640            SZA CLA
6405  5216            JMP OK
6406  1045            TAD HORD
6407  7510            SPA
6410  7041            CMA IAC
6411  7700            SMA CLA
6412  5216            JMP OK
6413  7360            CLA CLL CMA CML
6414  3653            DCA I AMNT2
6415  4654            JMS I RSHFT1        /YES: SHIFT FAC RIGHT ONE
6416  3040  OK,       DCA EX1
6417  3041            DCA AC1H
6420  1045            TAD HORD
6421  7700            SMA CLA
6422  5225            JMP .+3
6423  2041            ISZ AC1H
6424  4652            JMS I ACNEG3        /MAKE FAC POSITIVE
6425  1045            TAD HORD
6426  7004            RAL
6427  7710            SPA CLA             /IS BIT ONE NON-ZERO?
6430  5234            JMP .+4             /YES: DONE
6431  4255            JMS LSHFT           /NO: SHIFT FAC LEFT ONE
6432  2040            ISZ EX1
6433  5225            JMP .-6
6434  1047            TAD OVER2
6435  7104            CLL RAL
6436  7204            CLA RAL
6437  4273            JMS RNDOFF          /ROUNDOFF
6440  1040            TAD EX1
6441  7040            CMA
6442  3040            DCA EX1
6443  4311            JMS UNFLW
6444  5247            JMP .+3             /NO UNDERFLOW
6445  3044  EXIT0,     DCA EXP
6446  5600            JMP I DVORM
6447  1041            TAD AC1H
6450  7640            SZA CLA
6451  4652            JMS I ACNEG3
6452  5600  ACNEG3,   JMP I DVORM
6453  6655  AMNT2,    AMOUNT
6454  6670  RSHFT1,   RSHFT
6455  0000  LSHFT,    0                   /FOUR WORD LEFT SHIFT
6456  1047            TAD OVER2
6457  7104            CLL RAL
6460  3047            DCA OVER2
6461  1046            TAD LORD
6462  7004            RAL
6463  3046            DCA LORD
6464  1045            TAD HORD
6465  7004            RAL
```

```
6466  3045          DCA HORD
6467  1273          TAD RNDOFF
6470  7004          RAL
6471  3273          DCA RNDOFF
6472  5655          JMP I LSHFT
6473  0000  RNDOFF,  0                 /ADD C(AC) TO POSITIVE FAC
6474  7100          CLL
6475  1046          TAD LORD
6476  3046          DCA LORD
6477  7004          RAL
6500  1045          TAD HORD            /IF FAC BIT 0 IS SET, SHIFT
6501  7500          SMA                 /HORD WORD RIGHT ONE
6502  5306          JMP .+4
6503  2044          ISZ EXP
6504  7000          NOP
6505  7010          RAR
6506  3045          DCA HORD
6507  3047          DCA OVER2
6510  5673          JMP I RNDOFF
6511  0000  UNFLW,  0                 /EXPONENT UNDERFLOW CHECK
6512  1044          TAD EXP
6513  7710          SPA CLA
6514  1040          TAD,EX1
6515  7710          SPA CLA
6516  7040          CMA
6517  3334          DCA ADDOP
6520  1040          TAD EX1
6521  1044          TAD EXP
6522  7001          IAC
6523  7500          SMA                 /IS SUM POSITIVE?
6524  2334          ISZ ADDOP           /WERE EXP AND EX1 BOTH NEGATIVE?
6525  5332          JMP .+5             /NO
6526  7300          CLA CLL             /YES, UNDERFLOW: SET FAC = 0
6527  3045          DCA HORD
6530  3046          DCA LORD
6531  2311          ISZ UNFLW           /INCREMENT POINTER
6532  3044          DCA EXP
6533  5711          JMP I UNFLW
6534  0000  ADDOP,  0                 /ADD OP TO (RNDOFF,FAC)
6535  7300          CLA CLL
6536  1047          TAD OVER2
6537  1043          TAD OVER1
6540  3047          DCA OVER2
6541  7004          RAL
6542  1046          TAD LORD
6543  1042          TAD AC1L
6544  3046          DCA LORD
6545  7004          RAL
6546  1045          TAD HORD
6547  1041          TAD AC1H
6550  3045          DCA HORD
6551  7004          RAL
6552  1273          TAD RNDOFF
6553  3273          DCA RNDOFF
6554  5734          JMP I ADDOP
```

```
6555  0000  X10,     0                 /ADD C(ACNEG) TO IP * FAC
6556  1047            TAD OVER2         /OVERFLOW IS IN RNDOFF
6557  3043            DCA OVER1
6560  1046            TAD LORD
6561  3042            DCA AC1L
6562  1045            TAD HORD
6563  3041            DCA AC1H
6564  3273            DCA RNDOFF
6565  4255            JMS LSHFT
6566  4255            JMS LSHFT
6567  4334            JMS ADDOP
6570  4255            JMS LSHFT
6571  1652            TAD I ACNEG3
6572  3043            DCA OVER1
6573  3042            DCA AC1L
6574  3041            DCA AC1H
6575  4334            JMS ADDOP
6576  1273            TAD RNDOFF
6577  5755            JMP I X10         /EXIT WITH C(RNDOFF) IN AC
                *6600
6600  0000  DADD,     0                 /ADD OP TO FAC
6601  3050            DCA QUOL
6602  4255            JMS AMOUNT        /IS FAC = 0?
6603  5230            JMP GETOP         /YES: GET OP
6604  1051            TAD LOC1
6605  7650            SNA CLA           /IS OP = 0?
6606  5600            JMP I DADD        /YES: DONE
6607  1040            TAD EX1           /ARE EXPONENTS EQUAL?
6610  7041            CMA IAC
6611  1044            TAD EXP
6612  7450            SNA
6613  5245            JMP OFFSET        /YES
6614  3270            DCA RSHFT         /NO: CAN OP AND FAC BE ALIGNED?
6615  1270            TAD RSHFT
6616  7500            SMA
6617  7041            CMA IAC
6620  3255            DCA AMOUNT
6621  1255            TAD AMOUNT
6622  1327            TAD C24
6623  7700            SMA CLA
6624  5241            JMP ALIGN         /YES
6625  1270            TAD RSHFT         /NO: WHICH IS LARGER?
6626  7700            SMA CLA
6627  5236            JMP GETOP+6       /FAC
6630  1040  GETOP,    TAD EX1           /OP: GET OP
6631  3044            DCA EXP
6632  1041            TAD AC1H
6633  3045            DCA HORD
6634  1042            TAD AC1L
6635  3046            DCA LORD
6636  7040            CMA
6637  3050            DCA QUOL          /IF FAC = 0 OR IF NO ALIGNMENT
6640  5600            JMP I DADD        /POSSIBLE, SET QUOL = 7777
6641  1270  ALIGN,    TAD RSHFT
6642  7004            RAL
```

```
6643  7200            CLA
6644  4270            JMS RSHFT
6645  7340  OFFSET,   CLA CLL CMA      /SHIFT FAC AND OP RIGHT ONE
6646  3255            DCA AMOUNT
6647  4270            JMS RSHFT
6650  7360            CLA CLL CMA CML
6651  3255            DCA AMOUNT
6652  4270            JMS RSHFT
6653  4732            JMS I ADDUP
6654  5600            JMP I DADD
6655  0000  AMOUNT,   0                /TEST IF FAC = 0
6656  1045            TAD HORD
6657  7640            SZA CLA          /IF YES, EXIT NORMALLY
6660  5266            JMP .+6
6661  1046            TAD LORD
6662  7640            SZA CLA
6663  5266            JMP .+3
6664  1047            TAD OVER2
6665  7640            SZA CLA
6666  2255            ISZ AMOUNT       /IF NO, EXIT TO SECOND INSTRUCTION
6667  5655            JMP I AMOUNT
6670  0000  RSHFT,    0                /THREE WORD RIGHT SHIFT
6671  7420            SNL              /IF LINK = 1, SHIFT FAC
6672  1331            TAD TAG2         /IF LINK = 0, SHIFT OP
6673  1330            TAD TAG1
6674  3051            DCA LOC1
6675  1255            TAD AMOUNT       /NEGATIVE OF AMOUNT OF SHIFT
6676  7041            CMA IAC
6677  1451            TAD I LOC1
6700  3451            DCA I LOC1       /EXPONENT SHIFTED
6701  2051            ISZ LOC1         /SET UP MANTISSA ADDRESSES
6702  1051            TAD LOC1
6703  7001            IAC
6704  3052            DCA LOC2
6705  1052            TAD LOC2
6706  7001            IAC
6707  3053            DCA LOC3
6710  7100  SHIFT,    CLL
6711  1451            TAD I LOC1
6712  7510            SPA
6713  7020            CML
6714  7010            RAR
6715  3451            DCA I LOC1
6716  1452            TAD I LOC2
6717  7010            RAR
6720  3452            DCA I LOC2
6721  1453            TAD I LOC3
6722  7010            RAR
6723  3453            DCA I LOC3
6724  2255            ISZ AMOUNT
6725  5310            JMP SHIFT
6726  5670            JMP I RSHFT
6727  0030  C24,      0030
6730  0044  TAG1,     EXP
6731  7774  TAG2,     EX1-EXP
6732  6534  ADDUP,    ADDOP
```

```
6733  7117  TABLE1,   SBR-1              /OPCODE ADDRESS TABLE
6734  7143            ADD-1
6735  7142            SUB-1
6736  7150            MUL-1
6737  6301            DIV-1
6740  7077            GET-1
6741  7106            PUT-1
6742  7144            NRM-1
6743  0000  DMPY,     0                  /MULTIPLY AC BY LOC1
6744  3050            DCA QUOL
6745  3052            DCA LOC2
6746  1371            TAD CN12
6747  3255            DCA AMOUNT
6750  7100            CLL
6751  1050            TAD QUOL
6752  7010            RAR
6753  3050            DCA QUOL
6754  1052            TAD LOC2
6755  7420            SNL
6756  5361            JMP .+3
6757  7100            CLL
6760  1051            TAD LOC1
6761  7010            RAR
6762  3052            DCA LOC2
6763  2255            ISZ AMOUNT
6764  5351            JMP DMPY+6
6765  1050            TAD QUOL           /EXIT WITH LESS SIGNIFICANT
6766  7010            RAR                /TWELVE BITS IN AC AND MORE
6767  7100            CLL                /SIGNIFICANT BITS IN LOC2
6770  5743            JMP I DMPY
6771  7764  CN12,     7764
6772  0000  SQARE,    0                  /F.P. SQUARE
6773  4407            JMS I 0007
6774  6770            FPUT I CN12-1
6775  3770            FMPY I CN12-1
6776  0000            FEXT
6777  5772            JMP I SQARE

                *7000
7000  0000  FPNT,     0                  /F.P. INTERPRETER
7001  7600            7600
7002  3043            DCA OVER1
7003  3047            DCA OVER2
7004  3051            DCA LOC1
7005  1600            TAD I FPNT         /GET ADDRESS REFERENCED
7006  0212            AND .+4
7007  7650            SNA CLA            /PAGE 0?
7010  5213            JMP .+3            /YES
7011  1201            TAD FPNT+1
7012  0200            AND FPNT
7013  3260            DCA NEG            /BITS 0,--4 GIVE PAGE ID
7014  1201            TAD FPNT+1
7015  7040            CMA
7016  0600            AND I FPNT
7017  1260            TAD NEG
7020  3260            DCA NEG            /ADDRESS
```

```
7021  1255            TAD M1
7022  0600            AND I FPNT
7023  7650            SNA CLA             /INDIRECT?
7024  5227            JMP .+3             /NO
7025  1660            TAD I NEG           /YES; GET DIRECT ADDRESS
7026  3260            DCA NEG
7027  1260            TAD NEG             /MOVE F.P. WORD FROM ADDRESS TO OP
7030  3015            DCA AUT1            /AND TEST IF OP = 0
7031  1660            TAD I NEG
7032  3040            DCA EX1
7033  1415            TAD I AUT1
7034  7440            SZA
7035  2051            ISZ LOC1            /IF OP = 0, LOC1 = 0
7036  3041            DCA AC1H
7037  1415            TAD I AUT1
7040  7440            SZA
7041  2051            ISZ LOC1
7042  3042            DCA AC1L
7043  1600            TAD I FPNT          /GET OPCODE
7044  0007            AND 0007
7045  7106            CLL RTL
7046  7006            RTL
7047  1256            TAD TABL1           /GET ENTRY FROM TABLE
7050  3015            DCA AUT1
7051  1415            TAD I AUT1
7052  3015            DCA AUT1
7053  2200            ISZ FPNT
7054  5415            JMP I AUT1          /GO THERE
7055  0400  M1,       0400
7056  6732  TABL1,    TABLE1-1
7057  5774  TABL2,    TABLE2+13           /TABLE2 - MNSBR - 2
7060  0000  NEG,      0                   /NEGATE OP
7061  7300            CLA CLL
7062  1043            TAD OVER1
7063  7041            CMA IAC
7064  3043            DCA OVER1
7065  1042            TAD AC1L
7066  7040            CMA
7067  7430            SZL
7070  7101            CLL IAC
7071  3042            DCA AC1L
7072  1041            TAD AC1H
7073  7040            CMA
7074  7430            SZL
7075  7101            CLL IAC
7076  3041            DCA AC1H
7077  5660            JMP I NEG
7100  1040  GET,      TAD EX1             /OPCODE 5
7101  3044            DCA EXP
7102  1041            TAD AC1H
7103  3045            DCA HORD
7104  1042            TAD AC1L
7105  3046            DCA LORD
7106  5201            JMP FPNT+1
7107  1044  PUT,      TAD EXP             /OPCODE 6
7110  3660            DCA I NEG
```

```
7111  1260            TAD NEG
7112  3015            DCA AUT1
7113  1045            TAD HORD
7114  3415            DCA I AUT1
7115  1046            TAD LORD
7116  3415            DCA I AUT1
7117  5201            JMP FPNT+1
7120  1260  SBR,       TAD NEG           /OPCODE 0
7121  7450            SNA               /EXIT?
7122  5600            JMP I FPNT        /YES
7123  1342            TAD MNSBR         /NO: CHECK CODE
7124  7540            SMA SZA
7125  7402            HLT               /UNDEFINED SUBROUTINE
7126  1257            TAD TABL2         /GET ENTRY FROM TABLE
7127  3015            DCA AUT1
7130  1415            TAD I AUT1
7131  3015            DCA AUT1
7132  1200            TAD FPNT          /SAVE POINTER: SUBROUTINES
7133  3341            DCA SAV1          /CAN USE F.P. TO DEPTH OVF
7134  4415            JMS I AUT1        /JMS TO SUBROUTINE
7135  7200            CLA
7136  1341            TAD SAV1          /RESET POINTER
7137  3200            DCA FPNT
7140  5201            JMP FPNT+1
7141  0000  SAV1,      0
7142  7763  MNSBR,     7763              /NEGATIVE OF NO. OF SUBROUTINES
7143  4260  SUB,       JMS NEG           /OPCODE 2
7144  4747  ADD,       JMS I FLAD        /OPCODE 1
7145  4750  NRM,       JMS I DNORM2      /OPCODE 7
7146  5201            JMP FPNT+1
7147  6600  FLAD,      DADD
7150  6400  DNORM2,    DNORM
7151  4754  MUL,       JMS I UNFLW2      /OPCODE 3
7152  4755            JMS I MPLY
7153  5201            JMP FPNT+1
7154  6511  UNFLW2,    UNFLW
7155  6200  MPLY,      DMULT
7156  0000  SQROT,     0                 /F.P. SQUARE ROOT
7157  1341            TAD SAV1          /SHIFT POINTER TO USE LOG
7160  3372            DCA TYPOUT        /AND EXP SUBROUTINES HERE
7161  4407            JMS I 0007
7162  0007            LOG
7163  4771            FDIV I DOS
7164  0006            EXPT
7165  0000            FEXT
7166  1372            TAD TYPOUT
7167  3341            DCA SAV1
7170  5756            JMP I SQROT
7171  6134  DOS,       TWO
7172  0000  TYPOUT,    0
7173  6046            TLS
7174  6041            TSF
7175  5374            JMP .-1
7176  7300            CLA CLL
7177  5772            JMP I TYPOUT
```

```
                *7200
7200  0000  OUTPUT,  0                   /OUTPUT FAC
7201  3047          DCA OVER2             /FORMAT SPEC. HAS BEEN STORED IN
7202  3370          DCA READIN            /NDEC (NO. OF DIGITS TO RIGHT OF
7203  1045          TAD HORD              /DEC. PT) AND NDIG (TOTAL NO. OF
7204  7700          SMA CLA               /DIGITS) PRIOR TO ENTRY
7205  5210          JMP .+3
7206  4753          JMS I ACNEG4          /MAKE FAC POSITIVE
7207  1333          TAD CMINUS
7210  1334          TAD CPLUS
7211  3743          DCA I BUFADD          /SIGN (MINUS OR SPACE) INTO BUFFER
7212  4736          JMS I AMNT3           /IS FAC = 0?
7213  5240          JMP F0                /YES
7214  1044  RANGE,  TAD EXP               /NO. MAKE FAC INTO FAC'*(10**M),
7215  7450          SNA                   /WHERE 0.1 < FAC' < 1.0
7216  5235          JMP ROUND
7217  7700          SMA CLA
7220  5230          JMP REDUCE
7221  4407          JMS I 0007            /MULTIPLY FAC BY 10
7222  3637          FMPY I TEN1
7223  0000          FEXT
7224  7240          CLA CMA
7225  1370          TAD READIN
7226  3370          DCA READIN            /DECREMENT COUNTER
7227  5214          JMP RANGE
7230  4651  REDUCE, JMS I DVTEN1         /DIVIDE FAC BY 10
7231  2370          ISZ READIN            /INCREMENT COUNTER
7232  1044          TAD EXP
7233  7740          SMA SZA CLA           /IS FAC' IN RANGE?
7234  5230          JMP REDUCE            /NO, CONTINUE
7235  4754  ROUND,  JMS I RNDOT           /YES. ROUNDOFF OUTPUT
7236  5243          JMP .+5
7237  7500  TEN1,   TEN
7240  7040  F0,     CMA                   /SET VALUES FOR FAC = 0
7241  3044          DCA EXP
7242  2370          ISZ READIN
7243  1343          TAD BUFADD
7244  3015          DCA AUT1
7245  4755          JMS I DECML
7246  1343          TAD BUFADD
7247  3015          DCA AUT1
7250  1370          TAD READIN
7251  7510  DVTEN1, SPA
7252  7200          CLA
7253  1054          TAD NDEC
7254  7041          CMA IAC
7255  1055          TAD NDIG
7256  7510          SPA
7257  5321          JMP FRMERR            /DATA WILL NOT FIT FORMAT
7260  7450          SNA
7261  5270          JMP .+7
7262  7041          CMA IAC               /OUTPUT LEADING SPACES
7263  3053          DCA LOC3
7264  1335          TAD CSPCE
7265  4337          JMS OUTT
```

```
7266  2053            ISZ LOC3
7267  5264            JMP .-3
7270  1743            TAD I BUFADD      /OUTPUT SIGN
7271  4463            JMS I TYPE
7272  1370            TAD READIN
7273  7510            SPA
7274  5312            JMP NEGEXP
7275  7450            SNA               /FOR FAC > 0.1: OUTPUT DIGITS
7276  5305            JMP .+7
7277  7041            CMA IAC
7300  3044            DCA EXP
7301  4360            JMS GETT
7302  4337            JMS OUTT
7303  2044            ISZ EXP
7304  5301            JMP .-3
7305  1356            TAD CPER          /DECIMAL POINT
7306  4463            JMS I TYPE
7307  4360            JMS GETT
7310  4337            JMS OUTT
7311  5307            JMP .-2
7312  3044  NEGEXP,    DCA EXP           /FOR FAC < 0.1: OUTPUT DIGITS
7313  1356            TAD CPER
7314  4463            JMS I TYPE
7315  4337            JMS OUTT          /OUTPUT ZEROES RIGHT OF DEC. PT.
7316  2044            ISZ EXP
7317  5315            JMP .-2
7320  5307            JMP NEGEXP-3
7321  1054  FRMERR,   TAD NDEC
7322  7700            SMA CLA           /CAN LEFT-SHIFTED FORMAT FIT?
7323  5327            JMP .+4           /YES
7324  7144            CLL CMA RAL       /NO: OUTPUT DECIMAL POINTS
7325  4337            JMS OUTT
7326  5324            JMP .-2
7327  7240            CLA CMA           /SHIFT FORMAT ONE SPACE LEFT
7330  1054            TAD NDEC
7331  3054            DCA NDEC
7332  5250            JMP DVTEN1-1
7333  0015  CMINUS,    0255-0240
7334  0240  CPLUS,     0240
7335  7760  CSPCE,     0240-0260
7336  6655  AMNT3,     AMOUNT
7337  0000  OUTT,      0                 /OUTPUT DIGIT IN AC
7340  1357            TAD CZERO
7341  4463            JMS I TYPE
7342  2051            ISZ LOC1          /IS FORMAT FILLED?
7343  5737  BUFADD,   JMP I OUTT
7344  2053            ISZ LOC3          /YES: WAS FAC = 0?
7345  5350            JMP .+3           /NO
7346  1357            TAD CZERO         /YES: OUTPUT A ZERO
7347  4463            JMS I TYPE
7350  1061            TAD SWIT1         /IS CR-LF WANTED?
7351  7640            SZA CLA
7352  4464            JMS I CRLF        /YES
7353  5600  ACNEG4,   JMP I OUTPUT
7354  5512  RNDOT,    RNDOUT
7355  7533  DECML,    DECMAL
```

```
7356  0256  CPER,    0256
7357  0260  CZERO,   0260
7360  0000  GETT,    0                  /GET DIGIT FROM BUFFER
7361  2052           ISZ LOC2
7362  5366           JMP .+4            /GETS FIRST 6 DIGITS FROM BUFFER
7363  7240           CLA CMA            /GIVES 0 FOR ALL FURTHER DIGITS
7364  3052           DCA LOC2           /REQUESTED
7365  5760           JMP I GETT
7366  1415           TAD I AUT1
7367  5760           JMP I GETT
7370  0000  READIN,  0
7371  6031           KSF
7372  5371           JMP .-1
7373  6036           KRB
7374  6046           TLS
7375  6041           TSF
7376  5375           JMP .-1
7377  5770           JMP I READIN

      *7400
7400  0000  INPVT,   0                  /INPUT TO FAC
7401  7240           CLA CMA
7402  3052           DCA LOC2           /PERIOD SWITCH SET TO 7777
7403  1274           TAD C35
7404  3044           DCA EXP
7405  3045           DCA HORD
7406  3046           DCA LORD
7407  3047           DCA OVER2
7410  7040           CMA
7411  3053           DCA LOC3           /SIGN SWITCH SET TO 7777
7412  3015           DCA AUT1
7413  4315           JMS IN             /GET CHARACTER
7414  1051           TAD LOC1
7415  1275           TAD MSPCE
7416  7450           SNA
7417  5213           JMP .-4            /IGNORE LEADING SPACES
7420  1276           TAD MPLUS
7421  7450           SNA
7422  5227           JMP DATA           /PLUS SIGN; DIGIT NEXT
7423  1277           TAD MMINUS
7424  7640           SZA CLA            /MINUS SIGN?
7425  5230           JMP DATA+1         /NO
7426  3053           DCA LOC3           /YES; SET SIGN SWITCH TO 0
7427  4315  DATA,    JMS IN             /GET CHARACTER
7430  1051           TAD LOC1
7431  1303           TAD M272
7432  7500           SMA
7433  5247           JMP NODIG          /NOT A DIGIT
7434  1304           TAD C10
7435  7510           SPA
7436  5247           JMP NODIG          /NOT A DIGIT
7437  3665           DCA I ACNEG5       /DIGIT
7440  2015           ISZ AUT1
7441  4775           JMS I MUL10        /CONTINUE CONVERSION TO BINARY
7442  1045           TAD HORD
7443  0247           AND NODIG
```

```
7444  7640          SZA CLA
7445  7402          HLT                 /TOO MANY DIGITS INPUT: NUMBER
7446  5227          JMP DATA            /MUST BE LESS THAN 2,147,483,648
7447  7600  NODIG,  7600
7450  1051          TAD LOC1
7451  1305          TAD MPER
7452  7640          SZA CLA             /DECIMAL POINT?
7453  5257          JMP FIN             /NO: TERMINATE
7454  3015          DCA AUT1            /YES: RESET COUNTER
7455  3052          DCA LOC2            /RESET PERIOD SWITCH TO 0
7456  5227          JMP DATA            /DEC. PT. IS NOT A TERMINATOR
7457  4732  FIN,    JMS I DNORM3
7460  2053          ISZ LOC3            /GIVE FAC PROPER SIGN
7461  4665          JMS I ACNEGS
7462  2052          ISZ LOC2            /HAS DEC. PT. BEEN INPUT?
7463  1015          TAD AUT1            /YES
7464  7450          SNA                 /NO: IT FOLLOWS LAST DIGIT
7465  5600  ACNEGS, JMP I INPUT         /DONE
7466  7041          CIA                 /DIGITS TO RIGHT OF DEC. PT.
7467  3315          DCA IN              /DIVIDE BY 10 APPROPRIATE
7470  4310          JMS DIVTEN          /NUMBER OF TIMES
7471  2315          ISZ IN
7472  5270          JMP .-2
7473  5600          JMP I INPUT
7474  0043  C35,     0043
7475  7540  MSPCE,   -240
7476  7765  MPLUS,   240-253
7477  7776  MMINUS,  253-255
7500  0004  TEN,     0004
7501  2400          2400
7502  0000          0000
7503  7506  M272,    -272
7504  0012  C10,     272-260
7505  7522  MPER,    -256
7506  7401  MRBOUT,  -377
7507  0162  MCR,     377-215
7510  0000  DIVTEN,  0                   /DIVIDE FAC BY 10
7511  4407          JMS I 0007          /DO NOT RELOCATE
7512  4300          FDIV TEN
7513  0000          FEXT
7514  5710          JMP I DIVTEN
7515  0000  IN,     0                   /READ A CHARACTER
7516  4462          JMS I READ
7517  3051          DCA LOC1
7520  1051          TAD LOC1
7521  1306          TAD MRBOUT
7522  7450          SNA                 /RUBOUT?
7523  5201          JMP INPUT+1         /YES: RESTART INPUT
7524  1307          TAD MCR
7525  7640          SZA CLA             /CARRIAGE RETURN?
7526  5715          JMP I IN            /NO
7527  1771          TAD I C212P         /YES: OUTPUT LINE-FEED
7530  4463          JMS I TYPE          /THIS ALSO WILL TERMINATE INPUT
7531  5715          JMP I IN
7532  6400  DNORM3, DNORM
```

```
7533  0000  DECMAL,  0
7534  1044            TAD EXP          /SHIFT SO EXP = 0 AND DEC. PT. IS
7535  7440            SZA              /AT LEFT OF BIT 0
7536  5341            JMP .+3
7537  4772            JMS I LSHF
7540  5346            JMP .+6
7541  7001            IAC
7542  3773            DCA I AMNT4
7543  7120            CLL CML
7544  2044            ISZ EXP
7545  4774            JMS I RSHFT2
7546  3665            DCA I ACVEG5
7547  1376            TAD N6           /SET COUNTER
7550  3044            DCA EXP
7551  4775            JMS I MUL10      /CALCULATE FIRST DIGIT
7552  7440            SZA              /IS IT 0?
7553  5360            JMP .+5          /NO
7554  7240            CLA CMA          /YES: IGNORE THIS AND ADJUST
7555  1462            TAD I READ       /TO CALCULATE 6 MORE DIGITS
7556  3462            DCA I READ
7557  4775            JMS I MUL10      /CALCULATE NEXT DIGIT
7560  3415            DCA I AUT1       /STORE DIGIT IN BUFFER
7561  2044            ISZ EXP
7562  5357            JMP .-3
7563  1055            TAD NDIG         /DIGITS CALCULATED: SET COUNTERS
7564  7041            CMA IAC
7565  3051            DCA LOC1
7566  1377            TAD N7
7567  3052            DCA LOC2
7570  3053            DCA LOC3
7571  5733  C212P,    JMP I DECMAL
7572  6455  LSHF,     LSHFT
7573  6655  AMNT4,    AMOUNT
7574  6670  RSHFT2,   RSHFT
7575  6555  MUL10,    X10
7576  7772  N6,       -6
7577  7771  N7,       -7
```

ACNEG	5600
ACNEG1	6033
ACNEG2	6255
ACNEG3	6452
ACNEG4	7353
ACNEG5	7465
AC1H	0041
AC1L	0042
ADD	7144
ADDOP	6534
ADDUP	6732
ALIGN	6641
AMNT1	6375
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AMNT5	5576
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F0	7240
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GETOP	6630
GETT	7360
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LOC2	0052
LOC3	0053
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LSHF	7572
LSHFT	6455
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MMINUS	7477
MNSBR	7142
MPER	7505
MPLUS	7476
MPLY	7155
MRBOUT	7506
MSPCE	7475
MUL	7151
MULSW	6265
MULT	6257
MUL10	7575
M1	7055
M272	7503
M6	5550
NBRHI	0057
NBRLO	0060
NBRX	0056
NDEC	0054
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TR3	5745
TR4	5750
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TYPOUT	7172
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UNFLW	6511
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