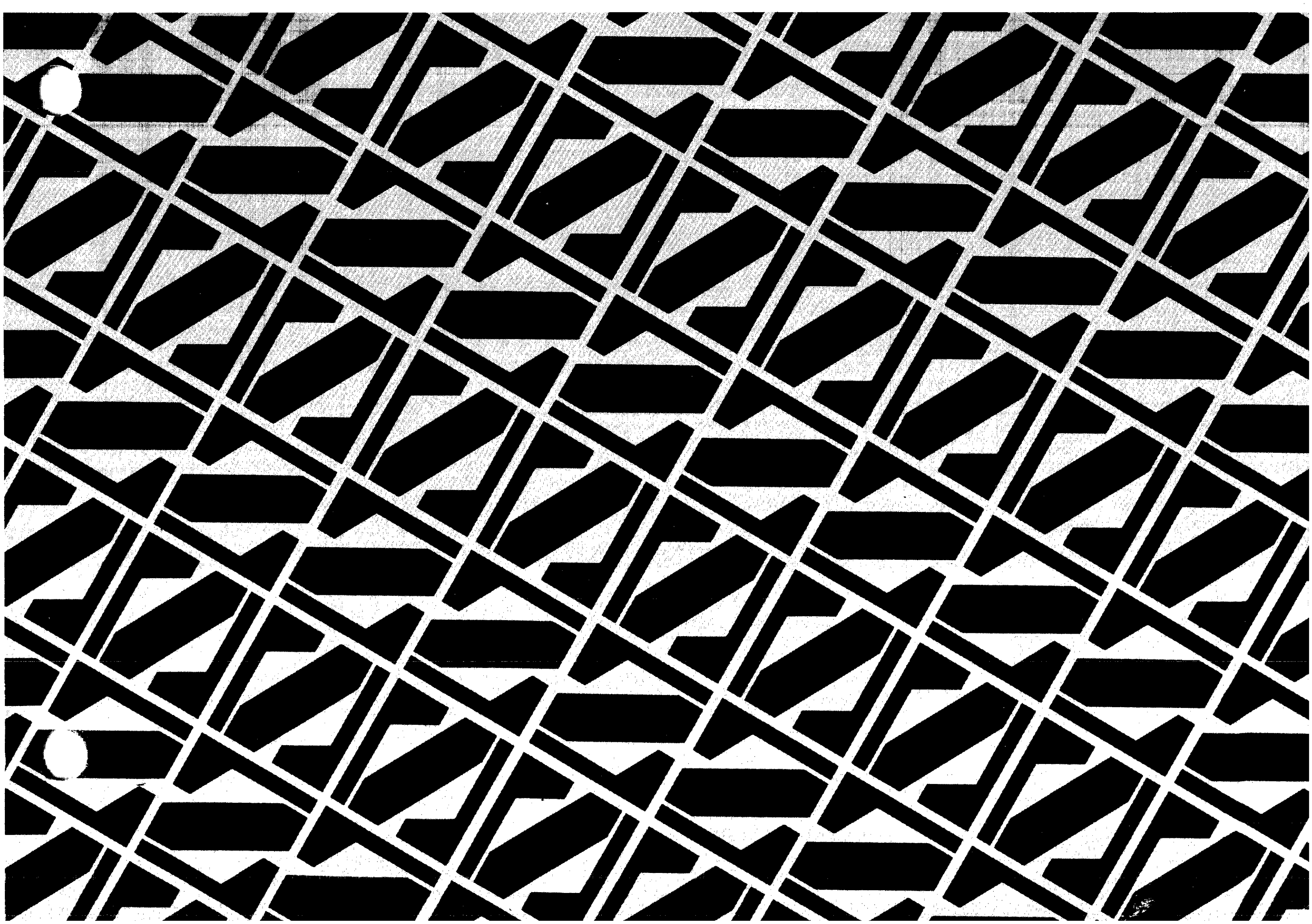
National Semiconductor
Order No. IMP-16F/972A
Pub. No. 4200072A

IMP-16F/400 Floating Point Firmware Technical Description



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Integrated MicroProcessor-16

IMP-16F/400

FLOATING POINT FIRMWARE

TECHNICAL DESCRIPTION

January 1975

National Semiconductor Corporation
2900 Semiconductor Drive
Santa Clara, California 95051

INTRODUCTION

This subroutine set provides an IMP-16 microprocessor with double-precision and floating-point capability. Double-precision and floating-point computation is very useful when additional precision is needed or the range of numbers is expected to be large. In the following pages, individual subroutines are described along with necessary user instructions. Subroutines included in the set are listed in the table below.

ARITHMETIC SUBROUTINE SET

SUBROUTINE	MNEMONIC	ENTRY POINT
Single Precision Multiply	MULT	FC01
Single Precision Divide	DIV	FC1A
Double Precision Multiply	DPMUL	FCCF
Positive Double Precision Divide	DPDIV	FDE3
Double Precision Square	DPSQUARE	FCCD
Double Precision Complement	DPCOMP	FDBA
Double Precision Shift	DPSH	FDDB
Double Precision Shift Right	DPSHR	FDCE
Double Precision Shift Left	DPSHL	FDDB
Quadrant Tests	QUAD	FDA0
Sine	SIN	FCFA
Cosine	COS	FCFC
Arctangent	ARCTAN	FD37
Floating Point Add	FPADD	FC30
Floating Point Multiply	FPMUL	FC5D
Floating Point Divide	FPDIV	FC6C
Floating Point Complement	FPCOMP	FCB9
Check Zero Exponent	CZERO	FC63
Extract Exponent to Stack	EXTEXP	FC7C
Add Exponent from Stack	ADDEXP	FCBD
Left Normalize	LFNOR	FC97
Double Left Normalize	DLNORM	FC8A
Fraction to Floating Point	FLOAT	FC85
Floating Point to Fraction	SFO	FCC7

GENERAL CHARACTERISTICS

The arithmetic subroutine set uses 512 memory words located at addresses FC00 through FDFF (64512 through 65023, decimal). All subroutines are contained wholly within the set; they require no external program code. The IMP-16 extended instruction set is required. Operands and results, in most cases, use the general registers. The only memory locations written into by the set are in the range 00E0 through 00EF. All constants are contained within the subroutine set.

EXECUTION TIMES

Execution times shown on each of the subroutine data sheets are expressed in terms of three variables, where

R = Number of main memory read cycles
W = Number of main memory write cycles
N = Number of microprogram cycles

These execution time expressions can thus be used to calculate subroutine execution time for any IMP-16 implementation. A few subroutine execution times are also dependent on user-specified variables (such as shift counts in shift instructions). These are defined on the individual data sheets. All execution times are based on worst-case conditions.

NUMBER REPRESENTATION

Numbers in a computer program often represent real world parameters. In this subroutine set, four different modes of numerical representation are used: integer, fractional, double-precision, and floating-point. All four modes have important applications in IMP-16 systems.

Integer notation is the most common and obvious mode of numerical representation. It is simply an integer count of something. In the IMP-16, numbers up to 2^{16} may be represented because of the 16-bit word length. To represent both positive and negative integers, a twos-complement system is used. This gives an integer range of

$$-2^{15} \leq \text{integer} < 2^{15}$$

With twos-complement notation, the most significant bit, bit 15, can be thought of as a sign bit, and the binary point can be thought of as being to the right of bit 0.

FRACTIONAL NOTATION

Many real-world parameters are continuous rather than discrete. Such values can never be indicated with perfect precision because of the limited word length of any computer. Take the airspeed of an aircraft as an example. It may have a potential range from zero to 1000 miles per hour. We would rarely expect its speed to be an exact round number. At some instant the speed may be 556.234..... If we want to express this speed as precisely as possible given a 16-bit word length, an integer notation of 556 miles per hour would not be the best choice. A more convenient technique is to use fractional notation. The parameter, in this case speed, can be scaled so that 1000 miles per hour is equivalent to 1.0000.... This would allow the full 16-bit capacity to be utilized. After scaling, the range of numerical expression of a fractional number is

$$-1.0 \leq N < 1.0$$

With fractional notation, the binary point can be thought of as being to the right of bit 15. Thus, the largest positive binary number that can be represented is 0.11111... or almost one. Precision is about $3.1 * 10^{-5}$.

DOUBLE PRECISION

When precision greater than 16-bits is required, double-precision numbers can be used. Double-precision numbers give a precision of one part in 2^{31} or about $4.6 * 10^{-10}$. Double-precision numbers are an extended fractional notation. Note that two IMP-16 words are required.

FLOATING POINT

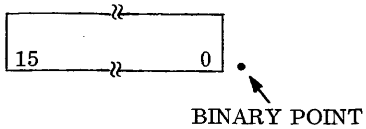
Floating-point representation is a technique to express numbers in a form similar to scientific notation, with a fractional mantissa and an exponent. The value of any floating-point number so represented is equivalent to mantissa * (2**exponent). The mantissa consists of 24 bits and gives a precision of one part in 2^{23}. The exponent has 8 bits and allows exponents in the range

$$-2^{7} \leq \text{exponent} < 2^{7}$$

The great advantage of floating-point numbers is that the scaling factor of a fractional number becomes a visible attribute which can be manipulated. Thus, the scaling factor can be altered to maintain precision or facilitate computations.

NUMBER REPRESENTATION EXAMPLES

- INTEGER

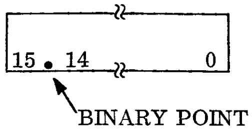


EXAMPLES:
$5 = 0005_{16}$
$-5 = FFFB_{16}$

RANGE: $-32768 \leqslant N < 32768$
MAXIMUM PRECISION: 1
SMALLEST VALUE: 1

$SPEED = 556.234 = 556_{10} = 022C_{16}$

- FRACTIONAL

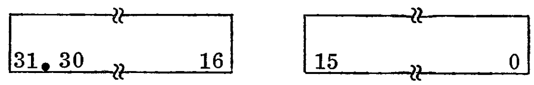


EXAMPLES:
$1/2 = 4000_{16}$
$-1/2 = C000_{16}$
$-1 = 8000_{16}$

RANGE: $-1 \leqslant N < 1$
MAXIMUM PRECISION: $1/2^{15} = 3.1 * 10^{-5}$
SMALLEST VALUE: 2^{-15}

$SPEED = \frac{556.234...}{1000.000} = 0.556234_{10} = 4732_{16}$

- DOUBLE PRECISION (FRACTIONAL)

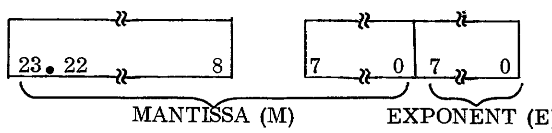


RANGE: $-1 \leqslant N < 1$
MAXIMUM PRECISION: $1/2^{31} = 4.6 * 10^{-10}$
SMALLEST VALUE: 2^{-31}

EXAMPLES:
$1/2 = 4000\ 0000_{16}$
$-1/2 = C000\ 0000_{16}$
$-1 = 8000\ 0000_{16}$

$SPEED = 4732\ ACFB_{16}$

- FLOATING POINT



RANGE: $-2^{127} \leqslant N < 2^{127}$
PRECISION: 2^{-23} ($2^{EXPONENT}$)
SMALLEST MAGNITUDE: 2^{-151}
LARGEST MAGNITUDE: $(1-2^{-23})\ 2^{127}$

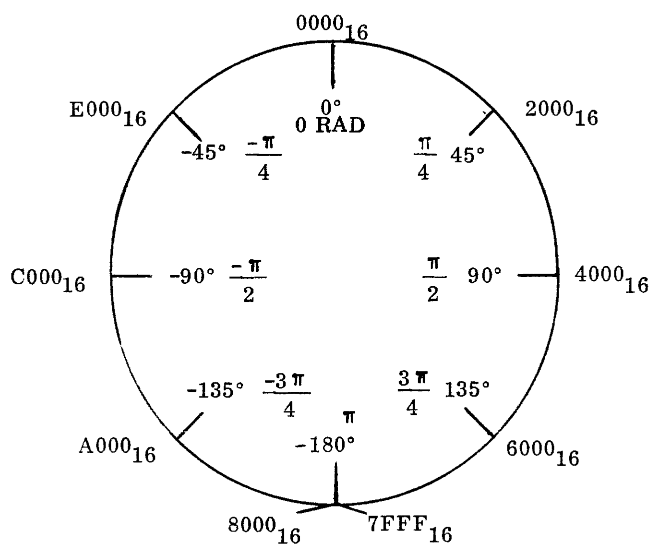
$N = M * 2^E$

EXAMPLES:
$1/2 = 4000\ 00_{16}\ (00_{16})$
$1/2 = 2000\ 00_{16}\ (01_{16})$
$1/2 = 1000\ 00_{16}\ (02_{16})$
$1/4 = 2000\ 00_{16}\ (00_{16})$
$1/4 = 4000\ 00_{16}\ (FF_{16})$

$SPEED = 556.234 = 4587\ 7A_{16}\ (0A_{16})$

ANGULAR REPRESENTATION

Angles are expressed as a double-precision fraction of π radians.



NOTATION

In the descriptions which follow, R0, R1, R2, and R3 represent the contents of the four accumulators = AC0, AC1, AC2, and AC3.

Normalization of a floating point number means that the mantissa is shifted left until the most significant bit is a 1, and the exponent adjusted accordingly.

SUBROUTINE: SINGLE PRECISION MULTIPLY	LABEL: MULT

DESCRIPTION: MULTIPLIES TWO SINGLE-PRECISION, SIGNED, FRACTIONAL 16-BIT NUMBERS TO GIVE A SIGN PLUS A 30-BIT RESULT

ENTRY POINT: FC01
ENTRY CONDITIONS: R_0 = X R_2 = Y
EXIT CONDITIONS: R_0, R_1 = X * Y R_2 - ALTERED R_3 = UNCHANGED
EXECUTION TIME: 30R + 243N + W

TEMPORARY LOCATIONS USED: 00E0
SUBROUTINES CALLED: DSHL, DPCOMP
STACK WORDS NEEDED: 2
(MAXIMUM DEPTH)

COMMENTS:
1. ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.
2. FRACTIONAL DIFFERS FROM AN INTEGER MULTIPLY IN THAT THE RESULT OF A FRACTIONAL MULTIPLY IS SHIFTED LEFT 1 BIT.

SUBROUTINE: SINGLE PRECISION DIVIDE	LABEL: DIV

DESCRIPTION: DIVIDES A SIGNED, FRACTIONAL 16-BIT NUMBER INTO A SIGNED, FRACTIONAL 32-BIT NUMBER, PROVIDING A QUOTIENT AND AN INTEGER REMAINDER

ENTRY POINT: FC1A
ENTRY CONDITIONS: R_0, R_1 = DIVIDEND R_2 = DIVISOR
EXIT CONDITIONS: R_0 = QUOTIENT R_1 = REMAINDER R_2 = ALTERED R_3 = UNCHANGED
EXECUTION TIME: 49R + W + 343N

TEMPORARY LOCATIONS USED: 00E0
SUBROUTINES CALLED: DSHR, DPCOMP
STACK WORDS NEEDED: 2
(MAXIMUM DEPTH)

COMMENTS:
1. ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.
2. OVERFLOW FLAG IS SET IF MSB OF DIVIDEND $\geq$ DIVISOR.

SUBROUTINE: DOUBLE PRECISION MULTIPLY	LABEL: DPMUL

DESCRIPTION: MULTIPLIES DOUBLE-PRECISION OPERANDS TO GIVE A DOUBLE-PRECISION PRODUCT

ENTRY POINT: FCCF
ENTRY CONDITIONS: R_0, R_1 = X R_2, R_3 = Y
EXIT CONDITIONS: R_0, R_1 = X * Y R_2, R_3 ALTERED
EXECUTION TIME: 200R + 8W + 1125N

TEMPORARY LOCATIONS USED: 00E0, 00E1, 00EE, 00EF
SUBROUTINES CALLED: QUAD, MULT, DPCOMP, DSHL
STACK WORDS NEEDED: 4
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: POSITIVE DOUBLE PRECISION DIVIDE	LABEL: DPDIV

DESCRIPTION: UNSIGNED FRACTIONAL DIVIDE OF R_2, R_3 INTO R_0, R_1, BOTH DOUBLE-PRECISION POSITIVE FRACTIONS

ENTRY POINT: FDE3
ENTRY CONDITIONS: R_0, R_1 = POSITIVE DIVIDEND R_2, R_3 = POSITIVE DIVISOR
EXIT CONDITIONS: R_0, R_1 = QUOTIENT R_2, R_3 = REMAINDER SELFF = 0
EXECUTION TIME: 510R + 97W = 2578N

TEMPORARY LOCATIONS USED: 00E0, 00EC-00EF
SUBROUTINES CALLED: NONE
STACK WORDS NEEDED: 0
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: DOUBLE PRECISION SQUARE	LABEL: DPSQUARE

DESCRIPTION: SQUARES THE DOUBLE-PRECISION NUMBER IN R_0, R_1

ENTRY POINT: FCCD
ENTRY CONDITIONS: R_0, $R_1 = X$
EXIT CONDITIONS: R_0, $R_1 = X^2$ R_2, R_3 ALTERED
EXECUTION TIME: 202R + 8W + 1137N

TEMPORARY LOCATIONS USED: 00E0, 00E1, 00EE, 00EF
SUBROUTINES CALLED: DPMULT, QUAD, MULT, DPCOMP, DSHL
STACK WORDS NEEDED: 4
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSED ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: DOUBLE PRECISION COMPLEMENT	LABEL: DPCOMP

DESCRIPTION: COMPUTES TWOS COMPLEMENT OF A DOUBLE-PRECISION NUMBER

ENTRY POINT: FDBA
ENTRY CONDITIONS: R_0, $R_1 = X$
EXIT CONDITIONS: R_0, R_1 = TWOS COMPLEMENT OF X R_2, R_3 PRESERVED SELFF = 0
EXECUTION TIME: 16R + 53N

TEMPORARY LOCATIONS USED: NONE
SUBROUTINES CALLED: NONE
STACK WORDS NEEDED: 0
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: DOUBLE PRECISION ARITHMETIC SHIFT	LABEL: DPSH

DESCRIPTION: SHIFTS A DOUBLE-PRECISION NUMBER TO RIGHT OR LEFT AS SPECIFIED BY R_2. ABSOLUTE VALUE OF R_2 INDICATES NUMBER OF BITS TO SHIFT. POSITIVE R_2 INDICATES LEFT SHIFT; NEGATIVE R_2 MEANS RIGHT SHIFT.

ENTRY POINT: FDDB
ENTRY CONDITIONS: R_0, R_1 = X R_2 = M (SHIFT COUNT)
EXIT CONDITIONS: R_0, R_1 = SHIFTED X R_2 = ALTERED R_3 PRESERVED
EXECUTION TIME: LEFT 5R + 20N + [8R + 32N] M
RIGHT 7R + 26N + [4R + 21N] M

TEMPORARY LOCATIONS USED: NONE
SUBROUTINES CALLED: NONE
STACK WORDS NEEDED: 0
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.
RIGHT SHIFT IS ARITHMETIC; THAT IS, SIGN BIT IS PRESERVED

SUBROUTINE: DOUBLE PRECISION ARITHMETIC SHIFT RIGHT	LABEL: DPSHR

DESCRIPTION: SHIFTS DOUBLE-PRECISION NUMBER RIGHT M BITS, WHERE R_2 = M

ENTRY POINT: FDCE
ENTRY CONDITIONS: R_0, R_1 = X R_2 = M (BITS TO SHIFT)
EXIT CONDITIONS: R_0, R_1 = RIGHT SHIFTED X R_2 ALTERED R_3 PRESERVED
EXECUTION TIME: 5R + 20N + (4R + 21N) M

TEMPORARY LOCATIONS USED: NONE
SUBROUTINES CALLED: NONE
STACK WORDS NEEDED: 0
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.
SIGN BIT IS PRESERVED

SUBROUTINE: DOUBLE PRECISION SHIFT LEFT	LABEL: DPSHL

DESCRIPTION: SHIFTS DOUBLE-PRECISION NUMBER LEFT M BITS, WHERE R_2 = M

ENTRY POINT: FDDB
ENTRY CONDITIONS: R_0, R_1 = X R_2 = M (NUMBER OF BITS TO SHIFT)
EXIT CONDITIONS: R_0, R_1 = LEFT SHIFTED X R_2 ALTERED R_3 PRESERVED
EXECUTION TIME: 5R + 20N + (8R + 32N) M

TEMPORARY LOCATIONS USED: NONE
SUBROUTINES CALLED: NONE
STACK WORDS NEEDED: 0
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: QUADRANT TESTS	LABEL: QUAD

DESCRIPTION: GIVEN TWO SIGNED DOUBLE-PRECISION NUMBERS C1 AND C2, THE INITIAL SIGN OF EACH IS INDICATED BY A FLAG IN MEMORY AND THE ABSOLUTE VALUE OF THE NUMBERS IS GIVEN.

ENTRY POINT: FDAO
ENTRY CONDITIONS: R_0, R_1 = C_1 R_2, R_3 = C_2
EXIT CONDITIONS: R_0, R_1 = ABS (C_1) R_2, R_3 = ABS (C_2)

00E1 =	C_1	C_2
0	+	+
1	+	-
2	-	-
3	-	+

WHERE ZERO IS +

EXECUTION TIME: 47R + W + 175N

TEMPORARY LOCATIONS USED: 00E1
SUBROUTINES CALLED: DPCOMP
STACK WORDS NEEDED: 1
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: SINE	LABEL: SIN

DESCRIPTION: CALCULATES SINE OF DOUBLE-PRECISION ANGLE IN R_0, R_1

CALCULATION IS MADE: SIN(X) = COS (X - $\pi/2$)

ACCURACY IS $0.00000\ 0002_{(10)}$

ENTRY POINT: FCFA
ENTRY CONDITIONS: R_0, R_1 = X
EXIT CONDITIONS: R_0, R_1 = SIN(X) R_2, R_3 ALTERED
EXECUTION TIME: 1697R + 82W + 9300 N

TEMPORARY LOCATIONS USED: 00E0-00EB, 00EE, 00EF
SUBROUTINES CALLED: DPCOMP, DPMULT, PEXPN
STACK WORDS NEEDED: 6
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: COSINE	LABEL: COS

DESCRIPTION: CALCULATES COSINE OF DOUBLE-PRECISION ANGLE IN R_0, R_1

POLYNOMIAL APPROXIMATION USED IS:

$$COS(X) = 1 + X^2 (A_2 + X^2 (A_4 + X^2 (A_6 + X^2 (A_8 + X^2 (A_{10})))))$$

WHERE: $A_2 = -0.49999\ 99963$ $A_8 = 0.00002\ 47609$
$A_4 = 0.04166\ 66418$ $A_{10} = -0.00000\ 02605$
$A_6 = -0.00138\ 88397$

FOR ANGLES IN THE FIRST QUADRANT

ACCURACY IS $0.00000\ 0002_{(10)}$

ENTRY POINT: FCFC
ENTRY CONDITIONS: R_0, R_1 = X
EXIT CONDITIONS: R_0, R_1 = COS(X) R_2, R_3 ALTERED
EXECUTION TIME: 1677R + 82W + 9285N

TEMPORARY LOCATIONS USED: 00E0-00EB, 00EE, 00EF
SUBROUTINES CALLED: DPCOMP, DPMULT, PEXPN
STACK WORDS NEEDED: 6
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: ARCTANGENT	LABEL: ARCTAN

DESCRIPTION: COMPUTES ARCTANGENT (C1/C2), WHERE C1 AND C2 ARE DOUBLE-PRECISION NUMBERS IN THE RANGE:

$$-1 \leq C1, C2 \leq 1$$

THE POLYNOMIAL APPROXIMATION USED WAS:

$$\text{ARCTAN}(X) = X(1 + X^2(A_2 + X^2(A_4 + X^2(A_6 + X^2(A_8 + X^2(A_{10} + X^2(A_{12} + X^2(A_{14} + X^2(A_{16})))))))))$$

WHERE

A_2 = -0.33333 14528	A_{10} = -0.07528 96400
A_4 = 0.19993 55085	A_{12} = 0.04290 96138
A_6 = -0.14208 89944	A_{14} = -0.01616 57367
A_8 = 0.10656 26393	A_{16} = 0.00286 62257

ACCURACY IS 0.00000 $002_{(10)}$

ENTRY POINT: FD37
ENTRY CONDITIONS: R_0, $R_1 = C_1$ R_2, $R_3 = C_2$
EXIT CONDITIONS: R_0, R_1 = ARCTAN (C_1/C_2) R_2, R_3 ALTERED
EXECUTION TIME: 2985R + 231W + 15892N

TEMPORARY LOCATIONS USED: 00E0-00EF
SUBROUTINES CALLED: QUAD, DPCOMP, DPDIV, DPMUL, PEXPN, DSHR
STACK WORDS NEEDED: 7
(MAXIMUM DEPTH)

COMMENTS:
1. ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.
2. SINGULARITY CASE WHERE C1 = C2 = 0 YIELDS ARCTAN(C1/C2) = 0.

SUBROUTINE: FLOATING POINT ADD	LABEL: FPADD

DESCRIPTION: ADDS TWO FLOATING-POINT NUMBERS.

ENTRY POINT: FC30
ENTRY CONDITIONS: R_0, $R_1 = X$ R_2, $R_3 = Y$
EXIT CONDITIONS: R_0, $R_1 = X + Y$ R_2, R_3 ALTERED
EXECUTION TIME: 147R + 7W + 613N

TEMPORARY LOCATIONS USED: 00E0, 00E1, 00E2
SUBROUTINES CALLED: EXTEXP, DSHR, CZERO, ADDEXP
STACK WORDS NEEDED: 1
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: FLOATING POINT MULTIPLY	LABEL: FPMUL

DESCRIPTION: MULTIPLIES TWO FLOATING-POINT NUMBERS

ENTRY POINT: FC5D
ENTRY CONDITIONS: R_0, R_1 = X R_2, R_3 = Y
EXIT CONDITIONS: R_0, R_1 = X * Y R_2, R_3 ALTERED
EXECUTION TIME: 1215R + 63W + 5077N

TEMPORARY LOCATIONS USED: 00E0, 00E1, 00E5, 00E6, 00EE, 00EF
SUBROUTINES CALLED: DLNORM, DPMUL, ADDEXP, CZERO
STACK WORDS NEEDED: 4
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: POSITIVE FLOATING POINT DIVIDE	LABEL: FPDIV

DESCRIPTION: DIVIDES TWO POSITIVE FLOATING-POINT NUMBERS

ENTRY POINT: FC6C
ENTRY CONDITIONS: R_0, R_1 = X R_2, R_3 = Y
EXIT CONDITIONS: R_0, R_1 = X/Y
EXECUTION TIME: 1540R + 152W + 6584N

TEMPORARY LOCATIONS USED: 00E0, 00E1, 00E2, 00E5, 00E6, 00EC, 00ED, 00EE, 00EF
SUBROUTINES CALLED: DLNORM, DSHR, DPDIV, ADDEXP, CZERO
STACK WORDS NEEDED: 4
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: FLOATING POINT COMPLEMENT	LABEL: FPCOMP

DESCRIPTION: COMPLEMENTS A FLOATING-POINT NUMBER IN R_0, R_1

ENTRY POINT: FCB9
ENTRY CONDITIONS: $R_0 = X_1$ $R_1 = X_2$, EX
EXIT CONDITIONS: $R_0 = \overline{X_1}$ $R_1 = \overline{X_2}$, EX R_2, R_3 PRESERVED
EXECUTION TIME: 50R + 2W + 183N

TEMPORARY LOCATIONS USED: 00E0
SUBROUTINES CALLED: EXTEXP, DPCOMP, ADDEXP
STACK WORDS NEEDED: 1
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: CHECK ZERO EXPONENT	LABEL: CZERO

DESCRIPTION: IF MANTISSA OF A FLOATING-POINT NUMBER IS ZERO, EXPONENT IS FORCED TO ZERO.

ENTRY POINT: FC63
ENTRY CONDITIONS: R_0, $R_1 = X_1$, X_2 (EX)
EXIT CONDITIONS: IF X_1, $X_2 = 0$ R_0, $R_1 = 0,0(0)$ } R_2, R_3 PRESERVED
IF X_1, $X_2 \neq 0$ R_0, $R_2 = X_1$, X_2 (EX)
EXECUTION TIME: 36R + 2W + 139N

TEMPORARY LOCATIONS USED: 00E0
SUBROUTINES CALLED: EXTEXP, ADDEXP
STACK WORDS NEEDED: 1
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: EXTRACT EXPONENT TO STACK	LABEL: EXTEXP

DESCRIPTION: EXTRACTS EXPONENT FROM A FLOATING-POINT NUMBER, STORES EXPONENT ON STACK, AND CLEARS EXPONENT FIELD OF NUMBER.

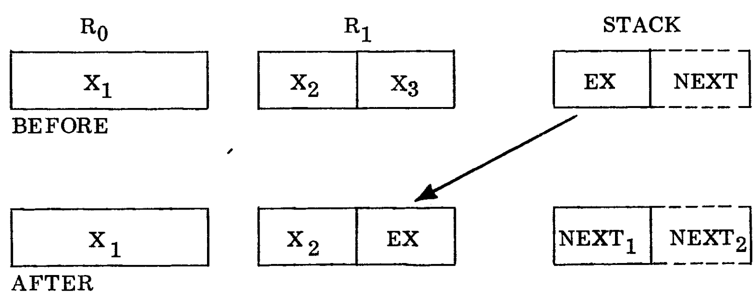
ENTRY POINT: FC7C
ENTRY CONDITIONS: R_0, R_1 = X_1, X_2 (EX)
EXIT CONDITIONS: R_0, R_1 = X_1, X_2 (0) STACK = EX R_2, R_3 PRESERVED
EXECUTION TIME: 13R + W + 51N

TEMPORARY LOCATIONS USED: 00E0
SUBROUTINES CALLED: NONE
STACK WORDS NEEDED: 0
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: ADD EXPONENT FROM STACK	LABEL: ADDEXP

DESCRIPTION: AN EXPONENT IN THE STACK IS PLACED IN A FLOATING-POINT WORD IN R_0, R_1.



ENTRY POINT: FCBD
ENTRY CONDITIONS: R_0, R_1 = X_1, X_2 (X_3) STACK = EX
EXIT CONDITIONS: R_0, R_1 = X_1, X_2 (EX) R_2, R_3 PRESERVED
EXECUTION TIME: 13R + W + 51N

TEMPORARY LOCATIONS USED: N 00E0
SUBROUTINES CALLED: NONE
STACK WORDS NEEDED: 1 FOR INPUT EXPONENT ONLY
(MAXIMUM DEPTH)

COMMENTS:
1. ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.
2. <u>WARNING</u>: ACCESS THIS SUBROUTINE ONLY BY A JSR INSTRUCTION!

SUBROUTINE: LEFT NORMALIZE	LABEL: LFNOR

DESCRIPTION: LEFT NORMALIZES A FLOATING-POINT NUMBER IN R_0, R_1

ENTRY POINT: FC97
ENTRY CONDITIONS: R_0, R_1 = X
EXIT CONDITIONS: R_0, R_1 = X NORMALIZED ;R_2, R_3 ARE PRESERVED
EXECUTION TIME: 449R + 24W + 1745N

TEMPORARY LOCATIONS USED: 00E0, 00E1
SUBROUTINES CALLED: CZERO, FPCOMP, EXTEXP, DSHL, ADDEXP
STACK WORDS NEEDED: 2
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: DOUBLE LEFT NORMALIZE	LABEL: DLNORM

DESCRIPTION: NORMALIZES TWO FLOATING-POINT NUMBERS R_0, R_1 AND R_2, R_3, WITH THE RESULTANTS SWITCHED (IN REGISTERS R_2, R_3 AND R_0, R_1, RESPECTIVELY). NEW EXPONENTS ARE IN MEMORY.

ENTRY POINT: FC8A
ENTRY CONDITIONS: R_0, R_1 = X_1, X_2 (EX) R_2, R_3 = Y_1, Y_2 (EY)
EXIT CONDITIONS: R_0, R_1 = Y NORMALIZED (EX = 0) R_2, R_3 = X NORMALIZED (EX = 0)
00E6 = EY 00E5 = EX
EXECUTION TIME: 947R + 52W + 3691N

TEMPORARY LOCATIONS USED: 00E0-00E2, 00E5, 00E6
SUBROUTINES CALLED: LFNOR, EXTEXP
STACK WORDS NEEDED: 3
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: FRACTIONAL TO FLOATING POINT — LABEL: FLOAT

DESCRIPTION: CONVERTS DOUBLE-PRECISION FRACTIONAL NUMBER TO FLOATING-POINT FORMAT BY TRUNCATING LEAST SIGNIFICANT 8 BITS.

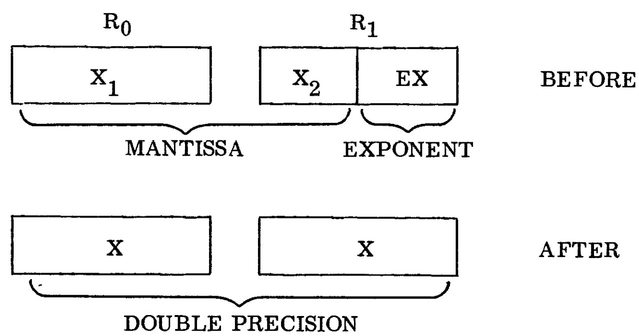
ENTRY POINT: FC85
ENTRY CONDITIONS: R_0, $R_1 = X_1$, X_2
EXIT CONDITIONS: R_0, $R_1 = X_1$, X_2' (0) R_2, R_3 PRESERVED
EXECUTION TIME: 3R + 9N

TEMPORARY LOCATIONS USED: NONE
SUBROUTINES CALLED: NONE
STACK WORDS NEEDED: NONE
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.

SUBROUTINE: FLOATING POINT TO FRACTIONAL — LABEL: SFO

DESCRIPTION: CONVERTS A FLOATING-POINT NUMBER TO A FRACTIONAL DOUBLE-PRECISION NUMBER



ENTRY POINT: FCC7
ENTRY CONDITIONS: R_0, $R_1 = X_1$, X_2 (EX)
EXIT CONDITIONS: R_0, R_1 = X DOUBLE PREC. R_2, R_3 PRESERVED
EXECUTION TIME: 207R + W + 822N

TEMPORARY LOCATIONS USED: 00E0
SUBROUTINES CALLED: EXTEXP, DSH
STACK WORDS NEEDED: 2
(MAXIMUM DEPTH)

COMMENTS: ALL ADDRESSES ARE EXPRESSED IN HEXADECIMAL NOTATION.
CAUTION: VALUE OF INPUT MUST BE < 1.0 IN MAGNITUDE.

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