Floating Point Routines for the 6502

by Roy Rankin, Department of Mechanical Engineering,
Stanford University, Stanford, CA 94305
(415) 497-1822

and

Steve Wozniak, Apple Computer Company
770 Welch Road, Suite 154
Palo Alto, CA 94304
(415) 326-4248

Editor's Note: Although these routines are for the 6502, it would appear that one could generate equivalent routines for most of the "traditional" microprocessors, relatively easily, by following the flow of the algorithms given in the excellent comments included in the program listing. This is particularly true of the transcendental functions which were directly modeled after well-known and proven algorithms, and for which, the comments are relatively machine-independent.

These floating point routines allow 6502 users to perform most of the more popular and desired floating point and transcendental functions, namely:

Natural Log - LOG
Common Log - LOG10
Exponential - EXP
Floating Add - FADD
Floating Subtract - FSUB
Floating Multiply - FMUL
Floating Divide - FDIV
Convert Floating to Fixed - FIX
Convert Fixed to Floating - FLOAT

They presume a four-byte floating point operand consisting of a one-byte exponent ranging from -218 through +127, and a 24-bit two's complement mantissa between 1.0 and 2.0.

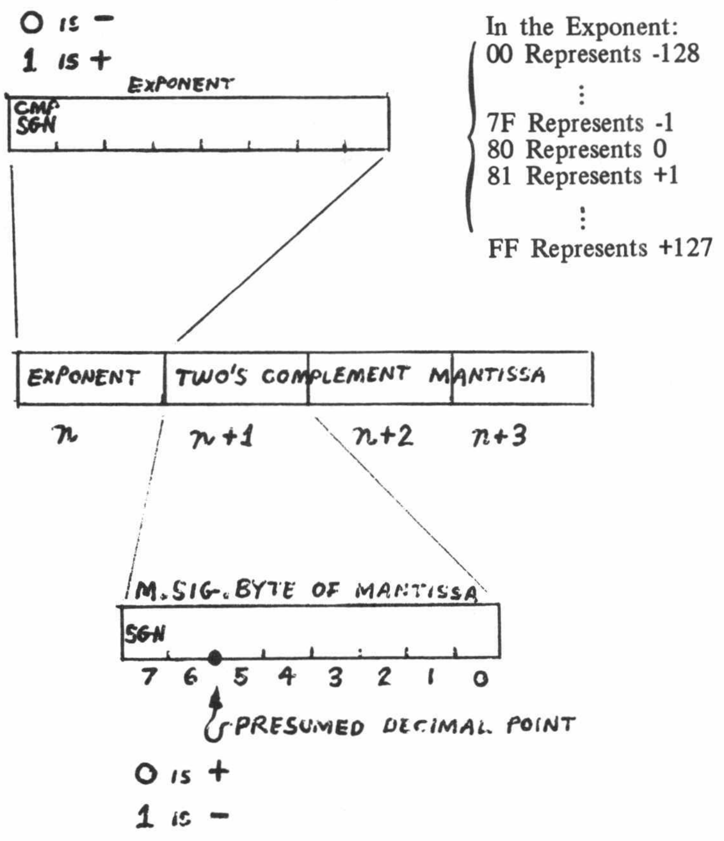
The floating point routines were done by Steve Wozniak, one of the principals in Apple Computer Company. The transcendental functions were patterned after those offered by Hewlett-Packard for their HP2100 minicomputer (with some modifications), and were done by Roy Rankin, a Ph.D. student at Stanford University.

There are three error traps; two for overflow, and one for prohibited logarithm argument. ERROR (1D06) is the error exit used in event of a non-positive log argument. OVFLW (1E3B) is the error exit for overflow occuring during calculation of *e* to some power. OVFL (1FE4) is the error exit for overflow in all of the floating point routines. There is no trap for underflow; in such cases, the result is set to 0.0.

All routines are called and exited in a uniform manner: The argument(s) are placed in the specified floating point storage locations (for specifics, see documentation preceeding each routine in the listing), then a JSR is used to enter the desired routine. Upon normal completion, the called routine is exited via a subroutine return instruction (RTS).

Note: The preceeding documentation was written by the Editor, based on phone conversations with Roy and studying the listing. There is a high probability that it is correct. However, since it was not written nor reviewed by the authors of these routines, the preceeding documentation may contain errors in concept or in detail.

– JCW, Jr.



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*         JULY 5, 1976
*      BASIC FLOATING POINT ROUTINES
*        FOR 6502 MICROPROCESSOR
*        BY R. RANKIN AND S. WOZNIAK
*
*      CONSISTING OF:
*         NATURAL LOG
*         COMMON LOG
*         EXPONENTIAL (E**X)
*         FLOAT      FIX
*         FADD       FSUB
*         FMUL       FDIV
*
*
*      FLOATING POINT REPRESENTATION (4-BYTES)
*                    EXPONENT BYTE 1
*                    MANTISSA BYTES 2-4
*
*      MANTISSA:    TWO'S COMPLIMENT REPRESENTATION WITH SIGN IN
*        MSB OF HIGH-ORDER BYTE.  MANTISSA IS NORMALIZED WITH AN
*        ASSUMED DECIMAL POINT BETWEEN BITS 5 AND 6 OF THE HIGH-ORDER
*        BYTE.  THUS THE MANTISSA IS IN THE RANGE 1. TO 2. EXCEPT
*        WHEN THE NUMBER IS LESS THAN 2**(-128).
*
*      EXPONENT:    THE EXPONENT REPRESENTS POWERS OF TWO.  THE
*        REPRESENTATION IS 2'S COMPLIMENT EXCEPT THAT THE SIGN
*        BIT (BIT 7) IS COMPLIMENTED.  THIS ALLOWS DIRECT COMPARISION
*        OF EXPONENTS FOR SIZE SINCE THEY ARE STORED IN INCREASING
*        NUMERICAL SEQUENCE RANGING FROM $00 (-128) TO $FF (+127)
*        ($ MEANS NUMBER IS HEXADECIMAL).
*
*      REPRESENTATION OF DECIMAL NUMBERS:    THE PRESENT FLOATING
*        POINT REPRESENTATION ALLOWS DECIMAL NUMBERS IN THE APPROXIMATE
*        RANGE OF 10**(-38) THROUGH 10**(38) WITH 6 TO 7 SIGNIFICANT
*        DIGITS.
*
*


0003                   ORG 3       SET BASE PAGE ADRESSES
0003  EA         SIGN  NOP
0004  EA         X2    NOP         EXPONENT 2
0005  00 00 00   M2    BSS 3       MANTISSA 2
0008  EA         X1    NOP         EXPONENT 1
0009  00 00 00   M1    BSS 3       MANTISSA 1
000C             E     BSS 4       SCRATCH
0010             Z     BSS 4
0014             T     BSS 4
```

```
0018                SEXP    BSS 4
001C  00            INT     BSS 1
                    *
1D00                        ORG $1D00       STARTING LOCATION FOR LOG
                    *
                    *       NATURAL LOG OF MANT/EXP1 WITH RESULT IN MANT/EXP1
                    *
1D00  A5 09         LOG     LDA M1
1D02  F0 02                 BEQ ERROR
1D04  10 01                 BPL CONT        IF ARG>0 OK
1D06  00            ERROR   BRK             ERROR ARG<=0
                    *
1D07  20 1C 1F      CONT    JSR SWAP        MOVE ARG TO EXP/MANT2 < A2 00  LDX # 0
1D0A  A5 04  < A2 00        LDA X2          HOLD EXPONENT
1D0C  A0 80                 LDY =$80
1D0E  84 04                 STY X2          SET EXPONENT 2 TO 0 ($80)
1D10  49 80                 EOR =$80        COMPLIMENT SIGN BIT OF ORIGINAL EXPONENT
1D12  85 0A                 STA M1+1        SET EXPONENT INTO MANTISSA 1 FOR FLOAT
1D14  A9 00   10 01         ~~LDA =0~~          BPL *+3
1D16  85 09   CA <86 09     ~~STA M1~~          CLEAR MSB OF MANTISSA 1  DEX < 86 09 STX M1
1D18  20 2C 1F              JSR FLOAT       CONVERT TO FLOATING POINT
1D1B  A2 03                 LDX =3          4 BYTE TRANSFERS
1D1D  B5 04         SEXP1   LDA X2,X
1D1F  95 10                 STA Z,X         COPY MANTISSA TO Z
1D21  B5 08                 LDA X1,X
1D23  95 18                 STA SEXP,X      SAVE EXPONENT IN SEXP
1D25  BD D1 1D              LDA R22,X       LOAD EXP/MANT1 WITH SQRT(2)
1D28  95 08                 STA X1,X
1D2A  CA                    DEX
1D2B  10 F0                 BPL SEXP1
1D2D  20 4A 1F              JSR FSUB        Z-SQRT(2)
1D30  A2 03                 LDX =3           4 BYTE TRANSFER
1D32  B5 08         SAVET   LDA X1,X        SAVE EXP/MANT1 AS T
1D34  95 14                 STA T,X
1D36  B5 10                 LDA Z,X         LOAD EXP/MANT1 WITH Z
1D38  95 08                 STA X1,X
1D3A  BD D1 1D              LDA R22,X       LOAD EXP/MANT2 WITH SQRT(2)
1D3D  95 04                 STA X2,X
1D3F  CA                    DEX
1D40  10 F0                 BPL SAVET
1D42  20 50 1F              JSR FADD        Z+SQRT(2)
1D45  A2 03                 LDX =3          4 BYTE TRANSFER
1D47  B5 14         TM2     LDA T,X
1D49  95 04                 STA X2,X        LOAD T INTO EXP/MANT2
1D4B  CA                    DEX
1D4C  10 F9                 BPL TM2
1D4E  20 9D 1F              JSR FDIV        T=(Z-SQRT(2))/(Z+SQRT(2))
1D51  A2 03                 LDX =3          4 BYTE TRANSFER
1D53  B5 08         M1T     LDA X1,X
1D55  95 14                 STA T,X         COPY EXP/MANT1 TO T AND
1D57  95 04                 STA X2,X        LOAD EXP/MANT2 WITH T
1D59  CA                    DEX
1D5A  10 F7                 BPL M1T
1D5C  20 77 1F              JSR FMUL    T*T
1D5F  20 1C 1F              JSR SWAP        MOVE T*T TO EXP/MANT2
1D62  A2 03                 LDX =3          4 BYTE TRANSFER
1D64  BD E1 1D      M1C     LDA C,X
1D67  95 08                 STA X1,X        LOAD EXP/MANT1 WITH C
1D69  CA                    DEX
1D6A  10 F8                 BPL M1C
1D6C  20 4A 1F              JSR FSUB        T*T-C
1D6F  A2 03                 LDX =3          4 BYTE TRANSFER
1D71  BD DD 1D      M2MB    LDA MB,X
1D74  95 04                 STA X2,X        LOAD EXP/MANT2 WITH MB
1D76  CA                    DEX
1D77  10 F8                 BPL M2MB
1D79  20 9D 1F              JSR FDIV        MB/(T*T-C)
1D7C  A2 03                 LDX =3          4 BYTE TRANSFER
1D7E  BD D9 1D      M2A1    LDA A1,X
1D81  95 04                 STA X2,X        LOAD EXP/MANT2 WITH A1
1D83  CA                    DEX
1D84  10 F8                 BPL M2A1
1D86  20 50 1F              JSR FADD        MB/(T*T-C)+A1
1D89  A2 03                 LDX =3          4 BYTE TRANSFER
1D8B  B5 14         M2T     LDA T,X
1D8D  95 04                 STA X2,X        LOAD EXP/MANT2 WITH T
1D8F  CA                    DEX
1D90  10 F9                 BPL M2T
1D92  20 77 1F              JSR FMUL        (MB/(T*T-C)+A1)*T
1D95  A2 03                 LDX =3          4 BYTE TRANSFER
1D97  BD E5 1D      M2MHL   LDA MHLF,X
1D9A  95 04                 STA X2,X        LOAD EXP/MANT2 WITH MHLF (.5)
1D9C  CA                    DEX
1D9D  10 F8                 BPL M2MHL
1D9F  20 50 1F              JSR FADD        +.5
1DA2  A2 03                 LDX =3          4 BYTE TRANSFER
1DA4  B5 18         LDEXP   LDA SEXP,X
1DA6  95 04                 STA X2,X        LOAD EXP/MANT2 WITH ORIGINAL EXPONENT
1DA8  CA                    DEX
1DA9  10 F9                 BPL LDEXP
1DAB  20 50 1F              JSR FADD        +EXPN
1DAE  A2 03                 LDX =3          4 BYTE TRANSFER
1DB0  BD D5 1D      MLE2    LDA LE2,X
1DB3  95 04                 STA X2,X        LOAD EXP/MANT2 WITH LN(2)
1DB5  CA                    DEX
1DB6  10 F8                 BPL MLE2
1DB8  20 77 1F              JSR FMUL        *LN(2)
1DBB  60                    RTS             RETURN RESULT IN MANT/EXP1
                    *
                    *       COMMON LOG  OF MANT/EXP1 RESULT IN MANT/EXP1
                    *
1DBC  20 00 1D      LOG10   JSR LOG         COMPUTE NATURAL LOG
1DBF  A2 03                 LDX =3
1DC1  BD CD 1D      L10     LDA LN10,X
1DC4  95 04                 STA X2,X        LOAD EXP/MANT2 WITH 1/LN(10)
1DC6  CA                    DEX
1DC7  10 F8                 BPL L10
1DC9  20 77 1F              JSR FMUL        LOG10(X)=LN(X)/LN(10)
1DCC  60                    RTS
                    *
1DCD  7E 6F         LN10    DCM 0.4342945
      2D ED
1DD1  80 5A         R22     DCM   1.4142136   SQRT(2)
      82 7A
1DD5  7F 58         LE2     DCM   0.69314718  LOG BASE E OF 2
      B9 0C
1DD9  80 52         A1      DCM   1.2920074
      B0 40
1DDD  81 AB         MB      DCM   -2.6398577
      86 49
1DE1  80 6A         C       DCM   1.6567626
      08 66
1DE5  7F 40         MHLF    DCM   0.5
      00 00
                    *
1E00                        ORG $1E00       STARTING LOCATION FOR EXP
                    *
                    *     EXP OF MANT/EXP1 RESULT IN MANT/EXP1
                    *
1E00  A2 03         EXP     LDX =3          4 BYTE TRANSFER
1E02  BD D8 1E              LDA L2E,X
1E05  95 04                 STA X2,X        LOAD EXP/MANT2 WITH LOG BASE 2 OF E
1E07  CA                    DEX
1E08  10 F8                 BPL EXP+2
1E0A  20 77 1F              JSR FMUL        LOG2(E)*X
1E0D  A2 03                 LDX =3          4 BYTE TRANSFER
1E0F  B5 08         FSA     LDA X1,X
1E11  95 10                 STA Z,X         STORE EXP/MANT1 IN Z
1E13  CA                    DEX
1E14  10 F9                 BPL FSA         SAVE Z=LN(2)*X
1E16  20 E8 1F              JSR FIX         CONVERT CONTENTS OF EXP/MANT1 TO AN INTEGER
1E19  A5 0A                 LDA M1+1
1E1B  85 1C                 STA INT         SAVE RESULT AS INT
1E1D  38                    SEC             SET CARRY FOR SUBTRACTION
1E1E  E9 7C                 SBC =124        INT-124
1E20  A5 09                 LDA M1
1E22  E9 00                 SBC =0
1E24  10 15                 BPL OVFLW       OVERFLOW INT>=124
1E26  18                    CLC             CLEAR CARRY FOR ADD
1E27  A5 0A                 LDA M1+1
1E29  69 78                 ADC =120        ADD 120 TO INT
1E2B  A5 09                 LDA M1
1E2D  69 00                 ADC =0
1E2F  10 0B                 BPL CONTIN      IF RESULT POSITIVE CONTINUE
1E31  A9 00                 LDA =0          INT<-120 SET RESULT TO ZERO AND RETURN
1E33  A2 03                 LDX =3          4 BYTE MOVE
1E35  95 08         ZERO    STA X1,X        SET EXP/MANT1 TO ZERO
1E37  CA                    DEX
1E38  10 FB                 BPL ZERO
1E3A  60                    RTS             RETURN
                    *
1E3B  00            OVFLW   BRK             OVERFLOW
                    *
1E3C  20 2C 1F      CONTIN  JSR FLOAT       FLOAT INT
1E3F  A2 03                 LDX =3
1E41  B5 10         ENTD    LDA Z,X
1E43  95 04                 STA X2,X        LOAD EXP/MANT2 WITH Z
1E45  CA                    DEX
1E46  10 F9                 BPL ENTD
1E48  20 4A 1F              JSR FSUB        Z=Z-FLOAT(INT)
1E4B  A2 03                 LDX =3          4 BYTE MOVE
1E4D  B5 08         ZSAV    LDA X1,X
1E4F  95 10                 STA Z,X         SAVE EXP/MANT1 IN Z
1E51  95 04                 STA X2,X        COPY EXP/MANT1 TO EXP/MANT2
1E53  CA                    DEX
1E54  10 F7                 BPL ZSAV
1E56  20 77 1F              JSR FMUL        Z*Z
1E59  A2 03                 LDX =3          4 BYTE MOVE
1E5B  BD DC 1E      LA2     LDA A2,X
1E5E  95 04                 STA X2,X        LOAD EXP/MANT2 WITH A2
1E60  B5 08                 LDA X1,X
1E62  95 18                 STA SEXP,X      SAVE EXP/MANT1 AS SEXP
1E64  CA                    DEX
1E65  10 F4                 BPL LA2
1E67  20 50 1F              JSR FADD        Z*Z+A2
1E6A  A2 03                 LDX =3          4 BYTE MOVE
1E6C  BD E0 1E      LB2     LDA B2,X
1E6F  95 04                 STA X2,X        LOAD EXP/MANT2 WITH B2
1E71  CA                    DEX
1E72  10 F8                 BPL LB2
1E74  20 9D 1F              JSR FDIV        T=B2/(Z*Z+A2)
1E77  A2 03                 LDX =3          4 BYTE MOVE
1E79  B5 08         DLOAD   LDA X1,X
1E7B  95 14                 STA T,X         SAVE EXP/MANT1 AS T
1E7D  BD E4 1E              LDA C2,X
1E80  95 08                 STA X1,X        LOAD EXP/MANT1 WITH C2
1E82  B5 18                 LDA SEXP,X
1E84  95 04                 STA X2,X        LOAD EXP/MANT2 WITH SEXP
1E86  CA                    DEX
1E87  10 F0                 BPL DLOAD
1E89  20 77 1F              JSR FMUL        Z*Z*C2
1E8C  20 1C 1F              JSR SWAP        MOVE EXP/MANT1 TO EXP/MANT2
1E8F  A2 03                 LDX =3          4 BYTE TRANSFER
1E91  B5 14         LTMP    LDA T,X
1E93  95 08                 STA X1,X        LOAD EXP/MANT1 WITH T
1E95  CA                    DEX
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1E96  10 F9             BPL LTMP
1E98  20 4A 1F          JSR FSUB      C2*Z*Z-B2/(Z*Z+A2)
1E9B  A2 03             LDX =3        4 BYTE TRANSFER
1E9D  BD E8 1E    LDD   LDA D,X
1EA0  95 04             STA X2,X      LOAD EXP/MANT2 WITH D
1EA2  CA                DEX
1EA3  10 F8             BPL LDD
1EA5  20 50 1F          JSR FADD      D+C2*Z*Z-B2/(Z*Z+A2)
1EA8  20 1C 1F          JSR SWAP      MOVE EXP/MANT1 TO EXP/MANT2
1EAB  A2 03             LDX =3        4 BYTE TRANSFER
1EAD  B5 10       LFA   LDA Z,X
1EAF  95 08             STA X1,X      LOAD EXP/MANT1 WITH Z
1EB1  CA                DEX
1EB2  10 F9             BPL LFA
1EB4  20 4A 1F          JSR FSUB      -Z+D+C2*Z*Z-B2/(Z*Z+A2)
1EB7  A2 03             LDX =3        4 BYTE TRANSFER
1EB9  B5 10       LF3   LDA Z,X
1EBB  95 04             STA X2,X      LOAD EXP/MANT2 WITH Z
1EBD  CA                DEX
1EBE  10 F9             BPL LF3
1EC0  20 9D 1F          JSR FDIV      Z/(**** )
1EC3  A2 03             LDX =3        4 BYTE TRANSFER
1EC5  BD E5 1D    LD12  LDA MHLF,X
1EC8  95 04             STA X2,X      LOAD EXP/MANT2 WITH .5
1ECA  CA                DEX
1ECB  10 F8             BPL LD12
1ECD  20 50 1F          JSR FADD      +Z/(***)+.5
1ED0  38                SEC            ADD INT TO EXPONENT WITH CARRY SET
1ED1  A5 1C             LDA INT       TO MULTIPLY BY
1ED3  65 08             ADC X1        2**(INT+1)
1ED5  85 08             STA X1        RETURN RESULT TO EXPONENT
1ED7  60                RTS           RETURN ANS=(.5+Z/(-Z+D+C2*Z*Z-B2/(Z*
1ED8  80 5C       L2E   DCM 1.4426950409   LOG BASE 2 OF E
      55 1E
1EDC  86 57       A2    DCM 87.417497202
      6A E1
1EE0  89 4D       B2    DCM 617.9722695               Z+A2))*2**(INT+1)
      3F 1D
1EE4  7B 46       C2    DCM .03465735903
      FA 70
1EE8  83 4F       D     DCM 9.9545957821
      A3 03
                  *
                  *
                  *        BASIC FLOATING POINT ROUTINES
                  *
1F00                    ORG $1F00     START OF BASIC FLOATING POINT ROUTINES
1F00  18          ADD   CLC           CLEAR CARRY
1F01  A2 02             LDX =$02      INDEX FOR 3-BYTE ADD
1F03  B5 09       ADD1  LDA M1,X
1F05  75 05             ADC M2,X      ADD A BYTE OF MANT2 TO MANT1
1F07  95 09             STA M1,X
1F09  CA                DEX           ADVANCE INDEX TO NEXT MORE SIGNIF.BYTE
1F0A  10 F7             BPL ADD1      LOOP UNTIL DONE
1F0C  60                RTS           RETURN
1F0D  06 03       MD1   ASL SIGN      CLEAR LSB OF SIGN
1F0F  20 12 1F          JSR ABSWAP    ABS VAL OF MANT1, THEN SWAP MANT2
1F12  24 09       ABSWAP BIT M1       MANT1 NEG?
1F14  10 05             BPL ABSWP1   NO,SWAP WITH MANT2 AND RETURN
1F16  20 8F 1F          JSR FCOMPL    YES, COMPLIMENT IT.
1F19  E6 03             INC SIGN      INCR SIGN, COMPLEMENTING LSB
1F1B  38          ABSWP1 SEC         SET CARRY FOR RETURN TO MUL/DIV
                  *
                  *       SWAP EXP/MANT1 WITH EXP/MANT2
                  *
1F1C  A2 04       SWAP   LDX =$04     INDEX FOR 4-BYTE SWAP
1F1E  94 0B       SWAP1  STY E-1,X
1F20  B5 07              LDA X1-1,X   SWAP A BYTE OF EXP/MANT1 WITH
1F22  B4 03              LDY X2-1,X   EXP/MANT2 AND LEAVEA COPY OF
1F24  94 07              STY X1-1,X   MANT1 IN E(3BYTES). E+3 USED.
1F26  95 03              STA X2-1,X
1F28  CA                 DEX          ADVANCE INDEX TO NEXT BYTE
1F29  D0 F3              BNE SWAP1    LOOP UNTIL DONE.
1F2B  60                 RTS
                  *
                  *
                  *
                  *     CONVERT 16 BIT INTEGER IN M1(HIGH) AND M1+1(LOW) TO
                  *     RESULT IN EXP/MANT1. EXP/MANT2 UNEFFECTED        F.P.
                  *
                  *
1F2C  A9 8E       FLOAT  LDA =$8E
1F2E  85 08              STA X1       SET EXPN TO 14 DEC
1F30  A9 00              LDA =0       CLEAR LOW ORDER BYTE
1F32  85 0B              STA M1+2
1F34  F0 08              BEQ NORM     NORMALIZE RESULT
1F36  C6 08       NORM1  DEC X1       DECREMENT EXP1
1F38  06 0B              ASL M1+2
1F3A  26 0A              ROL M1+1     SHIFT MANT1 (3 BYTES) LEFT
1F3C  26 09              ROL M1
1F3E  A5 09       NORM   LDA M1       HIGH ORDER MANT1 BYTE
1F40  0A                 ASL A        UPPER TWO BITS UNEQUAL?
1F41  45 09              EOR M1
1F43  30 04              BMI RTS1     YES,RETURN WITH MANT1 NORMALIZED
1F45  A5 08              LDA X1       EXP1 ZERO?
1F47  D0 ED              BNE NORM1    NO, CONTINUE NORMALIZING
1F49  60          RTS1   RTS          RETURN
                  *
                  *
                  *    EXP/MANT2-EXP/MAN1 RESULT IN EXP/MANT1
                  *
1F4A  20 8F 1F    FSUB   JSR FCOMPL   COMPL MANT1 CLEARS CARRY UNLESS ZERO
1F4D  20 5D 1F    SWPALG JSR ALGNSW   RIGHT SHIFT MANT1 OR SWAP WITH
                  *                                    MANT2 ON CARRY
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                  *     ADD EXP/MANT1 AND EXP/MANT2 RESULT IN EXP/MANT1
                  *
1F50  A5 04       FADD   LDA X2
1F52  C5 08              CMP X1       COMPARE EXP1 WITH EXP2
1F54  D0 F7              BNE SWPALG   IF UNEQUAL, SWAP ADDENDS OR ALIGN MANTISSAS
1F56  20 00 1F           JSR ADD      ADD ALIGNED MANTISSAS
1F59  50 E3       ADDEND BVC NORM     NO OVERFLOW, NOMALIZE RESULTS
1F5B  70 05              BVS RTLOG    OV: SHIFT MANT1 RIGHT. NOTE CARRY IS CORRECT SIGN
1F5D  90 BD       ALGNSW BCC SWAP     SWAP IF CARRY CLEAR, ELSE SHIFT RIGHT ARITH.
1F5F  A5 09       RTAR   LDA M1       SIGN OF MANT1 INTO CARRY FOR
1F61  0A                 ASL A        RIGHT ARITH SHIFT
1F62  E6 08       RTLOG  INC X1       INCR EXP1 TO COMPENSATE FOR RT SHIFT
1F64  F0 7E              BEQ OVFL     EXP1 OUT OF RANGE
1F66  A2 FA       RTLOG1 LDX =$FA     INDEX FOR 6 BYTE RIGHT SHIFT
1F68  A9 80       ROR1   LDA =$80   ]
1F6A  B0 01              BCS ROR2   ]
1F6C  0A                 ASL A      ]
1F6D  56 0F       ROR2   LSR E+3,X  ]SIMULATE ROR E+3,X
1F6F  15 0F              ORA E+3,X  ]
1F71  95 0F              STA E+3,X  ]
1F73  E8                 INX          NEXT BYTE OF SHIFT
1F74  D0 F2              BNE ROR1     LOOP UNTIL DONE
1F76  60                 RTS          RETURN
                  *
                  *
                  *     EXP/MANT1 X EXP/MANT2 RESULT IN EXP/MANT1
                  *
1F77  20 0D 1F    FMUL   JSR MD1      ABS. VAL OF THE MANT1, MANT2
1F7A  65 08              ADC X1       ADD EXP1 TO EXP2 FOR PRODUCT EXPONENT
1F7C  20 CD 1F           JSR MD2      CHECK PRODUCT EXP AND PREPARE FOR MUL
1F7F  18                 CLC          CLEAR CARRY
1F80  20 66 1F    MUL1   JSR RTLOG1   MANT1 AND E RIGHT.(PRODUCT AND MPLIER)
1F83  90 03              BCC MUL2     IF CARRY CLEAR, SKIP PARTIAL PRODUCT
1F85  20 00 1F           JSR ADD      ADD MULTIPLICAN TO PRODUCT
1F88  88          MUL2   DEY          NEXT MUL ITERATION
1F89  10 F5              BPL MUL1     LOOP UNTIL DONE
1F8B  46 03       MDEND  LSR SIGN     TEST SIGN (EVEN/ODD)
1F8D  90 AF       NORMX  BCC NORM      IF EXEN, NORMALIZE PRODUCT. ELSE COMPLEMENT
1F8F  38          FCOMPL SEC          SET CARRY FOR SUBTRACT
1F90  A2 03              LDX =$03     INDEX FOR 3-BYTE SUBTRACTION
1F92  A9 00       COMPL1 LDA =$00     CLEAR A
1F94  F5 08              SBC X1,X     SUBTRACT BYTE OF EXP1
1F96  95 08              STA X1,X     RESTORE IT
1F98  CA                 DEX          NEXT MORE SIGNFICANT BYTE
1F99  D0 F7              BNE COMPL1   LOOP UNTIL DONE
1F9B  F0 BC              BEQ ADDEND   NORMALIZE (OR SHIFT RIGHT IF OVERFLOW)
                  *
                  *
                  *     EXP/MANT2 / EXP/MANT1 RESULT IN EXP/MANT1
                  *
1F9D  20 0D 1F    FDIV   JSR MD1      TAKE ABS VAL OF MANT1, MANT2
1FA0  E5 08              SBC X1       SUBTRACT EXP1 FROM EXP2
1FA2  20 CD 1F           JSR MD2      SAVE AS QUOTIENT EXP
1FA5  38          DIV1   SEC          SET CARRY FOR SUBTRACT
1FA6  A2 02              LDX =$02     INDEX FOR 3-BYTE INSTRUCTION
1FA8  B5 05       DIV2   LDA M2,X
1FAA  F5 0C              SBC E,X      SUBTRACT A BYTE OF E FROM MANT2
1FAC  48                 PHA          SAVE ON STACK
1FAD  CA                 DEX          NEXT MORE SIGNIF BYTE
1FAE  10 F8              BPL DIV2     LOOP UNTIL DONE
1FB0  A2 FD              LDX =$FD     INDEX FOR 3-BYTE CONDITIONAL MOVE
1FB2  68          DIV3   PLA          PULL A BYTE OF DIFFERENCE OFF STACK
1FB3  90 02              BCC DIV4     IF MANT2<E THEN DONT RESTURE MANT2
1FB5  95 08              STA M2+3,X
1FB7  E8          DIV4   INX          NEXT LESS SIGNIF BYTE
1FB8  D0 F8              BNE DIV3     LOOP UNTIL DONE
1FBA  26 0B              ROL M1+2
1FBC  26 0A              ROL M1+1     ROLL QUOTIENT LEFT. CARRY INTO LSB
1FBE  26 09              ROL M1
1FC0  06 07              ASL M2+2
1FC2  26 06              ROL M2+1     SHIFT DIVIDEND LEFT


1FC4  26 05              ROL M2
1FC6  B0 1C              BCS OVFL     OVERFLOW IS DUE TO UNNORMALIZED DIVISOR
1FC8  88                 DEY          NEXT DIVIDE ITERATION
1FC9  D0 DA              BNE DIV1     LOOP UNTIL DONE 23 ITERATIONS
1FCB  F0 BE              BEQ MDEND    NORMALIZE QUOTIENT AND CORRECT SIGN
1FCD  86 0B       MD2    STX M1+2
1FCF  86 0A              STX M1+1     CLR MANT1 (3 BYTES) FOR MUL/DIV
1FD1  86 09              STX M1
1FD3  B0 0D              BCS OVCHK    IF EXP CALC SET CARRY, CHECK FOR OVFL
1FD5  30 04              BMI MD3      IF NEG NO UNDERFLOW
1FD7  68                 PLA          POP ONE
1FD8  68                 PLA          RETURN LEVEL
1FD9  90 B2              BCC NORMX    CLEAR X1 AND RETURN
1FDB  49 80       MD3    EOR =$80     COMPLIMENT SIGN BIT OF EXP
1FDD  85 08              STA X1       STORE IT
1FDF  A0 17              LDY =$17     COUNT FOR 24 MUL OR 23 DIV ITERATIONS
1FE1  60                 RTS          RETURN
1FE2  10 F7       OVCHK  BPL MD3      IF POS EXP THEN NO OVERFLOW
1FE4  00          OVFL   BRK
                  *
                  *
                  *     CONVERT EXP/MANT1 TO INTEGER IN M1 (HIGH) AND M1+1(LOW)
                  *      EXP/MANT2 UNEFFECTED
                  *
1FE5  20 5F 1F           JSR RTAR     SHIFT MANT1 RT AND INCREMENT EXPNT
1FE8  A5 08       FIX    LDA X1       CHECK EXPONENT
1FEA  C9 8E              CMP =$8E     IS EXPONENT 14?
1FEC  D0 F7              BNE FIX-3    NO,SHIFT
1FEE  60          RTRN   RTS          RETURN
                         END
```