1103 CENTRAL EXCHANGE

NEWSLETTER NUMBER 10

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FORM ERA 9

Newsletter Number 10

December 1956

EDITOR'S PAGE

Correction: On page 9-392 of Newsletter 9, line 2, paragraph 4, of RR-162 should read ". . .will be p-1 = 2^{35}-32=34, 359,738,336. . .".

Correction: The octal equivalent given for the constant A_4 in the descriptions for the arsin-arcos floating point (RR-75) and the arcsin-arcos stated point (RR-25) routines is in error and should read

37 50417 41233

instead of the listed value of

37 04174 41233.

This correction should be entered in Newsletter 3 (pg. 3-108) for RR-25 and in Newsletter 6 (pg. 6-73) for RR-75.

Editor,
Central Exchange

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REVISIONS

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RW-149 Arcsine-Arcosine Routine, Floating Point

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RR-86 FLEXIE - Flex Code Paper Tape Input Routine

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

General Card Read-In Routine

Specifications

Identification Tag:	CRI-3
Type:	Service Routine (with subroutine entrance)
Special Storage:	The constant pool and temporary pool are not used by this routine
Program Entrance:	40017b
Program Exit:	40020b
Alarm Exit:	The alarm routine is used by this routine

Coded by:	M. Perry	November, 1956
Approved by:	W. F. Bauer	November, 1956

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Description

This routine reads cards produced by MDP-1 (binary cards), CPO-0 (fixed point output), CPO-1 (floating point output) and cards key-punched on the 4 field format (described below) for input in floating point, double precision floating point, fixed point, or octal. These input forms may be intermixed on a card, and the cards may be in any sequence desired. The routine automatically differentiates the 2 card forms, and for 4 field cards, recognizes the type of input in each field. All input is rounded properly. This routine reads cards at full card reader speed and loads the memory as directed by the address or addresses appearing on the cards. Once activated, it continues to read cards until it has read and stored a card containing a stop code as described below. The input need not be normalized to retain full significance. The routine stores high speed memory on the drum, operates in high speed memory, and restores high speed memory from the drum prior to leaving the routine.

Operating Instructions

1. When routine is used as a service routine, set PAK to 40017b and start. Routine will read cards until a stop code is recognized, at which time the machine will stop (MSO) with PAK set to 40017b.

2. When routine is used as a subroutine, enter the routine with 37 40020 40017b. Routine will read cards until a stop code is recognized, at which time control is transferred to cell 40020b and hence to the cell following the return jump mentioned above.

   To restore high speed memory at any time, start at 40040b. A and Q will not be restored.

Card Positioning

Card positioning is required before the initial read only. Card reading automatically positions the next card to be read, and a card will be positioned for punching before leaving the routine. If the routine is used as a service routine, the initial positioning must be manual. If the routine is used as a subroutine, initial card positioning should be programmed. This can only be done by one instruction, [EF 00000 vvvvv] where vvvvv contains 00 00000 00114b.

Stop Codes

1. Read stop, 12 col 80. When this code is detected on either a binary card or a four field input card, the routine will stop reading, position a card on the punch side of the bull, and then exit properly (see operating instructions).

2. Machine stop, 12 col 79. When this code is detected on a 4 field input card, the routine will stop reading, position a card on the punch side of the bull, and stop MSO at 72431b. If the machine is started, the exit from the routine will proceed as described in operating instructions.

Either of the above codes may be entered on a blank card and the routine will sense them. The programmer is cautioned not to place the machine stop code on a binary card as this will result in improper loading (see MDP-1 write-up).

Alarm Conditions

1. Binary Cards - As a binary card is read, the words are summed and the result is compared with a sum punched in the card (see MDP-1 write-up). If the sums do not agree, the flexowriter will print

"ALARM 00271 000000000000 0000000vvvvv QQQQQQQQQQQQ"

and the machine will stop. vvvvv is the storage address appearing on the card. The contents of Q are not important. Starting the computer will bypass the alarm, the words will be stored as read, and in the absence of a stop code, reading will proceed.

2. 4 Field Cards - An alarm on a four field card indicates that a number was too large to be entered appropriately into the computer. For floating point numbers (single and double precision) this is equivalent to exponent overflow. For fixed point numbers, this indicates that the input properly scaled and rounded was too large to be entered into a single cell. If an alarm condition is detected, the flexowriter will print

"ALARM 00164 000000000000 0000000vvvvv 000000000000"

and the machine will stop. vvvvv is the storage address of the right-most incorrect number. Any or all of the other numbers may have been incorrect. vvvvv equal to 20,000 indicates that the indicated address field was blank. Starting the computer will cause the correct numbers to be stored, the incorrect numbers to be ignored, and in the absence of a stop code, reading will proceed.

4 Field Card Format

The format described below is one of the formats used by this routine and is the format used by CPO-0, CPO-1, CRI-2, and SNAP Read.

The card columns are designated as follows:

Col 1-4	Identification	This field is ignored by the reading routines
Col 5-23	Field 1	
Col 24-42	Field 2	
Col 43-61	Field 3	
Col 62-80	Field 4	

Each field (except identification) is divided as follows.

digit 1-5	Location or address	(x digit 1 for octal location)
digit 6-15	Value or Mantissa	(x digit 15 for negative value)
digit 16-17	Decimal exponent	(x digit 17 for negative exponent)
digit 18-19	Binary exponent	(x digit 19 for negative exponent)

Addressing Options

The following Addressing options are allowable on the 4 Field input card. Option 1 is used by CPO-0, CPO-1, CRI-2, and SNAP Input.

1. Decimal - Straight conversion to the octal equivalent of the decimal address in the card. No indication is necessary.

2. RAWOOP Decimal - Straight conversion to the octal equivalent of the decimal address except that 40,000 decimal is designated as the first drum address (40,000b). No indication is necessary.

3. Octal - The octal number appearing on the card is the actual address. This must be indicated by an x(11 punch) over the first digit of the address.

4. Blank - A completely blank address field indicates that the number in that field is not to be stored. This is differentiated from an address containing 1 or more zeros which will load cell zero.

Input Numbers

The following varieties of input may be punched on the 4 field input card. They may be in any combination on a card with the exception that for a double precision floating point number the two fields must be consecutive and on the same card. For all input, the decimal point is presumed to be at the extreme left end of the value field. It is recommended that the codes listed below be used for each field. However, cards from CPO-0 and CPO-1 are differentiated by the fact that their "B" (Binary Exponent) fields are non-blank and blank respectively.

1. Floating Point - RS. An input number is designated as floating point by the code RS (Read Snap) in the "B" field. There is no restriction on the "D" field. The resulting floating binary number is rounded and is in the form used by SNAP and by the internal floating point on the 1103A computer. A floating point number consists of 3 parts; a sign bit, followed by an 8 binary bit characteristic biased by 200b, and a 27 bit normalized mantissa. To negate a floating point number, the complete cell is complemented.

2. Double Precision Floating Point - RT. An input number is designated as double precision floating point by the code RT (Read Two) in the "B" field. The "value" portions of 2 consecutive fields are joined to allow 20 decimal digits of input. Both fields must contain addresses but the control information (RT code, algebraic sign, and decimal exponent) is taken from the first field only and ignored on the second field. The resulting floating binary number is rounded and is in the form used by double precision SNAP. The upper cell is identical to a single precision floating point number and the lower cell

consists of a sign bit and 35 binary digits which are an extension of the 27 binary digit mantissa in the upper cell.

The programmer is again cautioned that the two fields concerned must be consecutive and on the same card.

3. Fixed Point - No code. An input number is designated as fixed point by the fact that the "B" field is not blank and does not contain an R. Since the "B" field is used to express the binary scale factor desired, the only caution is that it must not be left blank. 00 (zero zero) must be punched if a scale factor of zero is desired. The binary scale factor is allowed to be negative and the only restriction is that the combination of the B and D fields result in a number which is not too large for a single cell. Normalization is not important since the conversion is done in double precision. The resulting binary number is rounded properly.

4. Octal - RU. An input number is designated as being octal by the code RU (Read Unconverted) in the "B" field. Since 12 octal digits are desirable, the "value" and "D" fields are joined giving 12 digits. Each digit is loaded modulo 8, such that an 8 becomes a zero, and a 9 becomes a 1.

Examples. The following list of input would be punched on two cards. The second card would have a "Stop Read" code in col 80 because of the "+" sign on the last line. The octal address and translation are listed in the comments.

QUANTITY	LOCATION	VALUE	±	D	±	B	±	COMMENTS
	$\overline{4}$,0,1,2,2	1,2,0		0,1		R,S		40122 20 14631 46315
	1,6,3,8,4	4,5,0,0,0,0,0,0,0,4		2,5		R,U		40000 45 00000 00425
	4,0,0,6,4	3,1,4,1,5,9,2,6,5,3	-	0,1		R,T		40100 57 51557 00452
	4,0,0,6,5	5,8,9,7,9,3,2,3,8,5						40101 75 67513 47562
	$\overline{0}$,0,1,2,3	0,0,1,5		0,4		0,0		00123 00 00000 00017
	9,9	1,5		0,2		1,5		00143 00 00017 00000
	1,0,0	1	-	0,1		1,2		00144 77 77777 67777
	$\overline{0}$,0,1,2,2	1,5	-	0,1		R,S	+	00122 57 61777 77777

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THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Eigenvalues of a Tri-Diagonal Matrix

Specifications

Identification Tag:	EGN-1
Type:	Subroutine available on cards for assembly.
Storage:	145 words of storage needed to assemble this routine. 18 + 2n cells of temporary storage immediately following the temporary pool used, but not stored with subroutine. (n = order of matrix). The constant pool and temporary storage pools are used by this routine.
Regional Addresses Used:	OOR, O1M, O2M, O1R, OOK, OOT, FOO, COO
Entrance and Exit:	RJ OOR01 OOR02 No Punching RJ OOR01 OOR03 Cards Punched } See Instructions
Machine Time:	See table in text.
Mode of Operation:	Floating Complex Arithmetic requiring SNIP be activated.

Coded by:	W. Frank	September 1956
Approved by:	W. Bauer	October 1956

Description

This subroutine computes the n eigenvalues of any real or complex tri-diagonal matrix D, having the form:

$$D = \begin{bmatrix} a_1 & b_1 & 0 & \cdot & \cdot & \cdot & 0 \\ 1 & a_2 & b_2 & \cdot & \cdot & \cdot & 0 \\ 0 & 1 & a_3 & b_3 & \cdot & \cdot & 0 \\ \cdot & & \cdot & & & & \cdot \\ \cdot & & & \cdot & & & \cdot \\ \cdot & & & & a_{n-1} & & b_{n-1} \\ 0 & \cdot & \cdot & \cdot & 1 & & a_n \end{bmatrix}$$

Since complex arithmetic is employed, the elements of the matrix must be presented according to the specification for number representation for use with SNIP. The n elements of the main diagonal, a_i, must be followed by the n-1 elements of the upper adjacent diagonal, b_i, in a region whose initial address is specified by a parameter word.

The more general tri-diagonal matrix J, (also called a "Jacobi Matrix") has all its non-zero elements on the main diagonal and on either of the two immediately adjacent diagonals:

$$J = \begin{bmatrix} a_1 & b_1 & 0 & & \cdot & \cdot & \cdot & 0 \\ c_1 & a_2 & b_2 & 0 & \cdot & \cdot & \cdot & 0 \\ 0 & c_2 & a_3 & b_3 & \cdot & \cdot & \cdot & 0 \\ \cdot & & & \cdot & & & & \\ \cdot & & & & \cdot & & & \\ \cdot & & & & & \cdot & & \\ 0 & \cdot & \cdot & \cdot & \cdot & c_{n-1} & a_{n-1} & b_{n-1} \end{bmatrix}$$

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This routine can also treat this case if in place of the n-1 elements of the upper adjacent diagonal, the n-1 products, $c_i b_i$, are supplied.

The subroutine occupies 145 cells and uses the constant and temporary storage pools. In addition 18 + 2n cells of temporary storage must be provided immediately following the Ramo-Wooldridge Temporary Pool. Practical limitations are imposed on n by the available 1024 words of ES storage and the use of SNIP, hence n must be less than 157. In all cases the eigenvalues can be found in the last 2n cells of the (18+2n) cells of temporary storage. In addition the eigenvalues λ_i and associated residues in the characteristic polynomial $P(\lambda_i)$ can be punched on cards. $P(\lambda_i)$ appears in fields one and two while λ_i is in fields five and six. The eigenvalues are also identified serially in the identification field. At the option of the programmer the successive approximations to the λ_i obtained during the iterative process can also be punched with their associated residues in the reduced polynomial. In the event that no punching is desired then a third entrance is available.

Programming Instructions

1. Complex mode of SNIP must be activated.
2. Entrance to the subroutine is made as follows:
   a. RJ OOR01 OOR03

      XX OOA00 vvvvv

      where

      OOR00 is the location of the first word of the subroutine

      OOA00 is the location of the real part of the first element of the diagonal

      vvvvv is the order n of the tri-diagonal matrix

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XX gives the option selected

XX = 20, only the eigenvalues λ_i and their respective residues in the characteristic equation are punched.

XX = 00, in addition to the above, the successive approximation to the eigenvalues are punched.

In either case the eigenvalues themselves are stored in the machine starting at the location 51 = 63b.

b. Should no punching of cards be desired then one must use the entrance:

RJ 00R01 00R02

20 00A00 vvvvv

3. Control is returned to the cell following the parameter word.

Machine Time

The time taken to find the n eigenvalues can be estimated from the following table of empirical times in seconds.

Order of Matrix	No Punching	Punching Eigenvalues	Punching Eigenvalues and Iterations
3	5 Sec.	8 Sec.	13 Sec.
5	17 "	22 "	36 "
8	50 "	58 "	92 "
10	81 "	91 "	143 "
27	776 "	803 "	-
39	2743 "	2782 "	-

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Given the tri-diagonal matrix J

$$J = \begin{bmatrix} a_1 & b_1 & 0 & \cdot & \cdot & \cdot & 0 \\ c_1 & a_2 & b_2 & & & & \\ 0 & c_2 & a_3 & b_3 & \cdot & \cdot & \\ & & & \cdot & & & \\ & & & & \cdot & & \\ & & & & & a_{n-1} & b_{n-1} \\ 0 & \cdot & \cdot & \cdot & \cdot & c_{n-1} & a_n \end{bmatrix}$$

The following recursion formula evaluates the characteristic polynomial $P_n(\lambda)$ of J for given λ:

$$P_i(\lambda) = (a_i - \lambda) P_{i-1}(\lambda) - b_{i-1} c_{i-1} P_{i-2}(\lambda) \qquad i = 1, 2, \ldots, n$$

where

$$P_{-1} = 0 \qquad P_o = 1$$

The problem loses no generality by assuming all $c_i = 1$ so that only the a_i and b_i need be given. Alternatively the general problem can be solved by this routine if one supplies $c_i b_i$ in place of b_i.

Using $P_n(-1)$, $P_n(1)$ and $P_n(0)$, the program enters a modified version of the Algebraic Equation Solver (POL-0) and finds, by iteration, the first root λ_1 of $P_n(\lambda)$.

Having found r roots the $(r+1)^{st}$ root is found by considering the polynomial

$$P_{n-r}(\lambda) = \frac{P_n(\lambda)}{\prod_{i=1}^{r} (\lambda - \lambda_i)}$$

where $\lambda_1, \lambda_2, \ldots, \lambda_r$ are the eigenvalues already found. This code prevents the re-computation of a multiple eigenvalue by not allowing λ_{r+1} to approach the value of any of the r roots already found. This, however, did not prohibit the determination of multiple roots in any of the matrices tested, for the reason stated below.

Convergence

A convergence criterion

$$\left| \frac{\lambda_{i+1} - \lambda_i}{\lambda_{i+1}} \right| < 10^{-k}$$

is applied to determine the end of the iteration. In this code k = 6. This gives an accuracy of 6 to 7 places in many low order cases. For large order ($n \geq 20$) accuracy is reduced since not enough figures are carried in the 27 bit word of SNIP to accurately define the roots after a large number of arithmetic operations have been performed. In the case eigenvalues are repeated the accuracy deteriorates. Furthermore, the residues of the characteristic polynomials in the neighborhood of such a root are exceedingly small. Hence, a second convergence criterion was introduced in order to avoid exponent overflow. If the residue

$$P_{n-r}(\lambda) \leq 2^{-100}$$

then λ_i is accepted as a root. If λ_p has multiplicity p then the code will find p estimates of λ_p such that

a) no two estimates are equal

b) all estimates have residues $\leq 2^{-100}$

If λ_k is an eigenvalue then $\det(D - \lambda_k I)$ should be zero. Inspecting successive iterations and associated residues can therefore give some indication of the convergence of the procedure. The programmer is, however, cautioned in regards

to using this quantity as a measure of accuracy of the root. It is possible, for example, to have a root accurate to 6 places and yet obtain a residue of high order.

```
D          00R00  00100
D          01M00  00118
D          02M00  00151
D          01R00  00204
D          00K00  00239
D          00T00  00033
D          F0000  00002
D          C0000  00003
00R00   00 00000  01R16
00R01   MJ 00000  00000      EXIT
00R02   MJ 00000  02M37      ENTRANCE 1
00R03   TP 01R34  02M50      ENTRANCE 2
00R04   SP 00R01  00015
00R05   TU A0000  00R07       S
00R06   TU A0000  02M32         E
00R07   TP 00000  A0000           T
00R08   TP 00013  00T15
00R09   TP 00013  00T14       A
00R10   TV A0000  00T15         D
00R11   TU A0000  00R00         O
00R12   TP 00K05  Q0000           R
00R13   RS 00T15  00016      N-1   E
00R14   LA A0000  00016      2N-2   $
00R15   QS A0000  01R06                S
00R16   TP 00T15  00T16                  E
00R17   TN 00016  00T17                    S
01M00   RA 00R01  00016
01M01   RP 10005  01M03      SET
01M02   TP 00013  00T09
01M03   TP 00K01  00T12       UP
01M04   TN 00K00  00T08
01M05   TP 00K00  00T10       STARTING
01M06   TN 00K01  00T06
01M07   TP 00013  00T07       VALUES
01M08   RJ 01R30  01R00
01M09   TP 00029  00T00
01M10   TP 00030  00T01
01M11   TP 00K01  00T06
01M12   RJ 01R30  01R00
01M13   TP 00029  00T02
01M14   TP 00030  00T03
01M15   TP 00013  00T06
01M16   RJ 01R30  01R00
01M17   TP 00029  00T04
01M18   TP 00030  00T05
01M19   MJ 00000  02M31
01M20 LDMP 00T00  00T08
01M21 ADST 00T04  00023
01M22 MPST 00T08  00025
01M23 LDMP 00T02  00T10
01M24 STSU 00027  00023      S
```

```
00144  00 00000 00000
00166  00 00000 00000
00227  00 00000 00000
00314  00 00000 00000
00357  00 00000 00000
00041  00 00000 00000
00002  00 00000 00000
00003  00 00000 00000
00144  00 00000 00334
00145  45 00000 00000
00146  45 00000 00274
00147  11 00356 00311
00150  31 00145 00017
00151  15 20000 00153
00152  15 20000 00267
00153  11 00000 20000
00154  11 00015 00060
00155  11 00015 00057
00156  16 20000 00060
00157  15 20000 00144
00160  11 00364 10000
00161  23 00060 00020
00162  54 20000 00020
00163  53 20000 00322
00164  11 00060 00061
00165  13 00020 00062
00166  21 00145 00020
00167  75 10005 00171
00170  11 00015 00052
00171  11 00360 00055
00172  13 00357 00051
00173  11 00357 00053
00174  13 00360 00047
00175  11 00015 00050
00176  37 00352 00314
00177  11 00035 00041
00200  11 00036 00042
00201  11 00360 00047
00202  37 00352 00314
00203  11 00035 00043
00204  11 00036 00044
00205  11 00015 00047
00206  37 00352 00314
00207  11 00035 00045
00210  11 00036 00046
00211  45 00000 00266
00212  14 30041 14051
00213  14 04045 34027
00214  14 14051 34031
00215  14 30043 14053
00216  14 34033 11027
```

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```
01M25 LDMP 00T04 00T10
01M26 ADNO F0000 00000
01M27   TN F0000 00029
01M28   TN C0000 00030
01M29 ADMP F0000 00T08
01M30 MPLD 00023 00T04    S
01M31 SUMP 00027 00T10
01M32 ADMP 00025 F0000    S
02M00 ADRT 00023 00023        S
02M01   TN C0000 C0000
02M02 LDMP F0000 00025
02M03   SJ 02M04 02M06
02M04   TN 00023 00023          F
02M05   TN 00024 00024            I
02M06 LDAD 00025 00023        S   N
02M07 PMNO 00000 00000            D
02M08   ZJ 02M10 02M09
02M09   TP 00K01 00023
02M10 LDDV 00029 00023            ITERANT
02M11 STMP 00T08 00T12        S
02M12 ADNO 00T06 00000    S       AND
02M13   RJ 01R30 01R00
02M14 DVPM 00T04 00000            FUNCTIONAL
02M15   TJ 00K02 02M20
02M16   TN 00K00 F0000            VALUE
02M17   TP 00013 C0000
02M18 LDMP F0000 00T08
02M19   MJ 00000 02M11
02M20   TP 00K01 F0000
02M21 ADNO 00T08 00000
02M22   TP F0000 00T10
02M23   TP 00T09 00T11
02M24   RP 30004 02M26          SET UP
02M25   TP 00T02 00T00
02M26   TP 00029 00T04            FORNEXT
02M27   TP 00030 00T05
02M28 LDDV 00T12 00T06            ITERATION
02M29 PMNO 00000 00000
02M30   TJ 00K03 02M40          CONVERGED
02M31   TP 02M29 A0000
02M32   TJ 00000 01M20
02M33   RP 30004 02M35
02M34   TP 00T04 00006
02M35 PDNO 00010 00000
02M36   MJ 00000 01M20
02M37   TP 02M39 02M50
02M38   MJ 00000 00R04
02M39   MJ 00000 02M51
02M40   TP 00T14 00004
02M41 LDST 00T06 00008
02M42 STST 00025 00T18        B
```

```
00217  14 30045 14053
00220  14 04002 00000
00221  13 00002 00035
00222  13 00003 00036
00223  14 04002 14051
00224  14 15027 30045
00225  14 10033 14053
00226  14 05031 14002
00227  14 04027 51027
00230  13 00003 00003
00231  14 30002 14031
00232  46 00233 00235
00233  13 00027 00027
00234  13 00030 00030
00235  14 30031 05027
00236  14 24000 00000
00237  47 00241 00240
00240  11 00360 00027
00241  14 30035 20027
00242  14 34051 15055
00243  14 05047 00000
00244  37 00352 00314
00245  14 20045 24000
00246  42 00361 00253
00247  13 00357 00002
00250  11 00015 00003
00251  14 30002 14051
00252  45 00000 00242
00253  11 00360 00002
00254  14 04051 00000
00255  11 00002 00053
00256  11 00052 00054
00257  75 30004 00261
00260  11 00043 00041
00261  11 00035 00045
00262  11 00036 00046
00263  14 30055 20047
00264  14 24000 00000
00265  42 00362 00277
00266  11 00264 20000
00267  42 00000 00212
00270  75 30004 00272
00271  11 00045 00006
00272  14 74012 00000
00273  45 00000 00212
00274  11 00276 00311
00275  45 00000 00150
00276  45 00000 00312
00277  11 00057 00004
00300  14 30047 34010
00301  14 34031 36063
```

```
02M43    RA 00T14 00K04                                  00302  21 00057 00363
02M44    RJ 01R15 01R01                                  00303  37 00333 00315
02M45    TP F0000 00006                                  00304  11 00002 00006
02M46    TP C0000 00007                                  00305  11 00003 00007
02M47    RA 00T17 00016                                  00306  21 00062 00020
02M48    SA 00016 00015                                  00307  32 00020 00017
02M49    TU A0000 00005          PUNCH                   00310  15 20000 00005
02M50  PDPD 00010 00010          ITERANT                 00311  14 74012 74012
02M51    IJ 00T16 01M01                                  00312  41 00061 00167
02M52    MJ 00000 00R01                                  00313  45 00000 00145
01R00    TV 00R00 01R15                                  00314  16 00144 00333
01R01    RP 10003 01R03                                  00315  75 10003 00317
01R02    TP 00013 00030          E                       00316  11 00015 00036
01R03    TP 00K01 00029           V                      00317  11 00360 00035
01R04    TU 00R00 00004                                  00320  15 00144 00004
01R05    TP 00T15 00023              L                   00321  11 00060 00027
01R06  LDMP 00000 00031  B     S      U                  00322  14 32000 15037
01R07  LDSU 00000 00T06  B                               00323  14 32000 10047
01R08  MPSU 00029 00031                 T                00324  14 14035 10037
01R09    TP 00029 00031                  E                00325  11 00035 00037
01R10    TP 00030 00032                   S               00326  11 00036 00040
01R11    TP F0000 00029          C                       00327  11 00002 00035
01R12    TP C0000 00030           H                      00330  11 00003 00036
01R13    RA 00004 00K04            A                     00331  21 00004 00363
01R14    IJ 00023 01R06               R                  00332  41 00027 00322
01R15    MJ 00000 00000                A                 00333  45 00000 00000
01R16    TP 00T17 A0000                 C                00334  11 00062 20000
01R17    SJ 01R28 01R18                 T                00335  46 00350 00336
01R18    TP 00T17 00023                   E              00336  11 00062 00027
01R19    TP 00K01 00031                  R               00337  11 00360 00037
01R20    TP 00013 00032           ISTIC                  00340  11 00015 00040
01R21    TP 00013 00004                                  00341  11 00015 00004
01R22  LDSU 00T06 00T18       B                         00342  14 30047 12063
01R23  MPPM 00031 00000    S                            00343  14 15037 24000
01R24    ZJ 01R25 01R31          EQUATION                00344  47 00345 00353
01R25    RA 00004 00K04                                  00345  21 00004 00363
01R26    IJ 00023 01R22                                  00346  41 00027 00342
01R27  LDDV 00029 00031                                  00347  14 30035 20037
01R28  STPM 00029 00000                                  00350  14 34035 24000
01R29    ZJ 01R30 02M40          CONVERGED               00351  47 00352 00277
01R30    MJ 00000 00000                                  00352  45 00000 00000
01R31    TP 00K00 F0000                                  00353  11 00357 00002
01R32  ADNO 00T06 00000    S                            00354  14 05047 00000
01R33    MJ 00000 01R01                                  00355  45 00000 00315
01R34  PDPD 00010 00010                                  00356  14 74012 74012
00K00    05 00000 00000 -01 F    C                       00357  20 04000 00000
00K01    01 00000 00000     F     O                      00360  20 14000 00000
00K02    01 00000 00000   1 F      N                     00361  20 45000 00000
00K03    01 00000 00000 -06 F       S                    00362  15 54143 36750
00K04    00 00002 00000               T                  00363  00 00002 00000
00K05    00 00777 00000 B              ANTS              00364  00 00777 00000
START                                                    00000  45 00000 00000
```

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THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Floating Point Card Dump

Specifications

Identification Tag:	MDP-5
Type:	Service Routine (with subroutine entrance)
Service Entrance:	Address 40024 b
Program Entrance and Exit:	37 40020 40024 b
Other Routines Used:	This routine uses MDP-4 and SNAP Output

Coded and Checked by:	R. Beach	October, 1956
Approved:	W. F. Bauer	October, 1956

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Description:

This routine operates exactly the same as MDP-4 (Octal Card Dump) with the following exceptions:

1. Entrance Address is 40024 b

2. Output is floating decimal on SNAP output cards. Addresses are five digit octal numbers with leading zeros suppressed.

3. A parameter word of zero will dump cells 00000 - 00777 b.

The routine treats each word to be dumped as a floating point (SNAP form) number and converts it to a floating decimal number. Non SNAP numbers (i.e. instructions and fixed point numbers) may be included among the words to be dumped but their converted values will be meaningless.

The listing will be double-spaced; however, if a card was omitted because it would have contained all zeros, no additional spacing is provided on the listing.

The routine is essentially a driver for the SNAP output routine and MDP-4, modifying each so that MDP-4 uses the SNAP output routine instead of its octal output section.

REMINGTON RAND UNIVAC

ST. PAUL DEPARTMENT—INFORMATION SCIENCE

18 December 1956

1103 TO 1103A CONVERSION ROUTINE

I. TYPE: Service routine or subroutine.

II. STATUS: Code checked and machine checked by Bill Wallace.

III. PURPOSE: This routine changes A and Q machine addresses from 20000 and 10000 to 32000 and 31000 respectively, and detects magnetic tape and external function instructions. Various options are provided for print out of those addresses where an A or Q reference is modified, (indicating also u or v portion) and punching the converted program in bioctal or flex code.

IV. USAGE:

A. STORAGE REQUIRED: The program is coded in RECO form and it is therefore possible to operate the program from a location providing 320 octal drum address and 2000 additional octal drum addresses for a HSS image region. Such a location of the program and image region is done by assigning the desired starting addresses to regions BB and IR respectively, of the reco tape (see coding) all other regions being in HSS, and hence remaining the same. The regional assignment can be on a separate tape from the main program reco tape, but this tape should have END. c.r. at the end. (See RECO write-up.)

In addition to the RECO tapes, a bioctal tape of the program is available where the program is stored at 66000-66320, with the image region 76000-77777.

B. INPUT-OUTPUT: Output is a punched tape in bioctal or flex code of the changed program if desired. Also the following is printed out as the conversion routine is operating: (This is also optional.) u aaaaa or vaaaaa, where aaaaa is the address where an A or Q reference has been modified and u or v shows whether the u or v address of the instruction has been modified. Also, TAPE is printed out when an 1103 magnetic tape instruction is encountered, and EF and address when an external function command occurs.

C. OPERATING INSTRUCTIONS:

(1) Used as a service routine proceed as follows: (the term "program" here refers to a program to be converted.)

a) Master clear, MD start
b) Set PAK to 66000, (or bb)
c) Insert in Q_u the first address of the program
d) Insert in Q_v the last address of the program
e) Insert in v address of A_R the address of the last instruction of the program, or the last address of the program wherein one wishes to have A and Q addresses modified.

f) Insert in v address of A_L the following codes for the various options:

00000 bioctal punch of converted program and print out of addresses where modification occurs.

00001 same as above but no print out.

00002 flex code punch of converted program and print out.

00003 same as above, but no print out.

00004 print out, but no punch of converted program.

00005 no print out and no punch of converted program.

A 56 0 66010 (bb10) stop occurs if a gross error is made in the set-up, e.g. transposition of Q_u and Q_v.

(2) Used as a subroutine, proceed as follows:

a) Program the transfer of parameter as listed above to the A and Q registers.
b) Execute the instruction:
RJ bb2 bb
c) The options are selected in the same manner as previously shown.

(3)

a) The use of this conversion routine assumes that the program to be converted is stored either all in core storage or all in drum storage.
b) The conversion routine is coded for operation on either an 1103A, or on the 1103 (Serial 9) at RRU, St. Paul.

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V. CODING

A. Regions

```
re bb66000          re ual24
re ir76000          re val37
re ff30000          re upl55
re cr0              re prl62
re cb33             re tpl73
re cd54             re ef200
re cf71             re cs205
re kk75             re dd212
re mml12            re tt310
```

B. Program

```
bb0          45  0      bbl0     Entrance
  1          56  0      bbl0     Error stop
  2          45  0      (ff)     Subroutine exit
  3          0   0      0        Storage first address
  4          0   0      0        Storage last address
  5          0   0      0        Storage initial A
  6          0   0      0        Storage initial Q^r
  7          45  0      ff       Constant
 10          tp  Q      bb6
111          lt  10000  bb5
 12          lt  00000  A
 13          tp  0      ir
 14          tp  bb     0
 15          rp  31777  bbl7
 16          tp  1      irl      Store HSS
 17          rp  30400  cb       To start of core program
 20          tp  bbl    crl      Conclusion of program
 21          rp  31777  bb23
 22          tp  irl    1        Restore HSS
 23          tp  ir     0
 24          tp  bb6    Q        Restore Q for dump
 25          tp  bb7    A
 26          ej  bb2    bb31     Test, subr. or serv?
 27          rj  70036  (70006)  No, subr.
 30          45  0      bb2      To exit
 31          rj  70036  (70006)
 32          56  00000  bb

 33  cb0     ej  dd43   cd       No punch
 34    1     ej  dd64   cd2      Punch flex
 35    2     ej  dd65   cd5      No print, no punch
 36    3     ej  dd66   cdl3     No print, punch flex
 37    4     ej  dd60   cd6      No print, punch bioctal
 40    5     tp  cr5    A        Last address
```

```
41    6     tj   dd     cf      HSS?
42    7     qt   dd1    cr4     Store first address
43   10     lq   q      25
44   11     qt   dd1    cr3     Store last address
45   12     tv   cr3    mm      Set up transfer
46   13     la   cr3    20017   of Modified Contents
47   14     tu   A      kk      Set up first address
50   15     ra   cr4    dd60    to be modified
51   16     st   cr3    tt      No. of words
52   17     ij   tt     kk
53   20     45   0      bb1     Error

54   cd0    tv   dd67   mm4
55    1     45   0      cb5     No punch
56    2     rs   bb27   dd60
57    3     rs   bb31   dd60
60    4     45   0      cb5     Flex punch
61    5     rj   cd1    cd
62    6     tv   up4    ua10
63    7     tv   up4    ua12
64   10     tv   va15   va7
65   11     tp   va15   va11    No print
66   12     45   0      cb5
67   13     rj   cd4    cd2
70   14     45   0      cd6

71   cf0    ra   cr5    dd3     Add 76000 to V
72    1     ra   Q      dd2     Add 76000 to U and V
73    2     tp   cs     pr      Arrange to print core address
74    3     45   0      cb7

75   kk0    tp   (ff)   Q
76    1     tp   Q      tt1
77    2     qt   dd5    tt3     Mask operation code
100   3     tp   tt3    A
101   4     ej   dd10   ef      External function
102   5     ej   dd11   mm      Final stop
103   6     ej   dd12   mm      Interpret
104   7     rp   20014  kk11    Commands where
105  10     ej   dd13   tp      V only to be modified
                                  and tape commands
106  11     rp   20004  kk13    Split instruction,
107  12     ej   dd27   mm10    Modify U only
110  13     rj   ua6    ua      Modify U
111  14     rj   va5    va      Modify V
112  mm0    tp   tt1    (tt1)   Transfer modified
113   1     tp   kk     A           Content
114   2     lt   25     A       Obtain current
115   3     rs   dd6    A       Address
116   4     ej   cr5    bb21    Test, end of
117   5     ra   kk     dd7     Modifiable address
```

```
120    6     ra   mm     dd60      Add 1
121    7     45   0      eb17
122   10     rj   ua6    ua        Modify U only
123   11     45   0      mm

124   ua0    tp   tt1    Q
125    1     lq   Q      25
126    2     qt   dd33   tt4       Mask 1st octal digit
127    3     tp   tt4    A
130    4     ej   dd34   ua7       Q?
131    5     ej   dd35   ua11      A?
132    6     45   0      ff
133    7     ra   tt1    dd36      Add 21000
134   10     45   0      up        To print
135   11     ra   tt1    dd37      Add 12000
136   12     45   0      up

137   va0    tp   tt1    Q
140    1     qt   dd33   tt4
141    2     tp   tt4    A
142    3     ej   dd34   va6       Q?
143    4     ej   dd35   va10      A?
144    5     45   0      ff
145    6     ra   tt1    dd40      Add 21000
146    7     45   0      va11      To print
147   10     ra   tt1    dd41      Add 12000
150   11     pr   0      dd42      Carriage return
151   12     pr   0      dd43      Space
152   13     pr   0      dd44      "V"
153   14     rj   pr10   pr
154   15     45   0      va5

155   up0    pr   0      dd42      Carriage return
156    1     pr   0      dd45      "U"
157    2     pr   0      dd43      Space
160    3     rj   pr10   pr
161    4     45   0      ua6

162   pr0    tp   kk     Q
163    1     lq   Q      6
164    2     tp   dd43   tt2       Index
165    3     lq   Q      3
166    4     qt   dd46   A
167    5     at   dd47   pr6       Print digit
170    6    (pr   0      ff)
171    7     ij   tt2    pr3
172   10     45   0      ff

173   tp0    rp   20004  kk14      Test for tape
174    1     ej   dd20   tp2         Instructions
```

```
175    2      pr   0       dd42        Carriage return
176    3      rp   10004   mm
177    4      pr   0       dd60        Print "tape"

200    ef0    pr   0       dd42        Carriage return
201    1      rp   10005   ef3
202    2      pr   0       dd70        Print "EF"
203    3      rj   pr10    pr          Print address
204    4      45   0       kk14        To V address modification

205    cs0    rj   cs4     cs1
206    1      tu   kk      tt5
207    2      rs   tt5     dd4         Subtract 76000 from V
210    3      tp   tt5     Q
211    4      45   0       ff

212    dd0    0    0       02000
213    1      0    0       77777
214    2      0    76000   76000
215    3      0    0       76000
216    4      0    76000   0
217    5      77   0       0
220    6      0    11      0
221    7      0    1       0
222    10     ef   0       0
223    11     fs   0       0
224    12     ip   0       0
225    13     lt   0       0
226    14     45   0       0
227    15     56   0       0
230    16     pr   0       0
231    17     pu   0       0
232    20     rm   0       0
233    21     wm   0       0
234    22     am   0       0
235    23     bm   0       0
236    24     rp   0       0
237    25     er   0       0
240    26     ew   0       0
241    27     sp   0       0
242    30     sa   0       0
243    31     sn   0       0
244    32     ss   0       0
245    33     0    0       70000
246    34     0    0       10000
247    35     0    0       20000
250    36     0    21000   0
251    37     0    12000   0
252    40     0    0       21000
```

253	41	0	0	12000	
254	42	0	0	45	Carriage return
255	43	0	0	4	Space
256	44	0	0	17	V
257	45	0	0	34	U
260	46	0	0	7	
261	47	61	0	dd50	
262	50	0	0	37	Flex code 0
263	51	0	0	52	1
264	52	0	0	74	2
265	53	0	0	70	3
266	54	0	0	64	4
267	55	0	0	62	5
270	56	0	0	66	6
271	57	0	0	72	7
272	60	0	0	1	flex code t
273	61	0	0	30	flex code a
274	62	0	0	15	flex code p
275	63	0	0	20	flex code e
276	64	0	0	2	
277	65	0	0	5	
300	66	0	0	3	
301	67	0	0	bb32	
302	70	0	0	47	Shift up
303	71	0	0	20	"E"
304	72	0	0	26	"F"
305	73	0	0	57	Shift down
306	74	0	0	4	
307	75	0	0	0	Not used
310	tt0	0	0	0	Temporary storage
311	1	0	0	0	
312	2	0	0	0	
313	3	0	0	0	
314	4	0	0	0	
315	5	0	0	0	

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Remington Rand Univac

Floating Vector Arithmetic Package

GENERAL DESCRIPTION

This package contains four subroutines: vector roll-off, vector unpack, scalar product of two vectors, and vector sum. Each of the subroutines is self-contained and can be used independently of the others. These operations are performed on arbitrarily located vectors of not more than 108 elements. The arithmetic is floating point with one biased characteristic serving for all of the elements of a vector. The bias of the characteristic is $40{,}000_{(8)}$.

PACKED FORM OF A VECTOR

Associated with every vector, $\bar{X} = (x_1,\ldots,x_n)$, is a set of numbers, $(b_1,\ldots,b_n)$, each element of which is either 0 or 1. This set of numbers is defined in the following way: if $x_i=0$, then $b_i=0$; if $x_i\neq 0$, then $b_i=1$. The three binary numbers,

$$b_1x2^{35}+b_2x2^{34}+\ldots+b_{36},$$
$$b_{37}x2^{35}+b_{38}x2^{34}+\ldots+b_{72},$$
$$b_{73}x2^{35}+b_{74}x2^{34}+\ldots+b_{108},$$

where $b_{n+1}=b_{n+2}=\ldots=b_{108}=0$ if $n\angle 108$, are called the Q-words of the vector $\bar{X}$. It is clear that a vector is well-defined if the Q-words, the number of elements, and an ordered list of the non-zero elements are given.

The operand vectors of the floating vector subroutines must be packed (or stored) in the manner which we now describe. The first three addresses of a vector storage location are occupied by the three Q-words.

The mantissae of the non-zero elements of the vector are stored sequentially in the addresses immediately following the address of the last Q-word. These mantissae are scaled so that the numerically largest has 32 binary digits. There are no blank addresses between successive vectors.

Each vector has a keyword. The v-address of the keyword contains the biased characteristic of the vector; the u-address contains the starting address (address of the first Q-word) of the vector. The address of the keyword of a vector is called the directory address of that vector; the aggregate of all the directory addresses of a system of vectors is called the directory of that system. The keywords are stored in the same order as the corresponding vectors, and there are no blank addresses between successive keywords. Following the last keyword in the directory is a pseudo keyword. If the last non-zero mantissa of the last stored vector is in location y, then y+1 is entered in the v-address of the pseudo-keyword.

NOTATION

1. Throughout the subroutines three blocks of addresses are utilized for vector work spaces and temporary storage. We shall refer to these blocks as R, S, and T. By R_i we will mean the ith address in the block R. We denote by m the number of elements in the operand vectors.

PROGRAM PARAMETERS

1. Locations 00005 through 00017 are reserved for constants and program parameters.

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The following parameters must be provided by the programmer:

00005: R_1=starting address of R

00006: S_1=starting address of S

00007: T_1=starting address of T

00010: m=number of elements in operand vectors.

The following parameters are provided by the various subroutines:

00011: Keyword of vector in R

00012: Keyword of next vector in the directory

00013: (u-address) 3+number of non-zero elements of vector in R

00014: Keyword of vector in S

00015: Keyword of vector in T

00016: (u-address) 3+number of non-zero elements of vector in S

00017: (u-address) 3+number of non-zero elements of vector in T.

In the event that the programmer wishes to use some of the routines without using the whole package, it will be necessary for him to provide some of the parameters in this last group.

ROLL-OFF

The roll-off subroutine transfers a packed vector, $\overline{X}$, including Q-words, from permanent storage to R. It is coded in standard form with one exit and one entrance, and is assembly modifiable.

UNPACK

The unpack subroutine unpacks (i.e., provides all zero elements that were omitted in the packed vector) the vector, $\overline{X}$, contained in R and leaves the result in either S or T, depending on which entrance is selected. It is coded in standard form with one exit and two entrances, and is assembly modifiable.

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Before entering the unpack subroutine, $\overline{X}$ must be rolled-off in R. The roll-off provides all program parameters.

SCALAR PRODUCT

If $\overline{X}=(x_1,\ldots,x_n)$ and $\overline{Y}=(y_1,\ldots y_n)$, then the scalar product, $\overline{X}\cdot\overline{Y}$, is defined by

$$\overline{X}\cdot\overline{Y}=\sum_{i=1}^{m} x_i y_i.$$

The scalar product subroutine forms the scalar product of the vector in S and the vector in T. It scales the mantissa of this product so that it contains 32 binary digits.

If either $x_i=0$ or $y_i=0$ then, of course, the term x_iy_i contributes nothing to the scalar product; in this case the subroutine avoids formation of the term x_iy_i.

We give a brief explanation of how the Scalar product is formed. Associated with the sum $\overline{X}\cdot\overline{Y} = \sum_{i=1}^{m} x_i y_i$ are three words

$$C_1: \quad c_1x2^{35}+c_2x2^{34}+\ldots+c_{36},$$

$$C_2: \quad c_{37}x2^{35}+c_{36}x2^{34}+\ldots+c_{108},$$

analogous to the Q-words of a vector (i.e., if $x_iy_i=0$, then $c_i=0$, and if $x_iy_i\neq0$, then $c_i=1$; and if $n<108$, then $c_{n+1}=\ldots=c_{108}=0$). It is clear that if A_1, A_2, A_3 are the Q-words of $\overline{X}$, and if B_1, B_2, B_3 are the Q-words of $\overline{Y}$, then

$$C_i = L(A_i)(B_i),\ i=1,\ 2,\ 3.$$

The subroutine forms C_1, C_2, C_3; it then stores sequentially in S all those x_i, and in T all those y_i, for which $c_i=1$; finally, with a repeated multiply add instruction, it forms the sum.

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$$\bar{X}\cdot\bar{Y} = \sum_{i=1}^{k} (S_i)\ (T_i),$$

where k is the number of non-zero terms in the sum

$$\sum_{i=1}^{m} x_i y_i.$$

Before entering this subroutine the vectors $\bar{X}$ and $\bar{Y}$ must be unpacked in S and T respectively. The unpack subroutine provides all program parameters.

VECTOR SUM

The sum of two vectors $\bar{X}=(x_1,\ldots,x_n)$ and $\bar{Y}=(y_1,\ldots,y_n)$ is defined by

$$\bar{X}+\bar{Y} = (x_1+y_1,\ldots,x_n+y_n).$$

The vector sum subroutine forms the sum of the vector in S and the vector in T and leaves the result in S.

The subroutine compares the characteristics of $\bar{X}$ and $\bar{Y}$; it then shifts right the mantissae of the vector with the smaller characteristic a number of bits equal to the absolute value of the difference of the characteristics; next it adds corresponding mantissae of the two vectors; finally it shifts the mantissae of the sum until the largest has 32 binary digits.

Before entering this subroutine, the vectors $\bar{X}$ and $\bar{Y}$ must be unpacked in S and T respectively. The unpack subroutine provides all necessary parameters.

Roll-Off

Author: P. Nikolai

Date: 27 August 1956

Type: subroutine

Code Check by: R. C. Gunderson

Machine Check by: P. Nikolai

Correction of Routine: R. C. Gunderson

Revision of Routine: C. D. Dixon

Form: Standard 1103 Subroutine;
Assembly modifiable

Exit: 01001

Entrance: 01002

Storage Required:

Instructions: 01000 through 01020

Constants: 01023 through 01023

Temporary Storage: 01021 through 01022

Number of commands for assembly modification: 240

Preliminary settings: The directory address of the vector to be rolled-off must be placed in the u-address of the accumulator.

Final Results:

(R)=Q-words and non-zero mantissae of vector

(00011)=Keyword of vector

(00012)=Next keyword in directory

(00013)=3+number of non-zero elements of vector

Time: 3.64 milliseconds, maximum

Unpack

Author: P. Nikolai Date: 27 August 1956

Type: subroutine

Code Check by: R. C. Gunderson

Machine Check by: P. Nikolai

Correction of Routine: _____

Revision of Routine: C. D. Dixon

Form: Standard 1103 Subroutine
Assembly modifiable

Exit: 01001

Entrance for unpack in T: 01002

Entrance for unpack in S: 01003

Storage Required:

Instructions: 01000 through 01046

Constants: 01047 through 01054

Temporary Storage: 01055 through 01056

Number of commands for assembly modification: $47_{(8)}$

Preliminary Settings: Before entering the unpack subroutine, the vector, $\bar{x}$, must be rolled-off in R. The roll-off subroutine provides all program parameters.

Final Results:

for unpack in S,

(S)=Q-words and mantissae of $\bar{x}$

(00014)=Keyword of $\bar{x}$

(00016)=3+number of non-zero elements of $\bar{x}$

for unpack in T,

(T)=Q-words and mantissae of $\bar{x}$

(00015)=Keyword of $\bar{x}$

(00017)=3+number of non-zero elements of $\bar{x}$

Operating instructions:

1. Directory address of $\bar{x} \longrightarrow A_u$.
2. Enter Roll-off subroutine; roll-off $\bar{x}$ in R.
3. Enter unpack subroutine at 01002 (01003); unpack $\bar{x}$ in T(S).

Time: 32.1 milliseconds, maximum

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Scalar Product

Author: E. Feller

Date: 27 August 1956

Type: subroutine

Code Check by: R. C. Gunderson

Machine Check by: E. Feller

Correction of Routine: R. C. Gunderson

Revision of Routine: C. D. Dixon

Form: Standard 1103 Subroutine;
Assembly modifiable

Exit: 01001

Entrance: 01002

Storage required:

Instructions: 01000 through 01124

Constants: 01125 through 01141

Temporary Storage: 01142 through 01152

Number of commands for assembly modification: $125_{(8)}$

Preliminary settings: Before entering this subroutine the vectors $\bar{x}$ and $\bar{y}$ must be unpacked in S ant T respectively. The unpack subroutine provides all program parameters.

Final Results:

(A)=(01152)= mantissa of $\bar{x}.\bar{y}$.

(Q)=(01151)= characteristic of $\bar{x}.\bar{y}$.

Accuracy: 32 bits

Other subroutines used: Roll-off
Unpack

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Operating Instructions:

1. Directory of $\bar{x}$ $\longrightarrow$ A_u.
2. Enter Roll-off subroutine; roll-off $\bar{x}$ in R.
3. Enter Unpack subroutine at 01003; unpack $\bar{x}$ in S.
4. Directory address of $\bar{y}$ $\longrightarrow$ A_u.
5. Enter Roll-off subroutine; roll-off $\bar{y}$ in R.
6. Enter Unpack subroutine at 01002, unpack $\bar{y}$ in T.
7. Enter Scalar product subroutine; for $\bar{x}\cdot\bar{y}$.

Time:

Vector Sum

Author: P. Nikolai Date: 27 August 1956

Type: subroutine

Code check by: R. Gunderson

Machine Check by: P. Nikolai

Correction of Routine: R. Gunderson

Revision of Routine: C. D. Dixon

Form: Standard 1103 Subroutine
Assembly modifiable

Exit: 01001

Entrance: 01002

Storage Required:

Instructions: 01000 through 01132

Constants: 01133 through 01142

Temporary Storage: 01143 through 01146

Number of Commands for assembly modification: $133_{(8)}$

Preliminary settings: Before entering this subroutine, the vectors $\overline{x}$ and $\overline{y}$ must be unpacked in S and T respectively. The unpack subroutine provides all program parameters.

Final Results:

(S)=mantissae of $\overline{x}+\overline{y}$. The routine does not provide Q-words for the vector sum.

(00014)=characteristic of $\overline{x}+\overline{y}$.

Accuracy: maximum 32 bits

Other Subroutines used: Roll-off
Unpack

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Operating Instructions:

1. Directory address of $\overline{x}$ $\longrightarrow$ A_u.
2. Enter Roll-off subroutine; roll-off $\overline{x}$ in R.
3. Enter Unpack subroutine at 01003; unpack $\overline{x}$ in S.
4. Directory address of $\overline{y}$ $\longrightarrow$ A_u.
5. Enter Roll-off subroutine; roll-off $\overline{y}$ in R.
6. Enter unpack subroutine at 01002; unpack $\overline{y}$ in T.
7. Enter Vector Sum subroutine; form $\overline{x}+\overline{y}$.

Time: 37.5 milliseconds, maximum

Unpack

01000	00	00000	00000	Alarm exit (not used)
01001	45	00000	30000	Normal exit
01002	45	00000	01040	Entrance for unpack in T
01003	16	00006	01017	Entrance for unpack in S
01004	16	00006	01024	} Set up
01005	16	00006	01026	
01006	11	00011	00014	Keyword of $\bar{x}$ → 14
01007	11	00013	00016	3+ number of non-zero elements of $\bar{x}$ → 16(u)
01010	31	00005	00017	} Set up instructions and constants
01011	15	20000	01023	
01012	15	20000	01026	
01013	21	01026	01051	
01014	31	00010	00017	
01015	35	01046	01016	
01016	00	00000	00000	
01017	11	01047	00000	
01020	11	00010	01055	
01021	23	01055	01053	
01022	11	01050	01056	
01023	11	00000	10000	Q-word → Q
01024	11	10000	00000	Q-word → S (or T)

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Unpack

```
01025  44  01026  01031
01026  11  00000  00000
01027  21  01026  01052
01030  45  00000  01032
01031  21  01026  01053
01032  41  01055  01034
01033  45  00000  01001
01034  41  01056  01025
01035  21  01023  01054
01036  21  01024  01053
01037  45  00000  01022
01040  16  00007  01017
01041  16  00007  01024
01042  16  00007  01026
01043  11  00011  00015
01044  11  00013  00017
01045  45  00000  01010
01046  75  10003  01020
01047  00  00000  00000
01050  00  00000  00043
01051  00  00003  00003
01052  00  00001  00001
01053  00  00000  00001
01054  00  00001  00000
01055  00  00000  00000
01056  00  00000  00000
```

$\bar{x}$ (unpacked) ⟶ S (or T)

Set up for unpack in T

Keyword of $\bar{x}$ ⟶ 15

3+ number of non-zero elements of $\bar{x}$ ⟶ M(u)

Constants and temporary storage

Vector Sum

01000	00	00000	00000	Alarm exit (not used)
01001	45	00000	30000	Normal exit
01002	31	00010	00017	Entrance
01003	35	01134	20000	
01004	15	20000	01063	
01005	15	20000	01077	
01006	15	20000	01126	
01007	11	01133	01143	
01010	35	01135	20000	
01011	15	20000	01044	
01012	15	20000	01065	
01013	15	20000	01073	Set up constants and instructions
01014	16	00006	01045	
01015	31	00007	00017	
01016	15	20000	01045	
01017	21	01045	01136	
01020	15	01045	01055	
01021	16	00007	01066	
01022	31	00006	00017	
01023	15	20000	01066	
01024	15	20000	01074	
01025	16	00005	01074	
01026	21	01066	01136	
01027	15	01066	01052	
01030	21	01074	01136	

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Vector Sum

01031	15	01074	01127
01032	11	01133	01144
01033	16	00014	01144
01034	11	01133	01145
01035	16	00015	01145
01036	11	01145	20000
01037	42	01144	01046
01040	43	01144	01130
01041	36	01144	01143
01042	42	01137	01053
01043	11	01145	00014
01044	75	00000	01001
01045	11	00000	00000
01046	11	01144	20000
01047	36	01145	01143
01050	42	01137	01056
01051	11	01144	00014
01052	45	00000	01001
01053	11	01145	00014
01054	15	01052	01064
01055	45	00000	01060
01056	11	01144	00014
01057	15	01055	01064
01060	11	01140	20000
01061	36	01143	01143
01062	16	01143	01064
01063	75	00000	01065

If the difference of the characteristics exceeds $31_{(10)}$, transmit the larger characteristic to 00014; and transmit the corresponding mantissae to S. Then go to the exit

If the characteristics differ by less than $32_{(10)}$, shift the mantissae of the smaller until the characteristics are equal; transmit the larger characteristic to 00014.

Vector Sum

```
01064  54  00000  00000
01065  75  00000  01067      Add corresponding mantissae and transmit
01066  21  00000  00000      to S,
01067  31  01074  00017
01070  15  20000  01076
01071  15  20000  01100
01072  21  01100  01141
01073  75  00000  01075
01074  12  00000  00000
01075  11  01133  01146
01076  11  00000  20000
01077  75  00000  01110
01100  42  00000  01101      Find the numerically largest mantissae of
01101  55  10000  00017      the  sum, and transmit to the accumulator
01102  15  01077  01146
01103  23  01146  10000
01104  21  01076  01146
01105  23  01077  01146
01106  21  01100  01146
01107  45  00000  01076      Calculate the characteristic of the sum
01110  47  01113  01111      and transmit it to 00014
01111  11  01133  00014
01112  45  00000  01001
01113  74  20000  01143
01114  11  01140  20000
```

Vector Sum

```
01115  36  01143  01143
01116  36  01142  01143
01117  46  01122  01120
01120  16  01143  01127
01121  45  00000  01125
01122  11  01140  20000
01123  35  01143  10000
01124  16  10000  01127
01125  23  00014  01143
01126  75  00000  01001        Shift the mantissae of the sum so that the
01127  54  00000  00000        numerically largest has 32(10) binary digits.
01130  11  01145  00014
01131  45  00000  01065
01132  11  00014  10000
01133  00  00000  00000
01134  00  20000  00000
01135  00  10000  00000
01136  00  00003  00003
01137  00  00000  00040
01140  00  00000  00110        Constants and temporary storage
01141  00  00001  00000
01142  00  00000  00003
01143  00  00000  00000
01144  00  00000  00000
01145  00  00000  00000
01146  00  00000  00000
```

Roll-Off

01000	00	00000	00000	Alarm exit (not used)
01001	45	00000	30000	Normal exit
01002	16	00005	01017	Entrance
01003	15	20000	01023	Set up instructions
01004	11	01023	01006	
01005	75	30002	01007	Keyword of $\bar{x}$ → 11
01006	11	00000	00011	Keyword of next vector → 12
01007	15	00011	01017	Starting address of $\bar{x}$ → 1017(u)
01010	11	01022	00013	
01011	15	00012	00013	Starting address of next vector → 13(u)
01012	11	01022	01021	
01013	15	00011	01021	Starting address of $\bar{x}$ → 1021(u)
01014	23	00013	01021	3+number of non-zero elements of x → 13(u
01015	35	01020	01016	
01016	00	00000	00000	$\bar{x}$ — R
01017	11	00000	00000	
01020	75	30000	01001	
01021	00	00000	00000	Constants and temporary storage
01022	00	00000	00000	
01023	11	00000	00011	

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Scalar Product

```
01000  00  00000  00000        Alarm exit (not used)
01001  45  00000  30000        Normal exit
01002  31  00007  00017        Entrance
01003  21  20000  00007
01004  15  20000  01037
01005  16  20000  01040
01006  15  20000  01044
01007  21  20000  01135
01010  35  01136  01055
01011  15  20000  01075
01012  31  00005  00017
01013  21  20000  00005
01014  16  20000  01036
01015  15  20000  01040
01016  21  20000  01135
01017  35  01136  01056        Set up instructions and constants
01020  16  20000  01075
01021  31  00006  00017
01022  15  20000  01036
01023  31  00010  00017
01024  35  01124  01035
01025  11  01125  01142
01026  11  01125  01143
01027  11  01130  01145
```

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Scalar Product

01030	11	01125	01151
01031	11	01127	01146
01032	11	00010	20000
01033	36	01133	01147
01034	11	01131	01150
01035	00	00000	00000
01036	11	00000	00000
01037	11	00000	10000
01040	51	00000	00000
01041	21	01037	01132
01042	21	01040	01134
01043	41	01150	01037
01044	31	00000	00000
01045	47	01052	01046
01046	23	01147	01137
01047	46	01072	01050
01050	21	01044	01132
01051	45	00000	01044
01052	15	01044	01053
01053	11	00000	10000
01054	44	01055	01067
01055	00	00000	00000
01056	00	00000	00000
01057	21	01055	01134
01060	21	01056	01134
01061	21	01145	01132
01062	41	01147	01064

$\bar{x} \longrightarrow R$

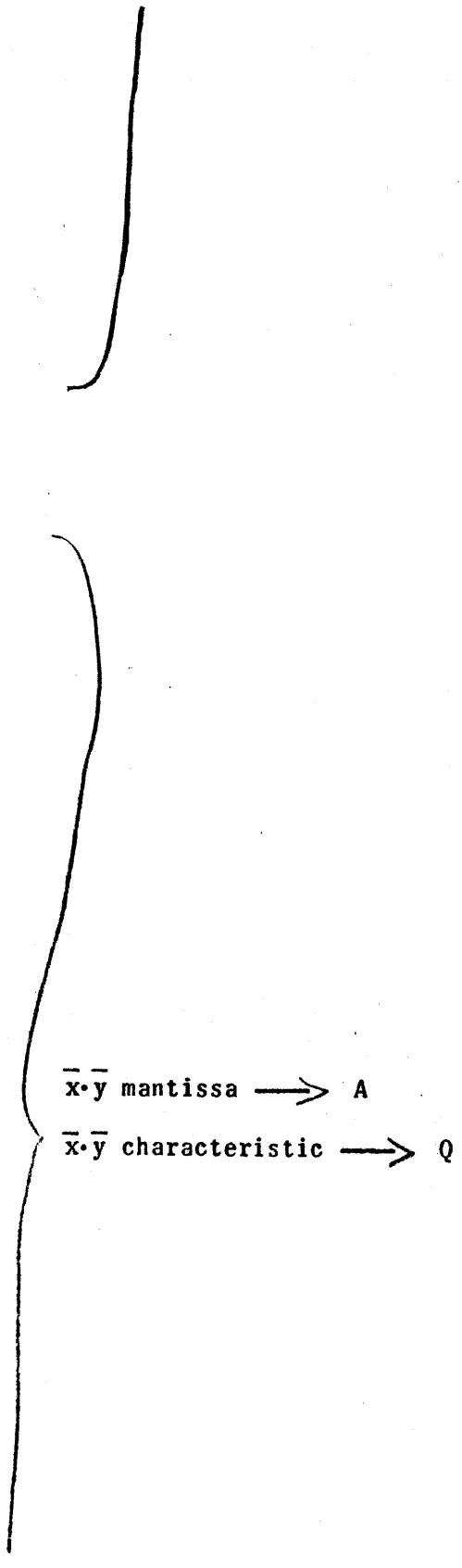
Logical product of Q-words of $\bar{x}$ and $\bar{y} \longrightarrow T_1, T_2, T_3$

Non-zero $x_i \longrightarrow R$

Non-zero $y_i \longrightarrow T$

Scalar Product

```
01063  45  00000  01072
01064  41  01146  01054
01065  11  01127  01146
01066  45  00000  01050
01067  21  01055  01132
01070  21  01056  01132
01071  45  00000  01062
01072  15  01145  01074
01073  11  01125  20000
01074  75  30000  01076
01075  72  00000  00000
01076  47  01102  01077
01077  11  01125  01151
01100  11  01125  01152
01101  45  00000  01121
01102  43  20000  01107
01103  74  20000  01151
01104  11  20000  01152
01105  54  01152  00105
01106  45  00000  01113
01107  74  20000  01151
01110  11  20000  01152
01111  54  01152  00105
01112  23  01151  01126
01113  21  01151  01140
01114  16  00014  01142
```



Scalar Product

01115	16	00015	01143
01116	21	01142	01143
01117	21	01151	01142
01120	23	01151	01141
01121	11	01152	20000
01122	11	01151	10000
01123	45	00000	01001
01124	75	30003	01037
01125	00	00000	00000
01126	00	00000	00110
01127	00	00000	00043
01130	00	30000	00000
01131	00	00000	00002
01132	00	00001	00000
01133	00	00000	00001
01134	00	00001	00001
01135	00	00003	00003
01136	11	00000	00000
01137	00	00000	00044
01140	00	00000	00003
01141	00	00000	40000
01142	00	00000	00000
01143	00	00000	00000
01144	00	00000	00000
01145	00	00000	00000
01146	00	00000	00000
01147	00	00000	00000

Constants

Temporary storage

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Scalar Product

```
01150  00  00000  00000
01151  00  00000  00000
01152  00  00000  00000
```

SIGNIFICANCE PRESERVING FLOATING BINARY POINT ARITHMETIC FOR DIGITAL COMPUTERS

I. Introduction to the System

The motivation for this system was a desire to be able to preserve in some way an indication of the significance of the result obtained from a series of floating binary point arithmetic operations on a digital computer. For the sake of abbreviation this system shall be referred to as "SP". Now the ideas and theory of SP are independent of any particular computer. However, since it was designed for the ERA 1103, it will be convenient here to make frequent references to the 1103 and to use "1103 language".

Most floating point systems use a packed form of 28 bits for the mantissa of a floating point number and 8 bits for the characteristic. After each arithmetic operation the mantissa is normalized so that 28 bits are always kept in the result. Now significant bits can be easily lost by subtraction and this would make any computations depending on this result less accurate. But when 28 bits are always kept the programmer has no indications of any significance being lost. It is the aim of SP to overcome this difficulty by preserving only the significant bits in the result of each arithmetic operation.

A desirable way to accomplish this goal is to make SP a non-normalizing system and hence one must use a different representation for floating point numbers. The representation used must be capable of indicating how many significant digits there are.

A 28-8 packed form was chosen but instead of the terms "mantissa" and "characteristic", the terms "significant part" and "exponent" shall be used respectively. In SP, both the significant part and the exponent are integers. Thus leading zeros are used in the significant part if there are less than 28 significant

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bits. A number, N, in this system, is then of the form

$$N = N_s \cdot 2^{N_x}$$

where N_s and N_x are the significant part and exponent respectively. Numbers of this type shall be referred to as SP numbers.

Numerous examples will be given throughout the rest of this introduction. Octal and binary representations will be used and it will be clear in each case which of the two applies.

The number 5 written with 3, 10, and 2 significant bits will appear as follows:

$$101 \times 10^{0},$$

$$1{,}010{,}000{,}000 \times 10^{-111},$$

$$11 \times 10^{1}.$$

Note that in the last case, 101 was rounded to 11 and the exponent adjusted accordingly. These numbers would appear in packed form in the 1103 as

0, 000, 000, 000, 000, 000, 000, 000, 000, 101; 00, 000, 000

0, 000, 000, 000, 000, 000, 001, 010, 000, 000; 11, 111, 000

0, 000, 000, 000, 000, 000, 000, 000, 000, 011; 00, 000, 001

respectively (recall that the 1103 uses the one's complement system) where the semi-colon marks the 28-8 split.

Consider the SP number 1011×10^{110}. This can be thought of as being the number 1011,0XXXXX.XXX...

where the X's denote uncertain bits and the comma marks the end of the significance. Note that one bit after the comma is a zero. If this were a one the significant part would have been rounded off to 1100. An analogous interpretation can be given

to SP numbers with negative exponents.

An SP number, $N = N_s \cdot 2^{N_x}$ satisfies the following inequality:

$$(N_s - 1/2) \cdot 2^{N_x} \leqq N < (N_s + 1/2) \cdot 2^{N_x}$$

Now suppose $N_s = 0$. This inequality implies

$$-2^{N_x-1} \leqq N < 2^{N_x-1}$$

SP can have many zeros instead of a unique zero. Note that the number 0×10^{111} could be interpreted as the number $\pm$ OXXXXXX.XXX..., where the X's are uncertain and there are no significant bits, i.e., as a number with order of magnitude only. Having these zeros in the system is an advantage. Such zeros can easily be generated by subtraction and an SP zero for an answer does not give a false indication of significance.

Let $N = 3764521 \times 2^{17}$, $M = 754321062 \times 2^{25}$.

Note that M is a full significance number. Suppose N and M are to be added. To do this they must be adjusted so that their exponents are equal. Then the addition is performed as follows:

M:	754321062	00	$x2^{17}$
N:	37645	21	$x2^{17}$
N+M:	754360727	21	$x2^{17}$

The vertical line indicates where the significance of the answer stops. Rounding and truncating here gives

$$N + M = 754360727 \times 2^{25}.$$

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Note that M was shifted left (25 - 17) = 6 binary places and the 6 bits were discarded. If the exponents of two numbers to be added differ by more than 28 then the larger number can be taken for the answer since there is no point in left shifting a number more than 28 places. Thus adding 0×2^{40} and 10×2^{2} gives 0×2^{40} for the answer. Take $N = 0 \times 2^{27}$, $M = 1234 \times 2^{23}$ and follow the same method as above:

N:	00, 000, 000, 000	000, 0	$\times 2^{23}$
M:	101, 001	110, 0	$\times 2^{23}$
N+M:	101, 001	110, 0	$\times 2^{23}$

Rounding and truncating gives $110{,}010 \times 10^{10111}$, i.e., 52×2^{27} for N + M.

Now subtraction reduces immediately to addition. Consider the following two problems, however, which are examples of how an SP zero can be generated and how significance can be lost.

(a) $(54 \times 2^{57}) - (1 \times 2^{64})$

- 1	00000	$\times 2^{57}$
+ 1	01100	$\times 2^{57}$
0	01100	$\times 2^{57}$

Answer: 0×2^{64}.

(b) $(-1073 \times 2^{-152}) - (-43 \times 2^{-146})$

+	100011	0000	$\times 2^{-152}$
-	100011	1011	$\times 2^{152}$
	-0	1011	$\times 2^{-152}$

Answer: -1×2^{-146} (Note: round off makes significant part different from zero).

Suppose that N and M as given in the first example of addition are to be multiplied ($N = 3764521 \times 2^{17}$, $M = 754321062 \times 2^{25}$).

$(3764521)\ (754321062) = 3646563 \mid 460351722.$

Only 7 octal digits can be kept in the final answer. Therefore the above product must be rounded and truncated where the vertical line is. Then the significant part of the answer is 3646564. Now 33 bits were discarded. This means the exponent of the answer is

$$17 + 25 + 33 = 77,$$

i.e., $N \cdot M = 3646564 \times 2^{77}$.

Consider the problem of multiplying 2 SP zeros, say $N = 0 \times 2^{10}$ and $M = 0 \times 2^{23}$. By the inequality given above,

$$|N| \leq 2^{7}, \quad |M| \leq 2^{22}.$$

Hence the product should be such that

$$|N \cdot M| \leq 2^{31}.$$

In view of this, 0×2^{32} could be given as the product. However, it turns out that the algorithms and the coding for the 1103 are simplified if the answer 0×2^{33} (obtained by simply adding N_x and M_x) is given. The decision was made to give this answer rather than the first one. This does not differ much from the other answer and the advantages outweigh the disadvantages.

One other case turns up, e.g., $(0 \times 2^{27})\ (1234 \times 2^{23})$. Since the operand with the least significance is an SP zero, the answer given must also be an SP zero. The answer here is obtained by adding the exponents and the

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number of bits which must be discarded. Hence the exponent is

$$27 + 23 + 12 = 64,$$

and the answer is 0×2^{64}.

The division is perhaps more difficult. Consider $N = 3764521 \times 2^{17}$ and $M = 754321062 \times 2^{25}$. Before dividing, shift N_s and M_s left until they both have 35 bits (and one leading zero, i.e., sign bit). One then has (adjusting the exponents):

N: 011, 111, 110, 100, 101, 010, 001, 000, 000, 000, 000, 000 $\times 2^0$

M: 011, 110, 110, 001, 101, 000, 100, 011, 001, 000, 000, 000 $\times 2^{15}$

If the division is carried out to 43 places, the result is (discarding remainder and not rounding)

01. 000, 010, 001, 011, 011, 000, 0 | 11, 111, 100, 110, 011, 0 .

The vertical line indicates where the quotient is to be rounded and truncated (keeping same number of bits as there are in N_s). Rounding here and moving the binary point to the line gives for the exponent

$$0 - 15 - 23 = -40.$$

Hence the answer is

$$10, 000, 100, 010, 110, 001, \times 10^{-100,000},$$

i.e., 2042661×2^{-40}.

The next case to consider is $N \div M$ where $N_s = 0$ and $M_s \neq 0$. Take $N = 0 \times 2^{27}$, $M = 1234 \times 2^{23}$. Clearly an SP zero is required for the answer. Comparing this with the multiplication of the same N and M above would lead one to take

$$27 - 23 - 12 = -6$$

for the exponent (subtracting 23 and 12 instead of adding). This can be justified by the above inequalities also as follows:

$$| N | \leq 2^{26} \text{ and } | M | \leq 1234 \times 2^{23} < 2^{35}.$$

Hence $| N | \div | M | < 2^{-7}$, i.e., $N \div M = 0 \times 2^{-6}$.

Now suppose $N_s = 0$, $M_s = 0$. For example, $N = 0 \times 2^{-66}$, $M = 0 \times 2^{-42}$.

SP zero divisors can be allowed providing the answer is interpreted correctly. Comparing again to multiplication, one would be lead to give

$$-66 - (-42) = -24$$

for the exponent. This case differs slightly from what the inequalities gives as did the same case in multiplication. $| N | \leq 2^{-67}$, $| M | \leq 2^{-43}$ would give approximately 2^{-24} or 0×2^{-23} for an answer. But as in multiplication, it is more convenient to take 0×2^{-24} for the answer. Note that in multiplication the exponent was given one higher than that given by the inequalities, and here it is one lower. One can not put this answer in an inequality very well since if the divisor is small compared to the dividend the result would be large, and if the relative sizes are the other way around the answer is small. Hence "approximately 2^{-24}" was used above. A reliable answer can not be given in this case.

If $N_s \neq 0$ and $M_s = 0$ the result is not quite so unpredictable. Take $N = 621 \times 2^{-77}$, $M = 0 \times 2^{124}$. Since the numerator is not zero, the number of bits in N should be added to the difference of the exponents. Hence the exponent is

$-77 - 124 + 11 = -212$

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(it turns out that this is out of range - see part II). Thus the answer is 0×2^{-212}. One can argue this case on the basis of the inequalities similarly to the previous one. Note that here, since the divisor is not bounded away from zero, the result is not bounded above, i.e.,

$$|N \div M| \geq 2^{-212}.$$

This is the interpretation for answers resulting from zero divisors which was referred to above.

II. SP Arithmetic Algorithms

A. General Remarks

It is intended that the discussion and examples given in Part I should serve as motivation and illustrations for the following algorithms.

A list of the notation used throughout the rest of this paper is given here for convenience.

1. Operands shall be denoted by N and M, where $N = N_s \cdot 2^{N_x}$ and $M = M_s \cdot 2^{M_x}$, the subscript s denoting the significant part and the subscript x denoting the exponent of an SP number.

2. The result of an operation shall be denoted by $R = R_s \cdot 2^{R_x}$.

3. B(X) shall denote the number of binary digits in an integer X, including <u>one and only one</u> sign bit. This convention is used on all bit counts.

4. Let $A = B(N_s)$,
$B = B(M_s)$,
$C = B(\min(|N_s|,|M_s|))$,
$D = B(\max(|N_s|,|M_s|))$,
and let E be the number of bits of the raw product, quotient, or sum of N_s and M_s. Observe that C = min(A,B) and D = max(A,B).

B. Addition Algorithm: R = N + M.

To add N and M it is necessary to adjust them so that their exponents are equal. This is accomplished by determining which number has the larger exponent and then shifting the binary point of the significant part of this number to the right so that the exponents will be equal. This adjusted significant part is

then added to the other unadjusted significant part and the sum is truncated and rounded to give the significant part of the answer. The exponent of the answer will be equal to the maximum of the two original exponents. This is the method in brief.

Without loss of generality, suppose $N_X = \max (N_X, M_X)$. Then N_S is shifted left a number of binary places equal to $(N_X - M_X)$. After adding M_S to this and rounding, the result is truncated by discarding the right most $(N_X - M_X)$ bits. This number becomes R_S, the lowest order bit is discarded (after the round off as above), and $R_X = N_X + 1$. (A carry of one bit can produce a 29 bit sum). In this case if $N_X = 127$ then $R_X + 1 = 128$ and is out of range. When this happens an alarm is given and computation stops.

Now there is one exception to the above outlined procedure. Namely, when $28 < |N_X - M_X|$. In this case R is taken as the number with the highest exponent. The preceeding method would give this result anyway. This exception is necessary since the computer used imposes a limit of how much a number can be shifted (the exponents could differ as much as 254 and the shifting limit is much less than this).

Note that this algorithm covers all possible SP numbers, including zeros.

C. Subtraction Algorithm: $R = N - M$.

To subtract M from N it is necessary only to change the sign of M and then add (change the sign of M by replacing M_S with $-M_S$). The nature of the 1103 puts one restriction on this (see part IV, subtract control routine).

D. Multiplication Algorithm: $R = N \cdot M$.

Briefly, multiplication is accomplished by adding the exponents, multiplying the significant parts, rounding and truncating and then compensating for the truncation by adjusting the sum of the exponents.

In order to determine the number of bits to keep it is necessary to count the bits of the operands. The smaller count gives the number to keep (this number has been denoted by C, see part A above).

Two distinct cases arise in multiplication.

Case 1. $N_S \neq 0$, $M_S \neq 0$. In this case N_S and M_S are multiplied and the product is rounded and truncated just to the right of the first (high order) C bits. This becomes R_S. R_X is given by the following:

$$R_X = N_X + M_X + (E - C).$$

Note that (E-C) is the number of bits that are discarded.

Case 2. $N_S = 0$ or $M_S = 0$. If one of the two operands is zero, i. e. has no significance, then the round off rules require that the product has no significance, i.e. $R_S = 0$. Hence it is only necessary to compute the exponent, R_X. Now if both $N_S \neq 0$ and $M_S = 0$ then $R_X = N_X + M_X$. Suppose one of the two is not zero. Then the number of bits it has, minus one, (to account for the sign bit) must be added to $N_X + M_X$. Using the conventions

adopted, R_x is given by

$$R_x = N_x + M_x + (D - 1).$$

Note that if $N_s = 0$ and $M_s = 0$ then $D = 1$, and this formula agrees with the above statement. Thus this equation is used for both possibilities in Case 2.

E. Division Algorithm: $R = N \div M$.

Consider first the case $N_s \neq 0$ and $M_s \neq 0$. Before dividing N_s by M_s, they are both scaled up to full 36 bit word length and N_s is shifted left 34 places in the accumulator. This assures a 35 or 36 bit quotient, and prevents a zero quotient or a divide overflow. This quotient is then rounded and truncated the same as in multiplication to give R_s. When computing R_x the scaling up of N_s and M_s, shifting of N_s, and the number of bits discarded from the quotient must be taken into account. C bits are kept as in multiplication, hence (E - C) bits are discarded. This must be added to $N_x - M_x$. Subtracting 34 accounts for shifting N_s and adding (A - B) accounts for the initial shifting of N_s and M_s. Thus R_x is given by

$$R_x = N_x - M_x - 34 + (A-B) + (E-C).$$

Now suppose $N_s = 0$ and $M \neq 0$. If the above algorithm for dividing N_s by M_s is followed, the quotient will be zero. However, the method used for counting the bits of the quotient will give a count of 35 (see Part IV). Now $C = 1$, hence $(E - C) = 34$ and this will cancel the -34 in the above expression for R_x. Since $A = 1$ the formula reduces to

$$R_x = N_x - M_x + (1 - B)$$

which is as it should be ($B \neq 1$ since $M_s \neq 0$). Thus the algorithm will give R correctly for all cases except when $M_s = 0$.

Suppose $M_s = 0$. Clearly the quotient must also be a zero by the round off rules used. Hence in this case it is necessary only to compute R_x. If $N_s = 0$, $R_x = N_x - M_x$. But if $N_s \neq 0$ then R_x must be adjusted to compensate for this. This adjustment is taken care of by adding $(A - 1)$ to $(N_x - M_x)$. If $N_s = 0$ then $A = 1$, hence one can say that for either case

$$R_x = N_x - M_x + (A - 1).$$

F. Comparison Algorithm

Two SP numbers are defined as equal if their difference is an SP zero (see the two examples on subtraction). Hence to compare N and M it suffices to subtract M from N and test the difference. If N - M is a positive SP number (not a zero) then N > M. If N - M is a negative SP number, N < M, and if M - N is a zero then N = M.

Note that under this definition of equality all SP zeros are equal.

G. Notes:

In multiplication and division it is possible for R_x to get out of range in two ways, i.e., $R_x > 127$ or $R_x < -127$. If $R_x > 127$ then an alarm is given as mentioned in part B above. If $R_x < -127$, low order bits of R_s are discarded and the exponent is increased to - 127. If $R_x + 127 + B(R_s) < 2$, i.e., if all the bits of R_s are discarded and the exponent will still be out of range, then $0 \cdot 2^{-127}$ is given for the result.

In all four arithmetic operations the truncating point is determined before rounding. Thus it is possible for the round

off to give a carry of one bit. If this extra bit makes $B(R_s) = 29$ then one low order bit is discarded and R_x is increased by one. This necessitates testing R_x again to see if it is still within range. (R_x is always tested before any truncating or rounding is done).

III. How to use the SP Interpretative System

A. Introduction.

There are 7 possible SP operations. These are all performed via the interpret instruction. The general format of such an IP order is IP X AAAA Y BBBB, where X and Y are operation codes and AAAA, BBBB are MC Addresses. Four of the 7 SP operations are single address instructions, i.e., the u and v part of the IP order are each a complete instruction. This necessitates a no-op code to fill in space if the programer happens to have an odd number of instructions to perform in a given group of IP orders. This no-op instruction makes a total of 8 permissable psuedo operations, one corresponding to each of the octal digits 0 through 7 (X and Y above are single octal digits). Two of the SP operations are of such a nature as to require both the u and v part of an IP order and hence are double address instructions. There is one quadruple address instruction, i.e., one which uses two 1103 words.

The 8 possible instructions and their codes are as follows:

CODE	INSTRUCTION	TYPE
0	No-op.	single address
1	Add	" "
2	Subtract	" "
3	Multiply	" "
4	Divide	" "
5	Compare	quadruple address
6	Repeat Multiply Add	double address
	Polynomial Multiply	" "

These instructions operate on packed operands (see part I for method of packing). A psuedo accumulator is used for the arithmetic operations, e.g., operation 1 adds the packed operand to the packed SP number contained in the psuedo accumulator, leaving the result in the psuedo accumulator. The other operations are of a similar nature. This psuedo accumulator shall henceforth be denoted by fa. The initial loading of fa and getting the answers out of fa is left up to the programer. Furthermore the contents of the 1103 A-register and Q-register are not saved. This is not inconvenient since the 1103 arithmetic operations use these registers.

B. Each of the 8 SP operations will now be described individually. Part C describes the alarms. See part V for address data.

0. No - op.

The code for this is 0 ZZZZ where this 5 digit number can be in either the u part or v part of the IP order. The Z's can be anything since they are ignored.

All this order does is to jump to the next instruction, which could be the v part of the same IP order or the 1103 instruction immediately following the IP order (this could be another IP order).

1. Add

The code for this is 1 AAAA where this 5 digit number can be in either the u part or the v part of the IP instruction. AAAA must be the MC address of the packed operand to be added to fa.

This instruction adds the SP number in AAAA to the number which is already in fa, leaving the sum in fa.

2. Subtract

The 5 digit code for subtraction is 2 AAAA and this too can be either in the u part or v part of the IP order; AAAA is the MC address of the operand which is subtracted from the operand already in fa. The difference is left in fa.

3. Multiplication.

The code here is 3 AAAA in u or v part of IP order. This instruction multiplies fa by the SP number in AAAA leaving the product in fa.

4. Division

The number 4 AAAA in the u or v part of an IP order causes the SP number in fa to be divided by the SP number in AAAA. The quotient is left in fa.

5. Compare

This is a quadruple address instruction - a 3 way jump - and requires 2 consecutive 1103 words. The format of the code is as follows:

1st word: IP 5 AAAA XXXXX

2nd word: 00 YYYYY ZZZZZ

This operation compares the SP number in MC address AAAA with the SP number in the psuedo accumulator, fa. It then causes a manual jump to one of the addresses XXXXY, YYYYY, or ZZZZZ as follows: let the SP number in fa be denoted by N and the SP number in

AAAA by M, then if M > N jump is to XXXXX, if M = N jump is to YYYYY, and if M < N jump is to ZZZZZ. Note that these can be either MC or MD address. The 2 digits OO can be anything since they are ignored.

By choosing the jump addresses correctly one can use order 5 for an equality jump, zero jump (if fa contains a zero), threshold jump, or a three way jump.

The final contents of fa is N - M.

6. Repeat Multiply Add

Format of code is IP 6 AAAA J BBBB. The number, n, of times the operation is to be done must be stored in the MC address denoted by wsl6 (work space 16). The J has the same function as the j in the usual 1103 repeat instruction. Thus if J = 3, this operation multiplies the SP numbers in AAAA and BBBB and adds the product to fa, then multiplies the two numbers in AAAA + 1 and BBBB + 1 and adds product to fa, etc. This is done a total of n times. Hence n operands must be stored in consecutive addresses starting at AAAA and n more starting at BBBB. If J = 1 then only the BBBB addresses are increased by 1 and if J = 2 only the AAAA. If J = 0 the numbers in AAAA and BBBB are multiplied and added to fa n times.

The first bit of J is ignored, so that J = 4, 5, 6, 7 will cause the same operation to be performed as J = 0, 1, 2, 3 respectively. Now if $n \geq 0$ the number in fa is left unchanged and the next instruction after the I^P is performed. Furthermore the index n stored in wsl6 is preserved and can be used again.

7. Polynomial Multiply

This SP IP instruction evaluates a polynomial of the form $P(X) = A_n X^n + A_{n-1}X^{n-1} + \ldots + A_1X + A_o$.

The format of the IP order is IP 7 XXXX 0 XXXX where XXXX is the address of X and AAAA is the address of A_n. A_{n-1}, A_{n-2}, ..., A_o must be stored in consecutive addresses following A_n. The octal digit 0 is ignored. The degree of the polynomial, n, must be stored in the MC address denoted by wsl7. Note that n is the degree of the polynomial and hence n + 1 coefficients are required. The only restriction on n is the amount of space available in MC for the n + 1 coefficients. This n is saved too as is the one for the multiply add operation and hence can be used as many times as desired. P(X) is in fa after the evaluation is completed. If n = 0 (or if a negative integer is given for n) then the first coefficient is left in fa. Thus evaluation of a zero degree polynomial is legal. Note that the contents of fa prior to the start of evaluating P(X) is lost.

C. Alarms

As mentioned previously, there are two alarms in the SP interpretive system. These are given if the exponent gets out of range or if one has an SP zero for a divisor.

If at any time the exponent of the result of an arithmetic operation exceeds 127, the typewriter prints mx xp (maximum exponent) and the address of the IP order being performed. This can happen also in the middle of the repeat multiply add or the polynomial multiply operation as well as during the simple

arithmetic operations. After the print out the computer stops on a manual stop. Starting will cause the alarm print out to be repeated.

When the SP zero divisor occurs the typewriter prints out div = 0 and the address of the IP instruction being performed. The computer stops on a manual stop. Starting the computer will cause the division operation to be completed and the program continues in the normal manner.

V. Miscellaneous Notes

1. If an input SP number is supposed to be zero use $0x2^{-177}$ and not an 1103 zero.

2. It is possible to gain significance in all arithmetic operations because of round off and carrys.

3. If a programmer gets an mx-mp alarm he can reset PAK and proceed only if further computations do not depend on the one which gave the alarm. The exponent which gave the alarm is lost but some information can be obtained by examining the contents of the working space (see coding, part IV).

4. Every 1103 number except all ones is a legal SP number.

5. When setting up od2 with the MC address of the operand, 00-07777-00000 is used for a mask. Thus an MC address must not exceed 1777 if an 1103 is used. This mask is used for two reasons:

(a) SP can be used in an 1103A

(b) If for the 1103 the programmer has an illegal address he will get an SCC fault instead of the computations being done wrong with no warning.

6. ws and fa must be assigned equal regional values.

7. All regional assignments should be in MC except pa, ea, da, and pc which can be in MD to save space (pc can be assigned to any place where the flex codes for 0 through 7 are stored in consecutive order).

IV. Description of Interpret System

SP is coded using Reco II. There are 18 regions in the system not counting constants and working space. A brief description of each of the 18 parts of the program will be given. The coding for these follows.

IP: Any interpret instruction causes control to be turned over to IP. This routine sets up the SP exit, locates and stores the interpret order and drives OD.

OD: OD decodes the SP operation code in the u and/or v part of the interpret order. It then causes a jump to the control routine corresponding to this operation code (or in case of no-op jumps back to IP). Note that for operations 5, 6, and 7 OD decodes only the u-op since these are not single address instructions.

CA: Add algorithm control.

CS: Subtract algorithm control.

CM: Multiply algorithm control.

CD: Divide algorithm control.

CC: Comparison algorithm control.

CC compares N and M and causes a jump to the specified destination for each of the three possible cases: $M > N$, $M = N$, $M < N$. Note that this is the only control routine that does not exit via the SP EXIT.

CN: CN controls the repeat multiply add: locates the N_1 and M_1 and does the prescribed multiply add operation.

CP: CP controls the polynomial multiply or polynomial evaluation: locates coefficients and X value and computes $\sum_{k=0}^{n} A_k X^k$

KU: KU clears working space and unpacks the SP numbers.

MD: MD counts the bits of N_s and M_s and lines them up. This routine is used only for multiplication and division.

GA: GA is the basic add algorithm routine.

GM: GM performs the main part of the multiply algorithm.

GD: GD performs the main part of the divide algorithm. GD jumps to an alarm when a divisor which is zero is encountered.

RP: RP is the round and pack routine. It is entered immediately after the completion of the GA, GM, or GD routines. When RP is entered the exponent determined in GA, GM, or GD, is in the 1103 accumulator and the significant bits of the answer are in ws14. From GM and GD, ws14 contains 36 bits of the rough answer, lined up. (If the answer is an SP zero, (ws14) = 0). RP then rounds and truncates this at the proper place. From GA, ws14 contains the significant bits of the answer and one extra for round off, except in the case when the larger number is taken for the sum, then it contains only the significant part of the answer (these bits are in the low order part of ws14, the higher order bits being sign bits). RP puts the significant part of the answer in A left and [illegible]. Then the answer is packed up and put in fa. RP [illegible]

PA: PA prints out the address of the IP instruction in case there is an alarm.

EA: Exponent alarm. EA prints out "mx xp"

DA: Divide alarm. DA prints out "div = 0".

Note: In the coding annotations that follow, octal numbers are used almost exclusively.

ws0	Packed answer (ws = fa = psuedo accumulator)
1	N_s
2	M_s
3	N_x
4	M_x
5	ga: max (N_x, M_x), md and gd: lined up N_s
6	ga: $\|N_x - M_x\|$, md and gd: lined up M_s
7	gm: bits of product (E)
10	$B(N_s)$
11	$B(M_s)$
12	no. bits to keep in rp: B(min ($\|N_s\|$, $\|M_s\|$) in md, gm, gd; 43 or 44 in ga
13	md, gm, gd: B(max ($\|N_s\|$, $\|M_s\|$)
14	significant part of answer (+ some bits to be discarded)
15	IP order for decoding
16	"n" for repeat multiply add
17	"n" for repeat polynomial multiply
20	temporary storage for (fx) in multiply add
21	various indexes

fx	"psuedo x - register" —used to store SP operands.

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A METHOD FOR GENERATING RANDOM NUMBERS ON THE FRA 1103

DISCUSSION

The number 3^{15} was taken as a starting point. This number was squared, and from the square the fourth digit through the eleventh were removed and designated as the first random number. The first random number was multiplied by 3^{15} and the fourth through the eleventh digits of the product became the second random number. This process was continued for as many random numbers as needed.

If less than 8 digits come out in the result, zeros are placed before the number until 8 digits are reached. When the random numbers are used in a problem on the 1103, they are stored on the drum and used as needed or put on magnetic tape.

Listings at the end of this report are from IBM cards containing 7 sets of 8 digits each.

The table of random numbers attached can be used for as many digits as needed. The digits within the 8 digit groups have been tested for randomness also.

RESULTS OF TESTS

One means of checking the randomness of these 8 digit numbers was the Chi Square test which is a test to determine the goodness of fit of the actual data to the theoretical distribution. The test involves the calculation of χ^2 (Chi Square), $\chi^2 = \sum \frac{(f_o - f)^2}{f}$ where f_o = actual frequencies, f = theoretical frequencies. By reference to a set of χ^2 tables Chi Square may be evaluated. A program was written and this test was applied to all of the 16,000 8-digit groups. The results are found in Table 5.

In order to check the randomness of the individual digits within the groups, the following tests were applied: poker test, even-odd test, frequencies of ordered pairs and the Chi Square test to individual digits.

TABLE I

POKER TEST

500 Groups of 5

CLASS	SYMBOL	f_o	f	$(f_o - f)$	$(f_o - f)^2$	$\frac{(f_o - f)^2}{f}$
Busts	abode	175	151	24	576	3.8
Pairs	aabod	230	252	- 22	484	1.9
2 Pairs	aabbc	61	54	7	49	.9
3's	aaabc	28	36	- 8	64	1.8
Full House	aaabb	4	4	0	0	0
4's	aaaab	2	2	0	0	0
5's	aaaaa	0	0	0	0	0

$\chi^2 = 8.4$

$P = .30$

The value of X^2 indicates a value for P of .30. It shows that there are 30 chances out of 100 that the fit obtained would be as bad or worse than the one shown.

RESULTS OF TESTS (Cont'd)

Statistically, when a value for P is between .05 and .95, the data is considered satisfactory. The nearer to .95 the higher is the level of randomness for the numbers generated.

TABLE 2(a)

FREQUENCIES OF 4000 DIGITS

DIGIT	f_o	f	$(f_o - f)$	$(f_o - f)^2$	$\frac{(f_o - f)^2}{f}$
0	388	400	− 12	144	.36
1	412	400	12	144	.36
2	421	400	21	441	1.10
3	411	400	11	121	.30
4	420	400	20	400	1.00
5	406	400	6	36	.09
6	368	400	− 32	1024	2.56
7	397	400	− 3	9	.02
8	393	400	− 7	49	.12
9	384	400	− 16	256	.64

$\chi^2 = 6.55$

$P = .75$

The value of X^2 indicates a value for P of .75. This shows that there are 75 chances out of 100 that the fit obtained would be as bad or worse than the one shown.

RESULTS OF TESTS (Cont'd)

TABLE 2(b)

EVEN-ODD TEST

	ACTUAL	THEORETICAL	$(f_o - f)$	$(f_o-f)^2$	$\frac{(f_o-f)^2}{f}$
Even	1990	2000	-10	100	.05
Odd	2010	2000	10	100	.05

$\chi^2 = .10$

$P = .95$

The value of X^2 indicates a value for p of .95. This shows that there are 95 chances out of 100 that the fit obtained would be as bad or worse than the one shown.

TABLE 3

FREQUENCIES OF ORDERED PAIRS OF DIGITS

X^2	P	First Digit	Second Digit										Total
			0	1	2	3	4	5	6	7	8	9	
5.45	.85	0	15	20	21	18	22	15	17	14	19	22	183
8.60	.55	1	24	22	13	24	20	25	17	16	26	21	208
3.25	.97	2	20	17	14	21	20	19	20	21	24	19	195
6.25	.79	3	15	22	16	22	16	20	25	17	21	15	189
9.95	.45	4	23	28	27	19	17	23	14	22	23	23	219
10.00	.42	5	18	28	22	18	18	18	21	15	23	29	210
8.35	.60	6	19	17	19	1[illegible]	23	20	2[illegible]	1[illegible]	15	21	195
10.95	.35	7	15	22	21	15	23	20	25	11	13	20	185
7.85	.65	8	19	15	17	15	23	23	22	21	15	27	197
9.25	.04	9	15	14	25	25	34	26	17	23	22	17	219
		Total	193	205	196	191	216	209	207	178	201	214	
		$\chi^2 =$	6.55	10.95	10.10	7.05	12.80	5.45	9.95	9.30	8.75	9.64	
		$P =$	.76	.35	.41	.72	.24	.85	.45	.50	.58	.48	

PX 71900-10-(174)

RESULTS OF TESTS (Cont'd)

Total - Right to Left

$\chi^2 = 7.36$

$P = .68$

Total - Top to Bottom

$\chi^2 = 7.86$

$P = .65$

The values for X^2 indicate, when converted to percents, the amount of chances out of 100 that the fit obtained would be as bad or worse than the one shown.

TABLE 4

GROUP FREQUENCIES TEST

3000 - 8-digit numbers done by hand

Group	f_o	f	$(f_o - f)$	$(f_o - f)^2$	$\frac{(f_o - f)^2}{f}$
00,000,000 - 9,999,999	315	300	15	225	.7
10,000,000 - 19,999,999	304	300	4	16	0
20,000,000 - 29,999,999	345	300	45	2025	6.7
30,000,000 - 39,999,999	302	300	2	4	0
40,000,000 - 49,999,999	294	300	-6	36	.1
50,000,000 - 59,999,999	268	300	-32	1024	3.4
60,000,000 - 69,999,999	318	300	18	324	1.0
70,000,000 - 79,999,999	275	300	-25	625	2.0
80,000,000 - 89,999,999	284	300	-16	256	.8
90,000,000 - 99,999,999	295	300	-5	25	0

$\chi^2 = 12.7$

$P = .28$

The value of X^2 indicates a value for P of .28. This shows that there are 28 chances out of a 100 that the fit obtained would be as bad or worse than the one shown.

RESULTS OF TESTS (Cont'd)

TABLE 5

GROUP FREQUENCIES TEST

16,000 8-digit numbers tested by the 1103.

GROUP	f_o	f	$(f_o - f)$	$(f_o - f)^2$	$\frac{(f_o - f)^2}{f}$
00,000,000 - 9,999,999	1633	1600	33	1089	.67
10,000,000 - 19,999,999	1612	1600	12	144	.09
20,000,000 - 29,999,999	1628	1600	28	784	.49
30,000,000 - 39,999,999	1598	1600	- 2	4	.00
40,000,000 - 49,999,999	1514	1600	- 86	7396	4.62
50,000,000 - 59,999,999	1612	1600	12	144	.09
60,000,000 - 69,999,999	1627	1600	27	729	.45
70,000,000 - 79,999,999	1609	1600	9	81	.05
80,000,000 - 89,999,999	1568	1600	- 32	1024	.64
90,000,000 - 99,999,999	1599	1600	- 1	1	.00

$\chi^2 = 7.10$

$P = .72$

The value of X^2 indicates a value for P of .72. This shows that there are 72 chances out of 100 that the fit obtained would be as bad or worse than the one shown.

PX 71900-10-(174)

GAP TEST: FFequency of Length of Gaps between Successive Digits in Sample

)etween iuccessive:	Sample Size	Average Gap between digits	f_o	f	$(f_o-f)^2$	$\frac{(f_o-f)^2}{f}$ (χ^2)	P
0	204	10.6	10.6	10	.36	.036	.85
1	218	8.9	8.9	10	1.21	.121	.72
2	209	10.7	10.7	10	.49	.049	.82
3	207	9.2	9.2	10	.64	.064	.80
4	205	9.6	9.6	10	.16	.016	.90
5	216	8.9	8.9	10	1.21	.121	.72
6	205	10.2	10.2	10	.04	.004	.95
7	204	9.5	9.5	10	.25	.005	.88
8	209	10.2	10.2	10	.04	.004	.95
9	202	9.8	9.8	10	.04	.004	.95

The Chi Square values of all digits give a satisfactory value for P in each case.

PX 71900-10-(174)

25425018	1544355	92934827	95996944	92154804	51671604	29706453
52091654	35247776	44974009	56969404	83906507	75883574	9915732
41505940	70739474	72593573	54568290	48114715	94959820	41387949
9772606	41666627	27727856	91241977	7924055	65641900	47736366
54577061	26421999	54417258	94301999	57841452	54215149	45786057
84209253	2694794	89987106	5589360	68983772	89731175	53584256
14462379	36712770	32510446	13029317	24549336	63223009	48719068
50758033	99246681	15613509	73431533	5449197	18280823	81676930
33873158	96319727	45769069	8961893	51982537	52613798	94289925
35185855	17894992	99248589	29817344	84631187	61236154	96069017
89350406	79340621	76322759	4476355	31042506	56508932	14969277
69512902	94849004	10958290	4790313	4830377	58155151	20716922
27912823	60178285	26506534	93172056	80277137	39562859	35271808
40319279	90067898	14631837	94226739	88136797	29814693	10054171
43709917	63668181	89895170	547953	57804581	90714747	74239768
59640776	72092429	49419970	38284777	51061924	58268645	68309031
50833670	79556969	67145092	56429731	68615501	82407170	41420007
69221130	74101375	58730855	93543697	66170487	19595307	16193469
14102943	2840746	55336257	43242663	72377528	16662798	63766778
45019601	69798315	70925172	95892930	66288920	89405394	15631291
36797697	92972589	16067295	88498249	69661847	54149717	84123845
15945567	19531435	98416637	34620792	56317660	2880616	21228542
59332898	909559	86031030	25077660	27683326	46498963	6775191
8157247	98755466	32700878	1487388	48733049	41413508	20611236
7580823	91731621	92211535	36995748	27330278	46786549	43981443
51733249	19051818	27769798	63180270	54359847	89848331	7939262
6274564	17552991	7653376	16892124	72635587	28532062	32091121
27883443	38976650	53023418	74853550	12256901	1558451	86825442
49104373	18389124	41355478	55804649	66547138	12210518	38905209
56535823	6343999	91826215	68942682	25526723	44101968	86857683
16572943	86133813	54007003	95874774	10753799	19180257	17092689
77716255	14247515	32030761	74687253	31667667	60799696	59521323
67125128	31680297	13449306	18840584	4739498	51715372	53013146
54320653	60998096	3696959	76574637	24462366	32532139	86418381
6311923	7195700	26611000	79183438	83689966	24024781	70573170
95020039	16734921	79440161	57975340	62609695	50836254	18031436
45329916	2892490	34585569	4960496	94739221	9588631	28506238
94023920	19647381	4726226	81005240	62821931	40020578	26762593
48778011	98309397	49685098	72409322	15959161	58497433	22649306
30891640	83659401	32819012	40179798	76699566	1480104	30278371
34963756	40785928	82487729	25976570	82575826	88371814	64563019

30235574	38972899	81719311	18161246	73221304	29461346	1930392
81158289	73376193	59256184	22651243	65382654	23977131	72277122
10548205	50602431	16872305	51965243	60661784	72142727	78243184
73681902	69421496	73583843	74799945	84930415	23297942	24464346
86799209	4989745	61280389	40285921	30271647	81800019	29414749
33256977	76215763	81309616	24674031	81438714	43349398	15750674
78439043	80592733	1042220	59908037	74393720	95597922	7077267
50337986	93789752	8782829	73194638	52087352	48443127	72709439
92845075	8566187	60189566	75424270	95645010	21056267	44790362
83493094	96993618	78738067	36915664	56136251	96431266	98537913
9686705	41048495	86956763	56957542	18644279	68562415	65405178
99241297	93116777	1582427	90221346	18479390	30550553	41483190
82242238	99230481	57280260	7921630	47128147	35840062	31882297
58898898	5584842	76102686	40326302	37349879	57509274	12159597
82808249	50146629	79309901	17424707	22690892	95552779	79307277
77824974	39043487	54210604	52145416	71266766	41820832	70802311
77234724	23974416	4248506	63724150	53782994	34114065	28328041
64005183	40860244	25636101	34078307	96138170	38543974	94945011
27439464	31361611	40872701	45449505	11685696	38744218	90995418
51133359	54587450	50246299	64619597	11255575	18324460	43372411
98524753	68207880	23860994	26376659	63452110	51258255	78457617
66239168	72657264	5016687	64872271	5853609	13545351	9001869
31846867	1718482	25359459	36309423	47225475	43664961	6941082
6044463	25531193	35632734	69761836	37843614	49141598	6165214
24378609	92228274	87751186	53575316	31400845	70848201	78055015
14668037	50850225	8405594	15183553	57653498	1249589	42863195
515447	4862188	13527110	32723275	94681137	95020891	14585745
17541506	87214510	72233635	45025417	26766480	23908024	7231031
82412964	70197084	14667672	40582171	67637166	74859404	42721878
51566297	20036349	75403567	50106283	18052001	86986474	15798176
33928345	38208597	55476148	86293802	84283379	74715880	31686166
44336257	82290366	96849164	41539917	87044596	40253451	1196652
40393830	57976038	82245590	59310058	29471215	11126232	3570554
50730232	40375683	84341820	41785869	26759378	92552471	98630749
97260693	75806870	82370130	73165356	33642619	53327221	31399929
45079606	74797687	51351033	4101679	93987312	63545604	27794393
83989667	53082604	70644411	34207296	49449184	54816558	52982408
14866526	70011250	21341220	7925969	34973667	51163298	91514679
29071949	53402300	21445062	85890509	54567114	15031890	86089708
21219942	85836127	1106498	49651483	66873439	64791943	27795458
76605374	36057882	84500605	11627128	1742225	22200687	26963453
62157518	5247943	52334371	18174384	40161794	50585291	71566662

22674565	70380456	72951720	63506282	98811223	74019207	28910460
73852331	32032998	3400036	35615012	89008974	3752319	63806711
94659128	38141419	44696068	22657501	59764574	65074040	44804789
17703331	82657258	97487311	8495159	75320344	94952517	42720054
254159	36373540	69004099	8458071	86155936	5274951	82508524
74103409	89096890	61055734	14536513	64134348	50606715	3170584
73201615	39574561	96032970	31883958	26354069	99046679	8195829
33214293	83403783	26287239	98056415	46422514	3621999	21568179
84424881	28869386	2671	75139643	7603252	83216092	91914267
96893230	73229843	72855633	44774575	83705637	62222751	95529684
61935511	68056984	73874183	91107404	8714289	65794263	38992313
90996335	76930086	43938108	40607562	30813014	42970268	59866052
53674185	25242751	81062189	54278775	90860229	6139530	8262661
80095769	36463914	98345582	57101315	36684772	3213271	66097990
61316019	89026840	9724529	31358363	83718815	30288508	51698880
79278983	87174315	65584858	53663277	89970185	66444549	79002251
86873582	61184931	25183198	43851841	29693245	83181948	93934924
66179507	4907373	76696357	45423353	81293040	58305751	96594491
33185172	69488246	72323576	47180056	13343621	42978511	23319822
80526018	3287095	91080222	20891066	95033421	98639917	86736244
95560836	37528560	57659263	29210848	68546838	29851583	30362324
66518645	15961660	69600964	22041913	30336502	59672216	17027544
95079140	42613740	96473208	68476206	56122497	15549417	15248009
49512882	46671028	15410079	8533705	85941267	6078615	8110311
8080848	97008857	33947181	31225525	62503966	87726895	41317942
16536122	57737650	86883185	62897751	25478958	42570780	95896892
96098816	5192675	49649912	64482686	52036765	20812761	39667879
36868126	60990949	71075482	29394591	3050002	36473676	63204790
73059370	4871123	21749834	94406878	55471207	81513026	5387095
16079292	23340522	14370636	5967242	96229049	44983753	62648788
1059766	16635131	90754667	12903592	74652819	2506379	44280364
5158619	31122389	22048496	40546150	48022325	46013112	29191075
14599627	5411947	44118525	15762572	17112982	54343379	29229432
49170550	1009419	76685740	15185036	99372741	32757560	63012345
27972279	85573467	69687478	39904749	63885487	29056951	34136933
554071	17677379	17232662	54459	55626753	28094301	65180980
62339674	29323899	27633016	87409855	43322108	25595427	97810952
64203799	88991261	42327238	89761669	54341634	48932499	15127382
88083080	78564694	66311331	89455913	94637055	88280054	33339253
91158471	74681235	99205987	39312160	96233791	44166329	18390894
91148506	62784756	67968153	95601708	20897173	54058228	60523757

49087588	83070219	37821065	25195863	99241761	49054460	90648871
97264750	55719263	80416808	18036874	64092124	70735296	52632521
34127977	96407113	88162707	87617216	42873974	35311093	14056192
18507386	12817978	82108472	94267996	40804907	79527484	98596684
78479986	24427503	88044153	59371328	8267210	37355315	76215218
66177864	92904793	77919582	97027813	23992558	75780024	37263952
56159719	21777753	74508166	93927758	47428678	56864272	79159443
6722890	13238603	71009797	60615071	34161114	9716964	86977855
79759561	50637946	76443911	57239337	27157850	27939870	15748771
41766903	30085335	14757794	25726288	21050981	30304166	89531139
63385233	48945802	3111794	29954395	47788428	42772239	25631638
42744462	15802937	33645423	67198429	80492769	7461818	13487307
77425993	35978684	4013496	29172745	70388238	23436798	38419225
75210197	76683808	95052407	95876593	61925278	48621221	56973326
60021127	34577032	33236019	23503464	34795899	16311312	88089218
33515994	5488244	42995704	19525887	76559947	37734874	16419552
65958525	96551359	39106492	81815019	26231056	73009383	75049128
11262737	85585640	68032392	53149181	42351625	44353244	42127664
19458903	71237408	21238093	59582872	53769854	1149761	808484
61196360	78264419	19383557	99113431	66046664	25910405	20294853
99791417	61071306	49949450	35265287	67634916	11563182	81883651
77914561	89996504	1535191	47717476	60041023	57413514	95206792
9797018	57327932	58888953	91187400	83195494	72353129	1367205
75468204	97600817	82941722	46866539	12531095	64678773	65361614
81673461	70502177	7503885	65182105	6840065	88339724	8604620
67631611	52805792	51910922	51231296	89785029	92191358	6254271
55375752	80560525	34501994	69776592	45636131	27292418	55463941
11326154	79937881	28490336	66229265	62504948	65640294	2556929
27877963	19032913	32811786	34505159	24595550	21122001	14948334
17222578	21975836	9766068	54908579	91548536	42001273	46632480
4732893	123524	3960716	20779040	30564460	30056922	5902272
13345934	36216340	99655215	60372524	41696373	59225677	71613198
72514719	63885271	22980514	87297364	37495860	3446732	57073461
58412042	98065272	27149121	50814116	66341513	47250332	71844852
63991250	51555088	98289467	25892140	77693926	57184446	93595950
59738811	11406870	55881901	92290048	98212674	13061659	92153995
28913095	13761512	50170634	83521623	9088054	46898812	43354291
85688645	12943427	64910081	32187975	68192128	8506734	62427438
82351303	80401613	79406202	42176587	12449386	47770808	83963402
65821309	18258226	66945584	81084222	3014875	22009536	18278722
22572324	12744277	22043339	29688936	96180378	17965286	63469176
17403804	73824640	58345727	13225951	16339263	88997509	83876087

18091996	4152436	45470681	70530695	4456034	91246182	54789731
60564009	5924788	10230503	38164847	32675825	40787536	62771679
60690317	60516851	71723179	11721358	63820327	75046549	72928929
93446389	13090031	34998923	71493122	554150	19899780	71743999
45401307	12039329	54913650	99986427	22218860	1329094	77084552
94354925	70342379	75524543	97918093	47509941	70953787	95573850
980725	74782420	24518251	3096729	8804207	45199522	92789943
68224558	90387541	2225549	62913840	75435960	21850864	47709570
63306764	13351941	70985460	47063640	54381440	26206502	94280016
86491620	53380232	46292046	91437711	11318429	41680995	29270281
6343780	85665383	29633525	13772289	84910016	70959535	49713251
75652060	61303598	8039018	95539458	98450154	61789435	86568476
67983007	6044714	22170668	76455525	93095260	67362261	54980387
98360448	9439173	56885700	10875891	74603670	96258710	74090383
17943167	86411323	76194163	10736795	53917196	22831475	55333307
94472010	8693922	29707771	89169174	81258313	68644495	92749987
17938003	97782728	36621539	15151354	91366457	20091454	14985641
5218902	32401370	31548737	70545251	11287210	74904816	82121673
62980781	79548839	28259521	15472423	27157685	23298147	30251337
79758982	34349718	80968099	91725983	67822997	68101461	43325467
60417199	36666189	17313651	69147492	15808535	56908696	79633104
10382052	6521628	92556418	75448661	89199648	27164823	89884167
62535014	21634402	68339231	95103262	50116865	47305711	19134999
86087559	94982745	15217484	72664564	38396641	99606066	19907127
64053591	60480085	60922937	36833602	29297812	99068918	75648549
96751088	56407410	32662741	2372312	30850252	16794987	24365644
3467241	97154647	45347474	94174892	25101531	28125406	691991
5281028	48866354	33407300	10083135	53208784	55014389	64849054
23809631	57845508	34099411	18739963	54821461	56694181	9600486
31484497	8198242	44053082	53790911	56647093	9352654	38882206
80512019	12125251	56122546	16927868	4431615	75496470	4687795
73619458	57598939	77027398	97131091	53766866	51310106	60717016
15297521	42536403	68339108	91643068	16988257	92661350	74569393
71514091	20160375	74799195	93773568	90371048	69094734	8033726
23958819	94001181	51050333	630096	8902749	34413354	8694769
53535283	33152061	77545136	32225172	40863449	97970267	38855864
10556622	85626310	4187221	84506180	34243373	42097338	64745290
57546670	83008968	59559572	69390949	19552568	21834248	53193240
20389138	67829883	32487495	38468359	51747886	28161658	80996626
88931317	64617726	92838978	46211010	93462349	59418049	82925669
22744759	31787877	87062659	11524610	70531306	21644475	83273929

56423209	19358580	67557742	71961793	14667992	49584301	97784908
58891947	78477169	79398361	90031742	53314329	71379825	1132063
37203422	98181148	65707222	6304096	43030638	13343557	8333181
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77940365	10599344	79507293	67461364	95314251	80006441	16458903
99225429	49376871	33798161	64870563	92022471	87021780	69490266
61082714	15183908	67640235	26977723	60943040	65493336	29134845
7721098	42975824	81947795	3343203	97421440	34483151	76562742
44708748	50013174	83096361	50643324	93518220	20548971	793832
51664545	99560561	81953478	28997666	65524261	93799886	25433558
76022956	26238866	79421182	60935585	66964909	87857529	92389813
86194876	26979746	98360155	1196599	81521167	81187313	84562960
20945968	28904769	47972815	81095654	56180490	36375709	32912119
38466141	52857610	40440609	31769415	46833954	35385235	86527385
62140416	61011304	11964429	95336391	31752627	34945941	76491418
51512557	61367486	60483684	27951033	61346972	20261840	72160657
89738287	5919459	94191492	36104474	53033362	86159265	98925228
59942983	97488189	33194752	70554038	4127660	19569455	94240310
67258294	19763789	58250368	14974089	70664694	15973194	6853901
74916109	27314599	8363525	70246427	60590610	83166284	55933875
86831841	94901101	138076	32110702	41858453	55401453	23051148
49885620	50644110	88108771	46703318	75642894	71884311	84030453
73028669	80725300	72728650	96411374	73813958	26278852	35207162
43095246	86043014	49817757	88619721	59275185	17713496	93739525
72209237	42820174	29676535	15755189	32592473	38883148	56237308
24147306	27743184	36659202	89193239	87157934	7413413	70641928
46616592	94648082	80920872	68044119	92895512	85265155	44846941
48937986	35268041	10891764	89512868	86262689	55623426	68718015
13505563	97659160	11053611	76658975	67547676	72504053	86359430
92753235	78516987	90887219	94324240	12428935	9321258	95184883
64549244	45375220	69409404	1851336	4665875	64514388	4342374
20031715	79259209	67769895	50649363	46131267	98794941	18632796
51147816	58633592	58280936	69596130	20271224	33147260	76702792
92232821	98935229	72852202	82472549	2969693	58950027	94297842
75115893	10424445	20495159	97585987	31232334	27975484	78105411
90213607	69203974	23945508	66742153	52433298	50182001	640953
45892664	7418668	851085	51673413	80596615	18748166	75471300
76499431	8496047	28157213	90169151	26542702	36895904	37125674
58484938	37147566	3254474	17246990	58484898	36022299	23016046
13129480	2685844	86648035	24407915	34804570	12874996	75506401
3819894	85755058	2202792	93810423	73421343	14101350	80917079
96945130	56867693	41180104	31239269	88850779	27489640	33823961
54504010	67551597	83580981	45104181	95044451	6278880	4751483
56249050	86033735	57219592	8569248	12082832	70765455	31974525

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THE RAMO-WOOLDRIDGE CORPORATION
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Evaluation of $|A - \lambda I|$ for Matrix A

Complex Single Precision Floating Point

	Specifications
Identification Tag:	DET-2
Type:	Subroutine available on cards for assembly
Regional Addresses Used:	00R, 01R, 02R, 03R, CON, F00, RWT, C00
Storage:	132 words total program storage Temporary storage used but not stored with program: 4n cells directly addressable by SNIP n(n+1) cells all in ES or all in MD where n is the order of the matrix. The constant and temporary storage pools are used.
Entrance and Exit:	RJ 00R01 00R02
Mode of Operation:	Floating Point. SNIP must be activated in ES.
Machine Time:	Approximately $n^2(5n+22)$ms (see text)
Coded by:	W. L. Frank July, 1956
Approved by:	W. F. Bauer July, 1956

Description

This subroutine employs complex floating point arithmetic (SNIP) in order to evaluate the determinant of the matrix $A - \lambda I$, where **A** is a square matrix of order n. For the special case $\lambda = 0$ one obtains the determinant of A. Furthermore, one has obtained an eigenvalue λ if the quantity

$$|A - \lambda I| = 0$$

The following options are provided:

Option No. 1 - A must be stored row by row in the memory (ES or MD). The location of the first element is supplied in the parameter words.

Option No. 2 - A must be supplied to this subroutine row by row by an auxiliary routine to be prepared by the programmer to fit his needs. This auxiliary must have the form which allows for entry from this subroutine by an RJ 00X00 00X01 instruction assuming it is stored starting at location 00X00. The auxiliary will be entered n times, each time requiring the succeeding row of A to be set up in a region TEM00 preassigned by the programmer in the parameter words.

In addition to the 132 words of storage needed by the subroutine, it is necessary to provide 4n cells of temporary storage addressable by SNIP and a block of n(n+1) cells either all on ES or all on MD.

Operating Instructions

1. SNIP must be activated.
2. Entrance to the subroutine is made by the following instructions assuming λ is in the floating accumulator.

a. Option No. 1 -

```
P      RJ   00R01   00R02
P+1    00   MAT00   vvvvv
P+2    00   TRI00   TEM00
```

where OOROO is the location of the first word of the subroutine.

MATOO is the region in which the matrix A is stored row by row.

vvvvv is the order of the matrix A.

TRIOO is the location of the first cell of the block of n(n+1) cells either all in ES or all in MD.

TEMOO is the location of the first cell of the block of 4n cells of temporary storage directly addressable by SNIP.

b. Option No. 2 - P RJ OOROl OOR02

. P+1 40 OOXOO vvvvv BRR

P+2 00 TRIOO TEMOO

where OOROO, vvvvv, TRIOO and TEMOO are as above.

OOXOO is the location of the first word of the auxiliary which supplies the successive rows of A. The auxiliary must provide successive rows of the matrix A and place each row in the first 2n cells of TEMOO.

3. Upon exit from the subroutine control is transferred to the word in cell P+3. The value of $|A - \lambda I|$ is left in the floating accumulator and also in the ninth and tenth words of the R-W temporary pool. The input λ can be found in the fifth and sixth words of the R-W temporary pool.

Machine Time

Computing time for operation of this subroutine is given by $n^2(5n + 22)$ ms where n is the order of the matrix.

In case the block of n(n+1) words is stored on MD the time must be increased by $8.5(n^2 + 3n)$ milliseconds. These times are approximate and will be conservative in most cases.

Mathematical Method

Elementary row operations are performed on the matrix $A - \lambda I$ reducing it to an upper triangular matrix $\bar{A}$. Before eliminating, leading elements of two rows which are to be linearly combined are compared and the element of largest magnitude becomes the pivotal point. The product of the diagonal elements of $\bar{A}$ is the value of $|A - \lambda I|$.

```
D          00R00 00500
D          01R00 00546
D          02R00 00562
D          03R00 00600
D          C0N00 00625
D          F0000 00002
D          C0000 00003
D          RWT00 00023
00R00   MJ 00000 00000
00R01   MJ 00000 00000          EXIT
00R02   54 00R01 A0015 BRR
00R03   TU A0000 00R06
00R04   AT 00015 A0000
00R05   TU A0000 00R14
00R06   TP 00000 A0000
00R07   TV A0000 C0N06          N
00R08   TU A0000 03R01
00R09   TP C0N01 Q0000
00R10   LA A0000 00016
00R11   TU A0000 C0N04
00R12   QS A0000 01R04
00R13   TU 01R04 03R00          S
00R14   TP 00000 A0000           E
00R15   TV A0000 02R01            T
00R16   TV A0000 03R01
00R17   TU 00R14 02R29          A
00R18   LA A0000 00015             D
00R19   TU A0000 01R05              D
00R20   TU A0000 02R27               R
00R21   LA A0000 00042                E
00R22   TV A0000 01R05                 S
00R23   QS 01R05 02R06                 S
00R24   QS 01R05 02R12                    E
00R25   QS 01R05 02R04                     S
00R26   RA 02R04 C0N04
00R27   TP C0N02 Q0000

00R28   RA 02R01 C0N06
00R29   RA 02R01 C0N06
00R30   QS 02R01 02R06
00R31   RS C0N06 00016
00R32   ST 00016 RWT02
00R33   TN F0000 RWT04
00R34   TN C0000 RWT05
00R35   QS 03R01 03R04
00R36   TU 00R06 00R37
00R37   TP 00000 A0000
00R38   SJ 00R39 00R45
00R39   TP 01R07 03R02
```

```
00764  00 00000 00000
01042  00 00000 00000
01062  00 00000 00000
01130  00 00000 00000
01161  00 00000 00000
00002  00 00000 00000
00003  00 00000 00000
00027  00 00000 00000
00764  45 00000 00000
00765  45 00000 00000
00766  54 00765 20017
00767  15 20000 00772
00770  35 00017 20000
00771  15 20000 01002
00772  11 00000 20000
00773  16 20000 01167
00774  15 20000 01131
00775  11 01162 10000
00776  54 20000 00020
00777  15 20000 01165
01000  53 20000 01046
01001  15 01046 01130
01002  11 00000 20000
01003  16 20000 01063
01004  16 20000 01131
01005  15 01002 01117
01006  54 20000 00017
01007  15 20000 01047
01010  15 20000 01115
01011  54 20000 00052
01012  16 20000 01047
01013  53 01047 01070
01014  53 01047 01076
01015  53 01047 01066
01016  21 01066 01165
01017  11 01163 10000

01020  21 01063 01167
01021  21 01063 01167
01022  53 01063 01070
01023  23 01167 00020
01024  36 00020 00031
01025  13 00002 00033
01026  13 00003 00034
01027  53 01131 01134
01030  15 00772 01031
01031  11 00000 20000
01032  46 01033 01041
01033  11 01051 01132
```

```
00R40    TU 03R01 03R02                                  01034  15 01131 01132
00R41    SP 03R02 00057                                  01035  31 01132 00071
00R42    TV A0000 03R02                                  01036  16 20000 01132
00R43    RA 03R02 00016                                  01037  21 01132 00020
00R44    MJ 00000 01R00                                  01040  45 00000 01042
00R45    TP 03R24 03R02                                  01041  11 01160 01132
01R00    TP C0N00 RWT08                                  01042  11 01161 00037
01R01    TP 00013 RWT09                                  01043  11 00015 00040
01R02    TU 00013 03R06                                  01044  15 00015 01136
01R03    RJ 03R06 03R00                                  01045  37 01136 01130
01R04    RP 30000 01R06                                  01046  75 30000 01050
01R05    TP 00000 00000                                  01047  11 00000 00000
01R06    TN 00016 RWT03                                  01050  13 00020 00032
01R07    RJ 03R06 03R00          GET ITH ROW             01051  37 01136 01130
01R08    TU 01R04 02R00                                  01052  15 01046 01062
01R09    54 01R05 A0015 BRR                              01053  54 01047 20017
01R10    TU A0000 02R01                                  01054  15 20000 01063
01R11    RA RWT03 00016                                  01055  21 00032 00020
01R12    TP RWT03 RWT01                                  01056  11 00032 00030
01R13    TP 00013 RWT00                                  01057  11 00015 00027
01R14    TU 02R06 02R02                                  01060  15 01070 01064
01R15    TP RWT00 00004                                  01061  11 00027 00004
02R00    RP 30000 02R02                                  01062  75 30000 01064
02R01    TP 00000 00000                                  01063  11 00000 00000
02R02  LDPM 00000 RWT06  B     S                        01064  14 32000 25035
02R03    ZJ 02R04 02R16          SKIP IF ZERO            01065  47 01066 01102
02R04  LDPM 00000 00000                                  01066  14 30000 24000
02R05    TJ RWT06 03R07          INTERCHANGE             01067  42 00035 01137
02R06  LDDV 00000 00000  B                               01070  14 32000 20000
02R07    TN F0000 RWT06                                  01071  13 00002 00035
02R08    TN C0000 RWT07                                  01072  13 00003 00036
02R09    TP C0N02 Q0000          L                       01073  11 01163 10000
02R10    QS 02R01 02R11           I                      01074  53 01063 01075
02R11  LDMP RWT06 00000            N                    01075  14 30035 14000
02R12  ADNO 00000 00000  BS           E                  01076  14 07000 00000
02R13    RA 02R11 C0N03                A                 01077  21 01075 01164
02R14    RA 00004 C0N05                 R                01100  21 00004 01166
02R15    TJ C0N04 02R11                  L               01101  42 01165 01075
02R16    TP 00021 Q0000                   Y              01102  11 00025 10000
02R17    TP 02R01 A0000                                  01103  11 01063 20000
02R18    QA 02R00 02R01          COMBINE                 01104  52 01062 01063
02R19    RS 02R00 C0N05                                  01105  23 01062 01166
02R20    RA RWT00 C0N05                                  01106  21 00027 01166
02R21    IJ RWT01 01R15          R                       01107  41 00030 01061
02R22    RA 02R27 C0N05           O                      01110  21 01115 01166
02R23    55 02R01 Q0021 BRR                              01111  55 01063 10025
02R24    TV Q0000 02R27                S                 01112  16 10000 01115
02R25    TU 02R00 02R26                                  01113  15 01062 01114
02R26    RP 30000 02R28                                  01114  75 30000 01116
02R27    TP 00000 00000                                  01115  11 00000 00000
02R28    IJ RWT02 01R07                                  01116  41 00031 01051
```

```
02R29    TU 00000 00004                                  01117  15 00000 00004
02R30  LDMP 00000 RWT08  B     S  PRODUCT               01120  14 32000 15037
02R31    RA 00004 CON04              OF                 01121  21 00004 01165
02R32    RS CON04 CON05           DIAGONAL              01122  23 01165 01166
02R33    IJ CON06 02R30                                  01123  41 01167 01120
02R34    RA 00R01 CON03           ELEMENTS               01124  21 00765 01164
02R35    TN RWT04 RWT04                                  01125  13 00033 00033
02R36    TN RWT05 RWT05                                  01126  13 00034 00034
02R37    MJ 00000 00R01                                  01127  45 00000 00765
03R00    RP 30000 03R02                                  01130  75 30000 01132
03R01    TP 00000 00000           NEXT                   01131  11 00000 00000
03R02    RA 03R01 CON04            ROW                   01132  21 01131 01165
03R03    TU 03R06 00004                                  01133  15 01136 00004
03R04  LDAD RWT04 00000       BS                        01134  14 30033 07000
03R05    RA 03R06 CON05                                  01135  21 01136 01166
03R06    MJ 00000 00000                                  01136  45 00000 00000
03R07    TU 02R00 03R19          D                       01137  15 01062 01153
03R08    TU 02R00 03R22           E                      01140  15 01062 01156
03R09    TP CON01 Q0000            T                     01141  11 01162 10000
03R10    QS 02R04 03R23             E                    01142  53 01066 01157
03R11    TP 02R02 A0000              R                   01143  11 01064 20000
03R12    AT RWT00 A0000               M                  01144  35 00027 20000
03R13    QS A0000 03R20                I                 01145  53 20000 01154
03R14    TP CON02 Q0000                 N                01146  11 01163 10000
03R15    LA A0000 00057                  E               01147  54 20000 00071
03R16    QS A0000 03R23          PIVOT                   01150  53 20000 01157
03R17    54 02R01 A0057 BRR                              01151  54 01063 20071
03R18    TV A0000 03R20                                  01152  16 20000 01154
03R19    RP 30000 03R21                                  01153  75 30000 01155
03R20    TP 00000 00000                                  01154  11 00000 00000
03R21    TN RWT08 RWT08                                  01155  13 00037 00037
03R22    RP 30000 01R15                                  01156  75 30000 01061
03R23    TP 00000 00000                                  01157  11 00000 00000
03R24    RA 03R01 CON04                                  01160  21 01131 01165
CON00    01 00000 00000      F   C                       01161  20 14000 00000
CON01    00 00777 00000 B         O                      01162  00 00777 00000
CON02    00 00000 00777 B          N                     01163  00 00000 00777
CON03    00 00000 00002             S                    01164  00 00000 00002
CON04    00 00000 00000              T                   01165  00 00000 00000
CON05    00 00002 00000               A                  01166  00 00002 00000
CON06    00 00000 00000                NTS               01167  00 00000 00000
START       00000                                        00000  45 00000 00000
```

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Floating Point Linear Matrix Equation Solver (AX=B)

Specifications

Identification Tag: MTI-1

Type: Subroutine available on cards for assembly

Regional Addresses Used: OOM, O1M, O2M, O3M, CON, AUG, RWT

Storage: 171 words total program storage.

Temporary storage used but not stored with program:
$2(n + m)$ cells directly addressable by SNAP and
$\frac{n(n + 1)}{2} + nm$ cells all in ES or all in MD,
where x is an n by m matrix.

The constant and temporary storage pools are used.

Entrance and Exit: RJ OOMO1 OOMO2

Alarm: The alarm exit is used to print "SINGUL" if a singularity is detected.

Mode of Operation: Floating point. SNAP must be in E.S.

Machine Time: Approximately

$$2n^2(n + 3m + 2) + 3000 \text{ milliseconds}$$

where X is an n by m matrix.

Coded by: W. L. Frank June, 1956

Approved by: W. F. Bauer July, 1956

Description

This subroutine employs floating point arithmetic in order to solve the linear matrix equation AX = B, where A is a non-singular matrix of size nxn and B has the dimensions nxm. The solution $X = A^{-1}B$, is a matrix of size nxm. For the special case, when B is the identity matrix (I), one obtains the inverse of the matrix A. Otherwise, one can solve m sets of n simultaneous linear equations in n unknowns.

Considerable flexibility is afforded the programmer with respect to the storage of the matrices A, B and the answer X. The programmer must code two auxiliary routines as follows:

(a) The first must provide successive rows of the augmented matrix $[A, B]$. (When B = I, one only need supply rows of A). Each row, consisting of (n + m) elements (or n elements when B = I), must be transferred to the first (n + m) cells of the 2(n + m) cells of temporary storage provided by the programmer.

(b) The second auxiliary must take the successive columns of X, found in the first n cells of the 2(n + m) cells of temporary storage and either store them internally or punch them out.

These auxiliary routines are automatically entered n and m times respectively by RJ instructions in the subroutine. The subroutine sets up these two RJ instructions from information gleaned from the parameters of the entry. This procedure allows storage of A, B and X on ES, MD, magnetic tape or externally on cards or tape. It is also possible to generate the elements of successive rows when a functional relation exists.

In addition to the 171 words of storage needed by the subroutine, it is necessary to provide 2(n + m) cells temporary storage addressable by SNAP and a block of $\frac{n(n+1)}{2} + nm$ cells, either all on ES or all on MD.

Operating Instructions

1. SNAP must be activated.
2. Entrance to the subroutine is made by the following orders (B ≠ I):

P	RJ	00M01	00M02
P + 1	00	00X00	00Y01
P + 2	--	uuuuu	vvvvv
P + 3	--	zzzzz	xxxxx

where OOMOO is the location of the first word of the subroutine
OOXOO is the location of the first word of the first auxiliary
OOYOl is the location of the second word of the second auxiliary
uuuuu = m (number of columns of B)
vvvvv = n (number of rows of A)
zzzzz = is the location of the first cell of the 2(n + m) cells of temporary storage addressable directly by SNAP.
xxxxx = is the location of the first cell of the block of $\frac{n(n+1)}{2}$ + nm cells all in ES or all in MD.

3. For the case when B = I, the P + 1 word must be 40 OOXOO OOYOl BRR.
4. The auxiliary routines must be available and coded so that they can be entered with

RJ OOXOO OOXOl
and RJ OOYOO OOYOl respectively.

This implies that the first and second words of both auxiliaries are exit and entrances respectively.

Alarm Conditions

If a singular matrix is detected in the process of inversion, the alarm routine ALR-1 is entered and "singul-wwwww" is printed where wwwww is the address of the cell from which the subroutine was entered. The routine cannot, however, detect all singularities due to round-off errors (see below).

Starting after an alarm print-out will return control to P + 4 in the main program.

Machine Time

The machine time is as indicated on the first page when all operations are carried on in ES. This time is exclusive of the times taken by the auxiliaries. In case the block of $\frac{n(n+1)}{2}$ + nm words is stored on MD, the time must be increased by $8.5(n^2 + 3n + nm^2 + mn)$ milliseconds. These times are approximate and will be a minimum in most cases.

Mathematical Method (Gauss elimination method)

Elementary row operations are performed on the matrix A reducing it to an upper triangular matrix $\bar{A}$. At the same time, these operations are performed on the matrix B giving a new matrix $\bar{B}$. Before eliminating, leading elements of two rows are compared and the element of largest magnitude becomes the pivotal element.

Next, successive columns of $\bar{B}$ are taken and the equation $\bar{A}\bar{X} = \bar{B}$ is

solved by the back substitution procedure.

Singularities in A are detected if a zero appears on the diagonal of $\bar{A}$. Since round-off errors can prevent this from occurring one must consider the magnitudes of the elements of X as compared to those of A. A large order of difference may indicate poor conditioning of A.

Accuracy

The accuracy in the result is a function of the condition of the matrix A. Six to seven decimal place accuracy was obtained for matrices of order 10 to 16. A test was performed in which the highly ill conditioned Hilbert matrices of order 2 - 10 were inverted. Seven place accuracy was obtained for the matrix of order 2. One more digit was lost for each succeeding higher order matrix.

PX 71900-10-(176)

```
D          00M00  00100                                  00144  00 00000 00000
D          01M00  00157                                  00235  00 00000 00000
D          02M00  00179                                  00263  00 00000 00000
D          03M00  00208                                  00320  00 00000 00000
D          AUG00  00255                                  00377  00 00000 00000
D          C0N00  00262                                  00406  00 00000 00000
D          RWT00  00023                                  00027  00 00000 00000
00M00   37 75701  75702 B       ALARM                    00144  37 75701 75702
00M01   MJ 00000  00000         EXIT                     00145  45 00000 00000
00M02   54 00M01  20017 BRB     ENTRY                    00146  54 00145 20017
00M03   TU A0000  00M09                                  00147  15 20000 00155
00M04   TU A0000  AUG00                                  00150  15 20000 00377
00M05   AT 00015  A0000                                  00151  35 00017 20000
00M06   TU A0000  00M26                                  00152  15 20000 00176
00M07   AT 00015  A0000                                  00153  35 00017 20000
00M08   TU A0000  00M19                                  00154  15 20000 00167
00M09   TP 00000  A0000                                  00155  11 00000 20000
00M10   TU A0000  01M00         SET                      00156  15 20000 00235
00M11   TV A0000  03M31                                  00157  16 20000 00357
00M12   AT 00015  A0000          A                       00160  35 00017 20000
00M13   SS 00016  00015           U                      00161  34 00020 00017
00M14   TU A0000  03M31            X                     00162  15 20000 00357
00M15   LA A0000  00042             I                    00163  54 20000 00052
00M16   TV A0000  01M00              L                   00164  16 20000 00235
00M17   TP 01M00  01M05                                  00165  11 00235 00242
00M18   TP C0N01  Q0000                                  00166  11 00407 10000
00M19   TP 00000  A0000         S                        00167  11 00000 20000
00M20   TV A0000  01M03          E                       00170  16 20000 00240
00M21   TU A0000  01M03           T                      00171  15 20000 00240
00M22   TU A0000  02M25                                  00172  15 20000 00314
00M23   QS 01M03  02M05                                  00173  53 00240 00270
00M24   QS 01M03  02M10          A                       00174  53 00240 00275
00M25   TU 02M25  02M03            D                     00175  15 00314 00266
00M26   TP 00000  A0000             D                    00176  11 00000 20000
00M27   TU A0000  C0N04         M     R                  00177  15 20000 00412
00M28   TV A0000  C0N06         N      E                 00200  16 20000 00414
00M29   54 C0N06  20017 BRB             S                00201  54 00414 20017
00M30   QS A0000  AUG02                  S               00202  53 20000 00401
00M31   AT 02M25  A0000                   E              00203  35 00314 20000
00M32   QS A0000  03M20                    S             00204  53 20000 00344
00M33   QS A0000  03M29                                  00205  53 20000 00355
00M34   TP AUG02  A0000                                  00206  11 00401 20000
00M35   AT C0N04  A0000                                  00207  35 00412 20000
00M36   QS A0000  C0N05                                  00210  53 20000 00413
00M37   QS A0000  01M02                                  00211  53 20000 00237
00M38   RA 02M03  C0N05                                  00212  21 00266 00413
00M39   55 C0N04  10025 BRB                              00213  55 00412 10025
00M40   TV Q0000  C0N07                                  00214  16 10000 00415
00M41   TP C0N03  Q0000                                  00215  11 00411 10000
00M42   54 03M20  20071 BRB                              00216  54 00344 20071
```

```
00M43    QS  A0000  AUG03                                00217  53 20000 00402
00M44    TV  AUG03  AUG04                                00220  16 00402 00403
00M45    TV  AUG03  02M27                                00221  16 00402 00316
00M46    AT  CON07  A0000                                00222  35 00415 20000
00M47    QS  A0000  02M01                                00223  53 20000 00264
00M48    QS  A0000  02M05                                00224  53 20000 00270
00M49    AT  CON06  A0000                                00225  35 00414 20000
00M50    QS  A0000  03M16                                00226  53 20000 00340
00M51    QS  A0000  03M20                                00227  53 20000 00344
00M52    QS  A0000  03M25                                00230  53 20000 00351
00M53    QS  A0000  03M28                                00231  53 20000 00354
00M54    RS  CON06  00016                                00232  23 00414 00020
00M55    ST  00016  RWT02                                00233  36 00020 00031
00M56    RS  CON07  00016                                00234  23 00415 00020
01M00    RJ  00000  00000        TO AUX 1                00235  37 00000 00000
01M01    RJ  AUG06  AUG00        AUGMENT                 00236  37 00405 00377
01M02    RP  30000  01M04                                00237  75 30000 00241
01M03    TP  00000  00000                                00240  11 00000 00000
01M04    TN  00016  RWT03        SET INDEX               00241  13 00020 00032
01M05    RJ  00000  00000        GET ITH ROW             00242  37 00000 00000
01M06    RJ  AUG06  AUG00        AUGMENT                 00243  37 00405 00377
01M07    TU  01M02  02M00                                00244  15 00237 00263
01M08    54  01M03  20017  BRB                           00245  54 00240 20017
01M09    TU  A0000  02M01                                00246  15 20000 00264
01M10    RA  RWT03  00016                                00247  21 00032 00020
01M11    TP  RWT03  RWT01                                00250  11 00032 00030
01M12    TP  00013  RWT00                                00251  11 00015 00027
01M13    TP  CON01  Q0000                                00252  11 00407 10000
01M14    QS  02M05  01M15                                00253  53 00270 00254
01M15    TM  00000  00002                                00254  12 00000 00002
01M16    TU  01M15  03M44                                00255  15 00254 00374
01M17    55  01M15  20025  BRB                           00256  55 00254 20025
01M18    TV  A0000  03M46                                00257  16 20000 00376
01M19    RA  01M15  00015                                00260  21 00254 00017
01M20    TP  00002  A0000                                00261  11 00002 20000
01M21    ZJ  02M00  02M14        SKIP IF ZERO            00262  47 00263 00301
02M00    RP  30000  02M02        TRANSMIT ITH            00263  75 30000 00265
02M01    TP  00000  00000        ROW TO ES               00264  11 00000 00000
02M02    TP  RWT00  00004        B BOX                   00265  11 00027 00004
02M03    TM  00000  A0000                                00266  12 00000 20000
02M04    TJ  00002  03M38                                00267  42 00002 00366
02M05  LDDV  00000  00000  B                             00270  14 32000 20000
02M06    TP  00002  RWT08                                00271  11 00002 00037
02M07    TP  CON03  Q0000        L                       00272  11 00411 10000
02M08    QS  02M01  02M09          I                     00273  53 00264 00274
02M09  LDMP  RWT08  00000            N                   00274  14 30037 14000
02M10  SUNO  00000  00000  BS          E                 00275  14 13000 00000
02M11    RA  02M09  00016              A                 00276  21 00274 00020
02M12    RA  00004  00015                R               00277  21 00004 00017
02M13    TJ  CON05  02M09                  L             00300  42 00413 00274
```

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```
02M14    TP 00021 Q0000                    Y          00301  11 00025 10000
02M15    TP 02M01 A0000                               00302  11 00264 20000
02M16    QA 02M00 02M01          COMBINE              00303  52 00263 00264
02M17    RS 02M00 00015                               00304  23 00263 00017
02M18    RA RWT00 00015            R                  00305  21 00027 00017
02M19    IJ RWT01 01M15             O                 00306  41 00030 00254
02M20    RA 02M25 00015              W                00307  21 00314 00017
02M21    55 02M01 10025 BRB           S               00310  55 00264 10025
02M22    TV Q0000 02M25                               00311  16 10000 00314
02M23    TU 02M00 02M24                               00312  15 00263 00313
02M24    RP 30000 02M26          REPLACE              00313  75 30000 00315
02M25    TP 00000 00000           REDUCED ROW         00314  11 00000 00000
02M26    IJ RWT02 01M05          N-2 TIMES            00315  41 00031 00242
02M27    TP CON02 00000                               00316  11 00410 00000
02M28    TP CON06 RWT05                               00317  11 00414 00034
03M00    TV 03M16 03M14                               00320  16 00340 00336
03M01    TU 02M01 03M14                               00321  15 00264 00336
03M02    TP 00021 Q0000                               00322  11 00025 10000
03M03    QS 00013 03M13                               00323  53 00015 00335
03M04    TP 00016 RWT01                               00324  11 00020 00030
03M05    TP 00013 RWT03                               00325  11 00015 00032
03M06    RA 03M14 00015                               00326  21 00336 00017
03M07    MJ 00000 03M09                               00327  45 00000 00331
03M08    RS 03M14 CON04                               00330  23 00336 00412
03M09    RA 03M13 00015          TRANSFER             00331  21 00335 00017
03M10    RA RWT01 00015          ROWS OF              00332  21 00030 00017
03M11    TU 03M14 03M16          UPPER                00333  15 00336 00340
03M12    RS 03M14 RWT01          TRIANGULAR           00334  23 00336 00030
03M13    RP 30000 03M15          MATRIX               00335  75 30000 00337
03M14    TP 00000 00000                               00336  11 00000 00000
03M15    RA 03M16 RWT02                               00337  21 00340 00031
03M16    TN 00000 00000          B                    00340  13 00000 00000
03M17    TP 00013 00004           A                   00341  11 00015 00004
03M18    TP RWT03 RWT00            C                  00342  11 00032 00027
03M19    TP 00013 RWT06             K                 00343  11 00015 00035
03M20  LDMP 00000 00000  B   B     S                  00344  14 32000 16000
03M21  ADNO RWT06 00000    S       U                  00345  14 05035 00000
03M22    RS 00004 00015              B                00346  23 00004 00017
03M23    IJ RWT00 03M20               S               00347  41 00027 00344
03M24    RA RWT03 00016                T              00350  21 00032 00020
03M25  NOLD 00000 00000        B      I               00351  14 00000 32000
03M26    ZJ 03M27 03M36                 T             00352  47 00353 00364
03M27    TN RWT06 00002                  U            00353  13 00035 00002
03M28  NODV 00000 00000        B                T     00354  14 00000 22000
03M29  STNO 00000 00000  B                       E     00355  14 36000 00000
03M30    IJ RWT05 03M08                               00356  41 00034 00330
03M31    RJ 00000 00000          TO AUX 2             00357  37 00000 00000
03M32    RA RWT02 00015                               00360  21 00031 00017
03M33    IJ CON07 02M27                               00361  41 00415 00316
```

```
03M34   RA 00M01 CON08
03M35   MJ 00000 00M01
03M36   11 CON00 75756 BRB      TO ALARM
03M37   MJ 00000 00M00
03M38   TU 02M03 03M46          INTERCHANGE
03M39   TU 02M00 03M43
03M40   TU 02M00 03M45           R
03M41   55 02M01 20025 BRB       O
03M42   TV A0000 03M44            W
03M43   RP 30000 03M45             S
03M44   TP 00000 00000
03M45   RP 30000 02M00
03M46   TP 00000 00000
AUG00   TP 00000 A0000          TEST TO SEE
AUG01   SJ AUG02 AUG06           IF INVERT
AUG02   RP 10000 AUG04
AUG03   TP 00013 00000           AUGMENT
AUG04   TP CON02 00000            IDENTITY
AUG05   RA AUG04 00016
AUG06   MJ 00000 00000
CON00   24 14061 33411 B
CON01   00 00777 00000 B        CONSTANTS
CON02   01 00000 00000     F
CON03   00 00000 00777 B          AND
CON04   00 00000 00000
CON05   00 00000 00000          TEMPORARY
CON06   00 00000 00000           STORAGE
CON07   00 00000 00000
CON08   00 00000 00003
START       00M00
```

```
00362  21 00145 00416
00363  45 00000 00145
00364  11 00406 75756
00365  45 00000 00144
00366  15 00266 00376
00367  15 00263 00373
00370  15 00263 00375
00371  55 00264 20025
00372  16 20000 00374
00373  75 30000 00375
00374  11 00000 00000
00375  75 30000 00263
00376  11 00000 00000
00377  11 00000 20000
00400  46 00401 00405
00401  75 10000 00403
00402  11 00015 00000
00403  11 00410 00000
00404  21 00403 00020
00405  45 00000 00000
00406  24 14061 33411
00407  00 00777 00000
00410  20 14000 00000
00411  00 00000 00777
00412  00 00000 00000
00413  00 00000 00000
00414  00 00000 00000
00415  00 00000 00000
00416  00 00000 00003
00000  45 00000 00144
```

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THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Complex Single Precision Floating Point Linear Matrix Equation Solver (AX = B)

Specifications

Identification Tag:	MTI-2
Type:	Subroutine available on cards for assembly
Regional Addresses Used:	OOM, O1M, O2M, O3M, CON, AUG, RWT
Storage:	185 words total program storage. Temporary storage used but not stored with program: $4(n + m)$ cells directly addressable by SNIP, and $n(n + 1) + 2nm$ cells all in ES or all in MD, where X is an n by m matrix. The constant and temporary storage pools are used.
Entrance and Exit:	RJ OOMO1 OOMO2
Alarm:	The alarm exit is used to print "SINGUL" if a singularity is detected.
Mode of Operation:	Floating point. Complex mode of SNIP must be activated in ES.
Machine Time:	See Text.

Coded by:	W. L. Frank	June, 1956
Approved by:	W. F. Bauer	June, 1956

Description

This subroutine employs single precision complex floating point arithmetic (SNIP) in order to solve the linear matrix equation AX = B, where A is a non-singular matrix of size nxn and B has the dimensions nxm. The solution, $X = A^{-1}B$, is a matrix of size nxm. For the special case, when B is the identity matrix (I), one obtains the inverse of the matrix A. Otherwise one can solve m sets of n simultaneous linear equations in n unknowns.

Considerable flexibility is afforded the programmer with respect to the storage of the matrices A, B and the answer X. The programmer must code two auxiliary routines as follows:

(a) The first must provide successive rows of the augmented matrix $[A, B]$. (When B = I, one only need supply rows of A). Each row, consisting of 2(n + m) elements (or 2n elements when B = I), must be transferred to the first 2(n + m) cells of the 4(n + m) cells of temporary storage provided by the programmer.

(b) The second auxiliary must take the successive columns of X, found in the first 2n cells of the 4(n + m) cells of temporary storage and either store them internally or punch them out.

These auxiliary routines are automatically entered n and m times respectively by RJ instructions in the subroutine. The subroutine sets up these two RJ instructions from information gleaned from the parameters of the entry. This procedure allows storage of A, B and X on ES, MD, magnetic tape or externally on cards or tape. It is also possible to generate the elements of successive rows when a functional relation exists.

In addition to the 185 words of storage needed by the subroutine, it is necessary to provide 4(n + m) cells temporary storage addressable by SNIP and a block of n(n + 1) + 2nm cells, either all on ES or all on MD.

Operating Instructions

1. Entrance to the subroutine is made as follows (B ≠ I):

```
P       RJ  00M01  00M02
P + 1   00  00X00  00Y01
P + 2   --  uuuuu  vvvvv
P + 3   --  zzzzz  xxxxx
```

where OOMOO is the location of the first word of the subroutine

OOXOO is the location of the first word of the first auxiliary

OOYOl is the location of the second word of the second auxiliary

uuuuu = m (number of columns of B)

vvvvv = n (number of rows of A)

xxxxx = is the location of the first cell of the block of n(n + 1) + 2nm cells all in ES or all in MD.

zzzzz = is the location of the first cell of the 4(n + m) cells of temporary storage addressable directly by SNIP.

2. For the case when B = I, the P + 1 word must be 40 OOXOO OOYOl (BRR)
3. The auxiliary routines must be available and coded so that they can be entered with

   RJ OOXOO OOXOl

   and

   RJ OOYOO OOYOl respectively.

   This implies that the first and second words of both auxiliaries are exit and entrances respectively.

Alarm Conditions

If a singular matrix is detected in the process of inversion, the alarm routine ALR-1 is entered and "singul-wwwww" is printed where wwwww is the address of the cell from which the subroutine was entered. The routine cannot, however, detect all singularities due to round-off errors (see below).

Machine Time

Computing time for operation of this subroutine can be estimated from the following table:

Order (n = m)	Time in seconds
3	1.7
5	4.7
8	15.6
10	27.7

This time is exclusive of the times taken by the auxiliaries. In case the block of n(n + 1) + 2nm words is stored on MD, the time must be increased $34(n^2 + nm + 2nm^2)$ milliseconds. These times are approximate and are conservative in most cases.

Mathematical Method (Gauss elimination method)

Elementary row operations are performed on the matrix A reducing it to an upper triangular matrix $\bar{A}$. At the same time, these operations are performed on the matrix B giving a new matrix $\bar{B}$.

Before eliminating, leading elements of two rows are compared and the element of largest magnitude becomes the pivotal point.

Next, successive columns of $\bar{B}$ are taken and the equation $\bar{A}X = \bar{B}$ is solved by the back substitution procedure.

Singularities in A are detected if a zero appears on the diagonal of $\bar{A}$. Since round-off errors can prevent this from occurring one must consider the magnitudes of the elements of X as compared to those of A. A large order of difference may indicate poor conditioning of A.

Accuracy

The accuracy in the result is a function of the condition of the matrix A. Six to seven decimal place accuracy was obtained for matrices of order 10 to 16.

```
D          00M00  00100
D          01M00  00161
D          02M00  00176
D          03M00  00210
D          AUG00  00267
D          CON00  00274
D          RWT00  00023
00M00  37  75701  75702  B     ALARM
00M01  MJ  00000  00000        EXIT
00M02  54  00M01  A0015  BRR  ENTRANCE
00M03  TU  A0000  00M09
00M04  TU  A0000  AUG00
00M05  AT  00015  A0000
00M06  TU  A0000  00M26
00M07  AT  00015  A0000
00M08  TU  A0000  00M19
00M09  TP  00000  A0000
00M10  TU  A0000  01M00        SET
00M11  TV  A0000  03M34          A
00M12  AT  00015  A0000           U
00M13  SS  00016  00015            X
00M14  TU  A0000  03M34             I
00M15  LA  A0000  00042              L
00M16  TV  A0000  01M00
00M17  TP  01M00  01M05
00M18  TP  CON01  Q0000
00M19  TP  00000  A0000
00M20  TV  A0000  01M03        S
00M21  TU  A0000  01M03         E
00M22  TU  A0000  02M27          T
00M23  QS  01M03  02M06
00M24  QS  01M03  02M12         A
00M25  QS  02M27  02M04          D
00M26  TP  00000  A0000           D
00M27  TU  A0000  CON04        M   R
00M28  TV  A0000  CON06        N    E
00M29  54  CON06  A0016  BRR       S
00M30  QS  A0000  AUG02              S
00M31  AT  02M27  A0000               E
00M32  QS  A0000  03M21                S
00M33  QS  A0000  03M32
00M34  54  CON04  A0001  BRR
00M35  AT  AUG02  A0000
00M36  QS  A0000  01M02
00M37  QS  A0000  CON05
00M38  RA  02M04  CON05
00M39  55  CON04  Q0021  BRR
00M40  TV  Q0000  CON07
```

```
00144  00  00000  00000
00241  00  00000  00000
00260  00  00000  00000
00322  00  00000  00000
00413  00  00000  00000
00422  00  00000  00000
00027  00  00000  00000
00144  37  75701  75702
00145  45  00000  00000
00146  54  00145  20017
00147  15  20000  00155
00150  15  20000  00413
00151  35  00017  20000
00152  15  20000  00176
00153  35  00017  20000
00154  15  20000  00167
00155  11  00000  20000
00156  15  20000  00241
00157  16  20000  00364
00160  35  00017  20000
00161  34  00020  00017
00162  15  20000  00364
00163  54  20000  00052
00164  16  20000  00241
00165  11  00241  00246
00166  11  00423  10000
00167  11  00000  20000
00170  16  20000  00244
00171  15  20000  00244
00172  15  20000  00313
00173  53  00244  00266
00174  53  00244  00274
00175  53  00313  00264
00176  11  00000  20000
00177  15  20000  00426
00200  16  20000  00430
00201  54  00430  20020
00202  53  20000  00415
00203  35  00313  20000
00204  53  20000  00347
00205  53  20000  00362
00206  54  00426  20001
00207  35  00415  20000
00210  53  20000  00243
00211  53  20000  00427
00212  21  00264  00427
00213  55  00426  10025
00214  16  10000  00431
```

```
00M41    TP  C0N03  Q0000                                  00215  11 00425 10000
00M42    54  03M21  A0057  BRR                             00216  54 00347 20071
00M43    QS  A0000  AUG03                                  00217  53 20000 00416
00M44    TV  AUG03  AUG04                                  00220  16 00416 00417
00M45    TV  AUG03  02M29                                  00221  16 00416 00315
00M46    AT  C0N07  A0000                                  00222  35 00431 20000
00M47    AT  C0N07  A0000                                  00223  35 00431 20000
00M48    QS  A0000  02M01                                  00224  53 20000 00261
00M49    QS  A0000  02M06                                  00225  53 20000 00266
00M50    AT  C0N06  A0000                                  00226  35 00430 20000
00M51    AT  C0N06  A0000                                  00227  35 00430 20000
00M52    QS  A0000  03M16                                  00230  53 20000 00342
00M53    QS  A0000  03M21                                  00231  53 20000 00347
00M54    QS  A0000  03M26                                  00232  53 20000 00354
00M55    QS  A0000  03M31                                  00233  53 20000 00361
00M56    RS  C0N06  00016                                  00234  23 00430 00020
00M57    ST  00016  RWT02                                  00235  36 00020 00031
00M58    RS  C0N07  00016                                  00236  23 00431 00020
00M59    TV  02M29  02M30                                  00237  16 00315 00316
00M60    RA  02M30  00016                                  00240  21 00316 00020
01M00    RJ  00000  00000                                  00241  37 00000 00000
01M01    RJ  AUG06  AUG00                                  00242  37 00421 00413
01M02    RP  30000  01M04                                  00243  75 30000 00245
01M03    TP  00000  00000                                  00244  11 00000 00000
01M04    TN  00016  RWT03          SET INDEX               00245  13 00020 00032
01M05    RJ  00000  00000          GET ITH ROW             00246  37 00000 00000
01M06    RJ  AUG06  AUG00          AUGMENT                 00247  37 00421 00413
01M07    TU  01M02  02M00                                  00250  15 00243 00260
01M08    54  01M03  A0015  BRR                             00251  54 00244 20017
01M09    TU  A0000  02M01                                  00252  15 20000 00261
01M10    RA  RWT03  00016                                  00253  21 00032 00020
01M11    TP  RWT03  RWT01                                  00254  11 00032 00030
01M12    TP  00013  RWT00                                  00255  11 00015 00027
01M13    TU  02M06  02M02                                  00256  15 00266 00262
01M14    TP  RWT00  00004          B BOX                   00257  11 00027 00004
02M00    RP  30000  02M02          TRANSMIT ITH            00260  75 30000 00262
02M01    TP  00000  00000          ROW TO ES               00261  11 00000 00000
02M02  LDPM  00000  RWT08  B    S                          00262  14 32000 25037
02M03    ZJ  02M04  02M16          SKIP IF ZERO            00263  47 00264 00300
02M04  LDPM  00000  00000                                  00264  14 30000 24000
02M05    TJ  RWT08  03M41                                  00265  42 00037 00373
02M06  LDDV  00000  00000  B                               00266  14 32000 20000
02M07    TP  00002  RWT08                                  00267  11 00002 00037
02M08    TP  00003  RWT09                                  00270  11 00003 00040
02M09    TP  C0N03  Q0000          L                       00271  11 00425 10000
02M10    QS  02M01  02M11            I                     00272  53 00261 00273
02M11  LDMP  RWT08  00000              N                   00273  14 30037 14000
02M12  SUNO  00000  00000  BS             E                00274  14 13000 00000
02M13    RA  02M11  C0N09                  A               00275  21 00273 00433
```

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```
02M14   RA 00004 CON10                R          00276  21 00004 00434
02M15   TJ CON05 02M11                 L         00277  42 00427 00273
02M16   TP 00021 Q0000                  Y        00300  11 00025 10000
02M17   TP 02M01 A0000                           00301  11 00261 20000
02M18   QA 02M00 02M01          COMBINE          00302  52 00260 00261
02M19   RS 02M00 CON10                           00303  23 00260 00434
02M20   RA RWT00 CON10          R                00304  21 00027 00434
02M21   IJ RWT01 01M14           O               00305  41 00030 00257
02M22   RA 02M27 CON10            W              00306  21 00313 00434
02M23   55 02M01 Q0021 'BRR       S              00307  55 00261 10025
02M24   TV Q0000 02M27                           00310  16 10000 00313
02M25   TU 02M00 02M26                           00311  15 00260 00312
02M26   RP 30000 02M28          REPLACE          00312  75 30000 00314
02M27   TP 00000 00000           REDUCED ROW     00313  11 00000 00000
02M28   IJ RWT02 01M05          N-2 TIMES        00314  41 00031 00246
02M29   TP CON02 00000                           00315  11 00424 00000
02M30   TP 00013 00000                           00316  11 00015 00000
02M31   TP CON06 RWT05                           00317  11 00430 00034
02M32   TP 00013 RWT03                           00320  11 00015 00032
02M33   TV 03M16 03M13                           00321  16 00342 00337
03M00   TU 02M01 03M13                           00322  15 00261 00337
03M01   TP 00021 Q0000                           00323  11 00025 10000
03M02   QS 00013 03M12                           00324  53 00015 00336
03M03   TP CON09 RWT01                           00325  11 00433 00030
03M04   RA 03M13 CON10                          00326  21 00337 00434
03M05   MJ 00000 03M08                          00327  45 00000 00332
03M06   RS 03M13 CON04                          00330  23 00337 00426
03M07   RS 03M13 CON04                          00331  23 00337 00426
03M08   RA 03M12 CON10          TRANSFER         00332  21 00336 00434
03M09   RA RWT01 CON10          ROWS OF          00333  21 00030 00434
03M10   TU 03M13 03M16          UPPER            00334  15 00337 00342
03M11   RS 03M13 RWT01          TRIANGULAR       00335  23 00337 00030
03M12   RP 30000 03M14          MATRIX           00336  75 30000 00340
03M13   TP 00000 00000                           00337  11 00000 00000
03M14   RA 03M16 RWT02                           00340  21 00342 00031
03M15   RP 30002 03M17                           00341  75 30002 00343
03M16   TN 00000 00000          B                00342  13 00000 00000
03M17   TP 00013 00004           A               00343  11 00015 00004
03M18   TP RWT03 RWT00            C              00344  11 00032 00027
03M19   TP 00013 RWT06             K             00345  11 00015 00035
03M20   TP 00013 RWT07          S                00346  11 00015 00036
03M21 LDMP 00000 00000  B   B    U               00347  14 32000 16000
03M22 ADNO RWT06 00000  S          B              00350  14 05035 00000
03M23   RS 00004 CON10              S             00351  23 00004 00434
03M24   IJ RWT00 03M21               T            00352  41 00027 00347
03M25   RA RWT03 00016                I           00353  21 00032 00020
03M26 NOLD 00000 00000                 T          00354  14 00000 32000
03M27 PMNO 00000 00000                  U         00355  14 24000 00000
03M28   ZJ 03M29 03M39                    T        00356  47 00357 00371
03M29   TN RWT06 00002                     E       00357  13 00035 00002
```

```
03M30    TN RWT07 00003                                    00360  13 00036 00003
03M31 LDDV 00002 00000      B                              00361  14 30002 22000
03M32 STNO 00000 00000   B                                 00362  14 36000 00000
03M33    IJ RWT05 03M06                                    00363  41 00034 00330
03M34    RJ 00000 00000            TO AUX 2                00364  37 00000 00000
03M35    RA RWT02 CON10                                    00365  21 00031 00434
03M36    IJ CON07 02M29                                    00366  41 00431 00315
03M37    RA 00M01 CON08                                    00367  21 00145 00432
03M38    MJ 00000 00M01                                    00370  45 00000 00145
03M39    11 CON00 75756 BRB        TO ALARM                00371  11 00422 75756
03M40    MJ 00000 00M00                                    00372  45 00000 00144
03M41    TU 02M00 03M53                                    00373  15 00260 00407
03M42    TU 02M00 03M55                                    00374  15 00260 00411
03M43    TP CON01 Q0000                                    00375  11 00423 10000
03M44    QS 02M04 03M56                                    00376  53 00264 00412
03M45    TP 02M02 A0000                                    00377  11 00262 20000
03M46    AT RWT00 A0000                                    00400  35 00027 20000
03M47    QS A0000 03M54                                    00401  53 20000 00410
03M48    TP CON03 Q0000                                    00402  11 00425 10000
03M49    LA A0000 00057                                    00403  54 20000 00071
03M50    QS A0000 03M56                                    00404  53 20000 00412
03M51    54 02M01 A0057 BRR                                00405  54 00261 20071
03M52    TV A0000 03M54                                    00406  16 20000 00410
03M53    RP 30000 03M54                                    00407  75 30000 00410
03M54    TP 00000 00000                                    00410  11 00000 00000
03M55    RP 30000 01M14                                    00411  75 30000 00257
03M56    TP 00000 00000                                    00412  11 00000 00000
AUG00    TP 00000 A0000            TEST TO SEE             00413  11 00000 20000
AUG01    SJ AUG02 AUG06             IF INVERT              00414  46 00415 00421
AUG02    RP 10000 AUG04                                    00415  75 10000 00417
AUG03    TP 00013 00000            AUGMENT                 00416  11 00015 00000
AUG04    TP CON02 00000             IDENTITY               00417  11 00424 00000
AUG05    RA AUG04 CON09                                    00420  21 00417 00433
AUG06    MJ 00000 00000                                    00421  45 00000 00000
CON00    24 14061 33411 B                                  00422  24 14061 33411
CON01    00 00777 00000 B          CONSTANTS               00423  00 00777 00000
CON02    01 00000 00000      F                             00424  20 14000 00000
CON03    00 00000 00777 B            AND                   00425  00 00000 00777
CON04    00 00000 00000                                    00426  00 00000 00000
CON05    00 00000 00000                                    00427  00 00000 00000
CON06    00 00000 00000            TEMPORARY               00430  00 00000 00000
CON07    00 00000 00000                                    00431  00 00000 00000
CON08    00 00000 00003            STORAGE                 00432  00 00000 00003
CON09    00 00000 00002                                    00433  00 00000 00002
CON10    00 00002 00000                                    00434  00 00002 00000
START       00M00                                          00000  45 00000 00144
```

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THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Complex Gill Method Routine

Specifications

Identification Tag: NUI-5

Type: Subroutine

Assembly Routine Spec: SUB 51071 12431

Storage: 124 words total program storage

The temporary pool is used. In addition, cells 33 through 38 (41b - 46b) are used as temporary storage.

The constant pool is used.

Entrance and Exit:
RJ GIM01 GIM02 set up
RJ GIM01 GIM03 to get next point
MJ 00000 GIM04 from derivative calculation

Coded by: W. Mancina May, 1956

Approved by: W. F. Bauer June, 1956

Description

The Gill Method Subroutine (NUI-5) integrates a system of first order, differential equations using a step-by-step process. Using the values of the variables at a point and the coding for computing the derivative of each of the dependent variables at that point, this subroutine produces the coordinates for the next point of the solution each time it is entered.

A special entrance sets up the subroutine for a particular system of equations, thus allowing the subroutine to solve concurrently several different systems in the same program.

The independent variable is incremented within the subroutine itself.

Notation

The system of equations to be solved is

$$\frac{dy_i}{dx} = f_i(x, y_1, y_2, \ldots, y_n), \quad (i = 1, 2, \ldots, n).$$

n is the number of equations in the system

q_i are intermediate values of the calculation (zero initially)

Δx is the increment of the independent variable x

Programming and Operating Instructions:

1. Assign NUI-5 to some arbitrary region, say GIM00. (The Complex Arithmetic Interpretive Routine, SNIP, must be in ES during the execution of NUI-5. SNIP begins in register 634 decimal and extends through register 1023 decimal). SNIP complex must be activated from the program with a 37 01541 01713 command before entering NUI-5.
2. In order to solve a given system, the following array of variables, derivatives intermediate values, and parameters should be assigned a region, say 00N00:

00N00	n	Fixed point form scaled 2^0.	
00N01	Δx	(real)	Floating point form
00N02	Δx	(imag.)	"
00N03	x	(real)	"
00N04	x	(imag.)	"
00N05	$\frac{dy_1}{dx}$	(real)	"
00N06	$\frac{dy_1}{dx}$	(imag.)	"

	00N07	y_1	(real)	Floating point form
	00N08		(imag.)	"
initially zero	00N09	q_1	(real)	"
	00N10		(imag.)	"
	00N11	$\frac{dy_2}{dx}$	(real)	"
	00N12		(imag.)	"
	00N13	y_2	(real)	"
	00N14		(imag.)	"
initially zero	00N15	q_2	(real)	"
	00N16		(imag.)	"
	.		.	
	.		.	
	.		.	

3. In addition, the coding for computing $\frac{dy_i}{dx}$ for all values of i,

(i = 1, 2, 3, ... n) should be assigned a region, say DEV00. This coding will use the values in region 00N00 to compute all $\frac{dy_i}{dx}$ as specified by the equations in the system and should store the results in the appropriate cells in region 00N00. It should then exit to NUI-5 with a MJ 0000 GIM04 (see below).

Entrances

Assuming NUI-5 is in region GIM00; the three entrances are GIM02, GIM03, and GIM04. The exit is GIM01.

1. The first entrance, GIM02, is used for setting up NUI-5 only for the particular system to be solved. It is entered by an RJ command followed by a parameter word which specifies the locations of the variables, and the location of the coding for calculating the derivatives:

```
RJ GIM01 GIM02
00 00N00 DEV00
```

2. The second entrance, GIM03, is the entrance for producing a point of the solution. It is entered by an RJ command: RJ GIM01 GIM03. The use of this entrance command results in four passes through both NUI-5 and the coding for computing the derivatives, and leaves in region 00N00 the new values of q, the variables, the derivatives at those values, and "x" advanced by "Δx", ready for the next step.

3. The third entrance, GIM04, is the entrance from the coding for calculating the derivatives and is used on each of the four passes necessary for computing one point. As noted above, it is entered by an MJ command in the DEV00 region:

MJ 00000 GIM04

Mathematical Analysis

Theory. "A Process for the Step-by-Step Integration of Differential Equations in an Automatic Digital Computing Machine" by S. Gill, published in Cambridge Philosophical Society Proceedings, Vol. 47, Part I, January 1951, should be consulted for a detailed analysis of the process on which the subroutine is based.

Suppose we know the point $(X, Y_1, Y_2, \ldots, Y_n)$ on the curve defined by the system of equations

$$\frac{dy_1}{dx} = f_1 (x, y_1, y_2, \ldots, y_n)$$

$$\frac{dy_2}{dx} = f_2 (x, y_1, y_2, \ldots, y_n)$$

$$\vdots$$

$$\frac{dy_n}{dx} = f_n (x, y_1, y_2, \ldots, y_n)$$

The Gill Method is a process by which we can find the next point on the curve: i. e. the value of $y_1, y_2, \ldots, y_n$ for $x = X + h$.

The process can be better understood if the case where n=1 is first considered.

We have the point (X,Y) on the curve $\frac{dy}{dx} = f(x,y)$, and we want to find y at $X + h$; i.e. we want $k = \delta y$ such that $\left.\frac{dy}{dx}\right]_{X + h,\ Y + k} = f(X + h, Y + k)$.

We derive k by making four approximations and averaging them in a particular way.

First approximate the curve by a straight line through (X,Y) with the slope $\left.\frac{dy}{dx}\right]_{X,Y} = f(X,Y)$, and find a first approximation to k:

$$k_o = h \cdot f(X,Y)$$

Then we travel a fraction m of the way along this line to the point $(X + mh, Y + mk_o)$ and find $f(X + mh, Y + mk_o)$.

This gives us a new straight line through $(X + mh, Y + mk_o)$ with slope $f(X + mh, Y + mk_o)$, and we find

$$k_1 = h \cdot f(X + mh, Y + mk_o)$$

We now use k_o and k_1 to find a third point at which f is calculated: $(X + nh, Y + [n-r]\, k_o + rk_1)$.

$$k_2 = h\, f(X + nh, Y + [n-r]\, k_o + rk_1)$$

Similarly,

$$k_3 = h \cdot f(X + ph, Y + [p-s-t]\, k_o + sk_1 + tk_2$$

The weighted average of k_o, k_1, k_2, and k_3 is the desired $k = \delta y$:

$$\delta y = y(X + h) - y(X) = c_o k_o + c_1 k_1 + c_2 k_2 + c_3 k_3$$

where $c_o + c_1 + c_2 + c_3 = 1$.

For a system of equations, the same four steps given above are made for each equation and

$$\delta y_i = c_o k_{io} + c_1 k_{i1} + c_2 k_{i2} + c_3 k_{i3} \text{ where } c_o + c_1 + c_3 = 1.$$

The above process is, for certain values of m, n, p, s, t, c_o, c_1, c_2, and c_3, the Runge-Kutta process. The Gill process was derived, with application to machine use in mind, by minimizing the number of storage cells required. For the Gill Method the above constants are

$$m = 1/2\,, \qquad r = 1 - \sqrt{1/2}\,, \qquad c_o = 1/6$$

$$n = 1/2\,, \qquad s = -\sqrt{1/2}\,, \qquad c_1 = (1/3)(1 - \sqrt{1/2})$$

$$p = 1\,, \qquad t = 1 + \sqrt{1/2}\,, \qquad c_2 = (1/3)(1 + \sqrt{1/2})$$

$$c_3 = 1/6$$

The Gill process further systematizes the calculation so as to increase the accuracy and simplify the coding.

The Subroutine As used in the Gill Method Subroutine, the process is as follows:

1st pass:

Advance x by (1/2)h

$$k_{io} = h \cdot f_i(x, y_{1o}, y_{2o}, \ldots, y_{no})$$

$$r_{i1} = (1/2)k_{io} - q_{io}$$

$$q_{i1} = q_{io} + 3r_{i1} - (1/2)k_{io}$$

$y_{i1} = y_{io} + r_{i1}$

Calculate $f_i\ (x, y_{11}, y_{21}, \ldots, y_{ni})$ in programmer's own coding.

2nd pass:

$k_{i1} = h \cdot f_i\ (x, y_{11}, y_{21}, \ldots, y_{n1})$

$r_{i2} = (1 - \sqrt{1/2})\ (k_{i1} - q_{i1})$

$q_{i2} = q_{i1} + 3r_{i2} - (1 - \sqrt{1/2})\ k_{i1}$

$y_{i2} = y_{i1} + r_{i2}$

Calculate $f_i\ (x, y_{12}, y_{22}, \ldots, y_{n2})$ in programmer's own coding.

3rd pass:

Advance x by (1/2)h

$k_{i2} = h \cdot f_i\ (x, y_{12}, y_{22}, \ldots, y_{n2})$

$r_{i3} = (1 + \sqrt{1/2})\ (k_{i2} - q_{i2})$

$q_{i3} = q_{i2} + 3r_{i3} - (1 + \sqrt{1/2})\ k_{i2}$

$y_{i3} = y_{i2} + r_{i3}$

Calculate $f_i\ (x, y_{13}, y_{23}, \ldots, y_{n3})$ in programmer's own coding.

4th pass:

$k_{i3} = h \cdot f_i\ (x, y_{13}, y_{23}, \ldots y_{n3})$

$r_{i4} = (1/6)\ (k_{i3} - 2q_{i3})$

$q_{i4} = q_{i3} - 3r_{i4} - (1/2)k_{i3}$

$y_{i4} = y_{i3} + r_{i4}$

Calculate $f_i\ (x, y_{14}, y_{24}, \ldots, y_{n4})$ in programmer's own coding.

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Errors The paper by S. Gill mentioned previously includes a detailed analysis of errors, both truncation error and round-off error.

The expression for the truncation error in δy_i is too complicated to give here, but its dominating term, the author states, is

$$\frac{h^5}{-120} \sum_{o}^{n} \left[f_j \frac{f_k}{y_j} \cdot \frac{f_m}{y_l} \cdot \frac{f_i}{y_m} \right]_{x=X} \quad \text{where } y_o = x,\ f_o = l, j, k, l, m$$

and the truncation error in δy_i will be approximately this when the second partial derivatives are all close to zero. It is probably more useful to say merely that the truncation error is of the order of h^5.

The standard deviation in $y_i - (1/3)\, q_i$ over one step from all rounding off errors is (where f is the quantity mentioned in the section on notation)

$$1/6 \left[7/3 \left\{ 2^{-2f} + (1/16)h^2 \sum_{j} \left(\frac{f_i}{y_j} \right)_X^2 \right\} \right]^{1/2}$$

u, u = the value of one unit in the last digit of y.

Machine Checking

A driver routine was used to solve the following system of equations using the NUI-5 method:

$$\frac{dy_1}{dx} = y_2$$

$$\frac{dy_2}{dx} = -\alpha^2 y_1$$

This system is equivalent to the second order equation:

$$\frac{d^2y}{dx^2} + \alpha^2 y = 0$$

The initial conditions used were:

$$\text{AT } X=0 \quad \begin{cases} y_1 = 1 \\ y_2 = -3i \end{cases}$$

α was taken as 3, and Δx as 0.0872664626 which is equivalent to five degrees.

The correct solution, $y_1 = \cos \alpha x - i \sin \alpha x$, when evaluated at $\alpha x = 90^\circ$ and at $\alpha x = 135^\circ$ yields $y_1 = 0 - 1i$ and $y_1 = 0.70710678 - 0.70710678\ i$.

The routine gave

$y_1 = 0.00000044704 - 1i$ and

$y_1 = 0.70710672 - 0.70710684\ i$ at these values of αx.

Another driver routine using NUI-5 was utilized to solve the following systems of equations:

(1) $$\frac{dy_1}{dx} = y_1 a_{11} + y_2 a_{12} + y_3 a_{13} + y_4 a_{14}$$

(2) $$\frac{dy_2}{dx} = y_1 a_{21} + y_2 a_{22} + y_3 a_{23} + y_4 a_{24}$$

(3) $$\frac{dy_3}{dx} = y_1 a_{31} + y_2 a_{32} + y_3 a_{33} + y_4 a_{34}$$

(4) $$\frac{dy_4}{dx} = y_1 a_{41} + y_2 a_{42} + y_3 a_{43} + y_4 a_{44}$$

where the a's were the elements of the following matrix:

$$\begin{bmatrix} .38942862 - .056561159\,i & .64293399 & -.38130278 & .31636930 \\ .31354398 \times 10^{-1} & .51067378 - .23430743\,i & .35343118 & -.15651804 \\ -.10142552 \times 10^{-2} & .63584848 \times 10^{-1} & .52424601 - .53041144\,i & .28190968 \\ -.91876338 \times 10^{-3} & -.57287441 \times 10^{-2} & .86142025 \times 10^{-1} & .52841129 - .94494028\,i \end{bmatrix}$$

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At x = 0, the initial conditions were:

$$y_1 = 1 \qquad y_2 = 0 \qquad y_3 = 0 \qquad y_4 = 0$$

consequently, at x = 0 the four derivatives were equivalent to the first column of the matrix, respectively.

Two cases were calculated. Case 1, with $\Delta x = .1$ and case 2 with $\Delta x = .025$. The former case was checked by hand calculations.

The following table of the calculated results indicate that at x = .1, the results of all calculations agree to six decimal places.

A SUMMARY OF THE VALUES OF

y_1 , y_2 , y_3 AND y_4 FOR THE

HAND CALCULATION, CASE 1, AND CASE 2 AT x = .1

	Hand Calculation $\Delta x = .1$	Case 1 $\Delta x = .1$	Case 2 $\Delta x = .025$
x	.1	.1	.1
y_1	1.0398008 -.0058823261	1.0398000 -.0058818996i	1.0397999 -.0058819007i
y_2	.0032784372 -.0000477404901	.0032785024 -.0000477392191	.0032785024 -.0000477400411
y_3	-.000097036022 +.0000029048977i	-.000097038351 +.0000029047554i	-.000097038244 +.0000029045580i
y_4	-.000097412743 +.0000048894666i	-.000097414832 +.0000048844414i	-.000097414673 +.0000048843484i

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```
D          GIL00  01024
D          GIN00  01114
D          GIM00  51071
D          GCN00  51161
GIM00   MS 00000  GIL00
GIM01   MJ 00000  00000
GIM02   MJ 00000  GIL59
GIM03   MJ 00000  GIL10
GIM04   RA GIN01  00016
GIM05   EJ GIN27  GIL79
GIM06   EJ GIN28  GIL01
GIM07   TP GIN32  00023
GIM08   TP GIN33  00024
GIM09   MJ 00000  GIL24
GIM10   TP 00016  GIN01
GIM11   TU GIN02  GIL26
GIM12   RP 30004  GIL14
GIM13   TP 00000  00023
GIM14   TP 00023  GIN32
GIM15   TP 00024  GIN33
GIM16 LDAD 00023  00025
GIM17   TP 00002  00037
GIM18   TP 00003  00038
GIM19   TP GIN03  00027
GIM20   TP GIN04  00028
GIM21 ADMP 00025  00027
GIM22   TP 00002  00000
GIM23   TP 00003  00000
GIM24   TV 00000  GIN00
GIM25   RP 30006  GIL27
GIM26   TP 00000  00031
GIM27   RA GIL26  GIN29
GIM28   TU GIL78  GIL31
GIM29   TV GIL78  GIL54
GIM30   RP 30006  GIL32
GIM31   TP 00000  00025
GIM32 LDMP 00033  00029
GIM33   TP 00002  00033
GIM34   TP 00003  00034
GIM35 LDMP 00025  00023
GIM36   TP 00002  00023
GIM37   TP 00003  00024
GIM38 MPSU 00031  00033
GIM39   TP 00002  00031
GIM40   TP 00003  00032
GIM41 ADNO 00027  00000
GIM42   TP 00002  00027
GIM43   TP 00003  00028
GIM44 LDMP 00023  00035
```

```
                02000  00 00000 00000
                02132  00 00000 00000
                65477  00 00000 00000
                65631  00 00000 00000
                65477  56 00000 02000
                65500  45 00000 00000
SET UP ENTRA    65501  45 00000 02073
1ST PASS        65502  45 00000 02012
                65503  21 02133 00020
EQLTY AGNST3    65504  43 02165 02117
EQLTY AGNST5    65505  43 02166 02001
BRING IN DEL    65506  11 02172 00027
BRING IN DEL    65507  11 02173 00030
                65510  45 00000 02030
SET PASS CNT    65511  11 00020 02133
SET LOC A       65512  15 02134 02032
DELTA T IN23    65513  75 30004 02016
24 IN 25 26     65514  11 00000 00027
STORE DELTAT    65515  11 00027 02172
REAL / IMAG     65516  11 00030 02173
T PLUS DELTA    65517  14 30027 04031
STOR T PLUS     65520  11 00002 00045
DELTA T         65521  11 00003 00046
BRG ONE HALF    65522  11 02135 00033
TO 27 28        65523  11 02136 00034
GET T PLUS 0    65524  14 04031 14033
STORE T PLUS    65525  11 00002 00000
ONE HALF DEL    65526  11 00003 00000
SET EQ COUNT    65527  16 00000 02132.
A31 32 B33      65530  75 30006 02033
C 35 36         65531  11 00000 00037
SETABC FOR      65532  21 02032 02167
SET UP Y ADD    65533  15 02116 02037
REVERSE PREV    65534  16 02116 02066
Y25 26Y27 28    65535  75 30006 02040
Q 29 30         65536  11 00000 00031
BQ              65537  14 30041 14035
STORE BQ IN     65540  11 00002 00041
33 AND 34       65541  11 00003 00042
COMP Y DEL T    65542  14 30031 14027
STORE K IN      65543  11 00002 00027
23 AND 24       65544  11 00003 00030
AK BQ EQS R     65545  14 14037 10041
STORE R IN      65546  11 00002 00037
31 AND 32       65547  11 00003 00040
R PLUS 4        65550  14 04033 00000
NEW Y STORED    65551  11 00002 00033
IN 27 AND 28    65552  11 00003 00034
                65553  14 30027 14043
```

```
GIM45    TP 00002 00035          STORE CK IN     65554  11 00002 00043
GIM46    TP 00003 00036          35 AND 36       65555  11 00003 00044
GIM47    TP GIN23 00033          BRING IN        65556  11 02161 00041
GIM48    TP 00013 00034          ONE THIRD       65557  11 00015 00042
GIM49 LDDV 00031 00033           COMPUTE 3R      65560  14 30037 20041
GIM50 ADSU 00029 00035                           65561  14 04035 10043
GIM51    TP 00002 00029          NEW Q STORED    65562  11 00002 00035
GIM52    TP 00003 00030          IN 29 AND 30    65563  11 00003 00036
GIM53    RP 30006 GIL55          YDAT IN25 26    65564  75 30006 02067
GIM54    TP 00025 00000          YIN27 28 QIN    65565  11 00031 00000
GIM55    RA GIL31 GIN29                          65566  21 02037 02167
GIM56    RA GIL54 GIN30                          65567  21 02066 02170
GIM57    RS GIN00 00016          SUB1 FMEQ CN    65570  23 02132 00020
GIM58    ZJ GIL83 00000                          65571  47 02123 00000
GIM59    TP GIL01 A0000          SET UP          65572  11 02001 20000
GIM60    LA A0000 00015                          65573  54 20000 00017
GIM61    TU A0000 GIL62          SET PARAMETE    65574  15 20000 02076
GIM62    TP 00000 A0000          PARA WORK A     65575  11 00000 20000
GIM63    TV A0000 GIL58          SET DER ENTR    65576  16 20000 02072
GIM64    TU A0000 GIL24          SET EQ C ADD    65577  15 20000 02030
GIM65    AT 00015 A0000          SET DEL T AD    65600  35 00017 20000
GIM66    TU A0000 GIL13                          65601  15 20000 02015
GIM67    LA A0000 00057                          65602  54 20000 00071
GIM68    AT GIN31 A0000                          65603  35 02171 20000
GIM69    TV A0000 GIL22          SET T REL AD    65604  16 20000 02026
GIM70    AT 00016 A0000                          65605  35 00020 20000
GIM71    TV A0000 GIL23          SET T IM ADD    65606  16 20000 02027
GIM72    AT 00016 A0000                          65607  35 00020 20000
GIM73    TV A0000 GIL78          SET LOC Y       65610  16 20000 02116
GIM74    LA A0000 00015                          65611  54 20000 00017
GIM75    TU A0000 GIL78          SET LOC Y       65612  15 20000 02116
GIM76    RA GIL01 00016          SET BY PAR W    65613  21 02001 00020
GIM77    MJ 00000 GIL01                          65614  45 00000 02001
GIM78    00 00000 00000 B        LOC OF Y        65615  00 00000 00000
GIM79 LDNO 00037 00000                           65616  14 30045 00000
GIM80    TP GIN32 00023          RESTORE DEL     65617  11 02172 00027
GIM81    TP GIN33 00024          IN 23 24        65620  11 02173 00030
GIM82    MJ 00000 GIL22                          65621  45 00000 02026
GIM83    TP GIN32 00023                          65622  11 02172 00027
GIM84    TP GIN33 00024                          65623  11 02173 00030
GIM85    TU GIL26 GIL88                          65624  15 02032 02130
GIM86    RS GIL88 GIN29                          65625  23 02130 02167
GIM87    RP 30006 GIL89                          65626  75 30006 02131
GIM88    TP 00000 00031                          65627  11 00000 00037
GIM89    MJ 00000 GIL30                          65630  45 00000 02036
GCN00    00 00000 00000 B        EQ COUNTER      65631  00 00000 00000
GCN01    00 00000 00000 B        PASS COUNTER    65632  00 00000 00000
GCN02    00 GIN03 00000 BRB       LOCATION A     65633  00 02135 00000
GCN03    05 00000 00000 -01 F        A1          65634  20 04000 00000
```

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GCN04	00	00000	00000	B		A1	65635	00	00000 00000
GCN05	01	00000	00000	00 F		B1	65636	20	14000 00000
GCN06	00	00000	00000	B		B1	65637	00	00000 00000
GCN07	05	00000	00000	-01 F		C1	65640	20	04000 00000
GCN08	00	00000	00000	B		C1	65641	00	00000 00000
GCN09	02	92893	21881	-01 F		A2	65642	17	74537 30314
GCN10	00	00000	00000	B		A2	65643	00	00000 00000
GCN11	02	92893	21881	-01 F		B2	65644	17	74537 30314
GCN12	00	00000	00000	B		B2	65645	00	00000 00000
GCN13	02	92893	21881	-01 F		C2	65646	17	74537 30314
GCN14	00	00000	00000	B		C2	65647	00	00000 00000
GCN15	01	70710	67812	00 F		A3	65650	20	16650 11714
GCN16	00	00000	00000	B		A3	65651	00	00000 00000
GCN17	01	70710	67812	00 F		B3	65652	20	16650 11714
GCN18	00	00000	00000	B		B3	65653	00	00000 00000
GCN19	01	70710	67812	00 F		C3	65654	20	16650 11714
GCN20	00	00000	00000	B		C3	65655	00	00000 00000
GCN21	01	66666	66667	-01 F		A4	65656	17	65252 52525
GCN22	00	00000	00000	B		A4	65657	00	00000 00000
GCN23	03	33333	33333	-01 F		B4	65660	17	75252 52525
GCN24	00	00000	00000	B		B4	65661	00	00000 00000
GCN25	05	00000	00000	-01 F		C4	65662	20	04000 00000
GCN26	00	00000	00000	B		C4	65663	00	00000 00000
GCN27	00	00000	00003	B			65664	00	00000 00003
GCN28	00	00000	00005	B			65665	00	00000 00005
GCN29	00	00006	00000	B			65666	00	00006 00000
GCN30	00	00000	00006	B			65667	00	00000 00006
GCN31	00	00000	00002	B			65670	00	00000 00002
GCN32	00	00000	00000	B		FOR STORING	65671	00	00000 00000
GCN33	00	00000	00000	B		DELTA T	65672	00	00000 00000
START		00000						45	00000 00000

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POL-0
Pg. 1 of 11
9-4-56

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Algebraic Equation Solver

Specifications

Identification Tag:	POL-0
Type:	Subroutine available on cards for assembly
Regions Used:	00M, 01M 02M, 00K, F00, C00. 00T
Storage:	157 words total program storage 2n + 17 cells temporary storage used immediately following the RW temporary pool where n is the order of the polynomial (See text) The constant pool and temporary storage pool are used by this routine
Entrance and Exit:	RJ SUB01 SUB02 results not punched RJ SUB01 SUB03 results punched } See text
Alarm Exit:	A SNIP exponent overflow alarm may occur. (See text).
Machine Time:	See enclosed table.
Mode of Operation:	Floating Complex Arithmetic. SNIP must have been activated.
Coded by:	Werner L. Frank May, 1956
Approved by:	W. F. Bauer July, 1956

Description

This subroutine employs a new iterative procedure due to D. Muller[1] for finding the n roots of the polynomial equation

$$P(x) = \sum_{j=0}^{n} a_j x^{n-j} = 0$$

where the coefficients a_j can be real or complex and the roots need not be distinct. The routine operates using the complex arithmetic version of SNIP, finding the real and complex roots in an approximately ascending order of magnitude. As each root is obtained, the intermediate and final iterants can be punched out on cards, depending on the option chosen by the programmer. The polynomial is reduced one order after finding each root so that the kth root is obtained from the polynomial $P_k(x)$ where

$$P_k(x) = \frac{P(x)}{\prod_{i=1}^{k-1}(x-x_i)} \qquad k > 1$$

In addition to the 157 words of storage needed by the subroutine, it is necessary to provide 2n + 17 cells of temporary storage immediately following the Ramo-Wooldridge Temporary Pool.

The polynomial coefficients must appear in succession beginning with the coefficient of the highest power of x, in a block of cells all of which must be in ES or all on the drum. Each coefficient occupies two cells, one for the real component and one for the complex. This code can theoretically solve polynomials of extremely large order. However, practical limitations are imposed by the available 1024 words of ES storage when using SNIP so that n must be less than 211.

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[1] A paper "A Method for Solving Algebraic Equations using an Automatic Computer" by D. Muller is forthcoming in MTAC.

A serious deterioration in accuracy can result for polynomials with multiple roots and arbitrary polynomials of high degree. This is probably due to the low precision of the coefficients (27 binary bits) which necessarily define the roots. Also, for large degree, the range of numbers in SNIP ($\pm 2^{128}$) is often exceeded (see Alarm section). Hence, for problems of degree larger than 20, special care must be taken.

Operating Instructions

SNIP must have been activated, and be in ES.

The code provides for three options for output depending upon the entrance selected. In every case, the n roots of the polynomial P(x) can be found in the 2n cells starting at cell 50 = 62b when the subroutine is exited. The programmer is cautioned to note that the output hopper of SNIP is used regardless of the option selected. Assuming that the subroutine is assigned to region SUB00; that 00X00 is the location of the real part of the coefficient of the highest power of x in P(x) and that vvvvv is the degree, n, of the polynomial, then the options available to the programmer are:

Entrance No. 1a: RJ SUB01 SUB03

20 00X00 vvvvv

n sets of 3 cards each are punched each set containing the following information

Card No. 1	x_i	$P(x_i)$ $\quad$ $P'(x_i)$
Card No. 2	x_{i+1}	$\left\lvert \frac{P(x_i)}{x_{i+1}P'(x_i)} \right\rvert$
Card No. 3	blank	

where x_{i+1} and x_i are the last two successive iterations for the root, real part in field one and imaginary part in field two.

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$$P(x_2) \sim a_n + a_{n-1} + a_{n-2}$$

$$P(x_3) = a_n$$

At each step of the iteration violent jumps in the function $P(x_{j+1})$ are prevented in order to provide a smooth convergence. This is accomplished by testing to see if

$$\left|\frac{P(x_{j+1})}{P(x_j)}\right| < 10$$

If this inequality does not hold then d_{j+1} is continually multiplied by 1/2 until an x^*_{j+1} is found sufficiently close to x_j so that the test is passed. In case the denominator of d_{i+3} is zero, unity is used in place of the denominator and the computation is resumed. The iteration continues until the convergence criterion

$$\left|\frac{x_{j+1} - x_j}{x_{j+1}}\right| < 10^{-m}$$

is met.

In this code m = 4. After an iterant x_{j+1} meets the above criterion one cycle of the second order Newton procedure is performed obtaining thereby the finally accepted approximation x_{j+2}

$$x_{j+2} = x_{j+1} - \frac{P(x_{j+1})}{P'(x_{j+1})}$$

This is approximately equivalent to a convergence criterion of 10^{-2m}.

After one root is obtained the polynomial is depressed one degree and another root is sought. Possible errors in successive roots, due to errors in the deflated polynomial, are eliminated by the final cycle of the Newton process which always refers back to the original polynomial. The code provides for the punching of successive iterants, their associated residues in the

$P(x_1)$ = residue of polynomial at x_1, components in field three and four respectively.

$P'(x_1)$ = derivative of polynomial at x_1, components in field five and six respectively

$\left|\frac{P(x_1)}{x_{i+1}P'(x_1)}\right|$ = measure of accuracy of root (see Mathematical Method) in field three.

Entrance No. 1b: RJ SUB01 SUB03

00 00X00 vvvvv

Each set of three cards is preceded by cards containing the values of all the successive iterants and their corresponding residues in the associated polynomial. These cards contain:

x_j $P_k(x_j)$

in fields one, two, three and four in addition to the results indicated for entrance No. 1a.

Entrance No. 2: RJ SUB01 SUB02

20 00X00 vvvvv

No cards are punched.

Alarm Conditions

It is possible to obtain a SNAP alarm for exponent overflow when the number range of $\pm 2^{128}$ is violated. It is advised in such instances that the problem be rescaled. This can be done by making the transformation $x = 10^k y$ or by dividing the coefficients of the polynomial by some factor. The latter procedure will yield a polynomial whose roots are equal to those of the original problem.

Mathematical Method

The [illegible] procedure, due to D. Muller[1] of the University of Illinois,

is employed in which quadratic fits are made to the polynomial

$$P(x) = \sum_{j=0}^{n} a_j x^{n-j} = 0$$

Given three arbitrary points, x_i, x_{i+1}, and x_{i+2}, we find the parabola passing through the points $P(x_i)$, $P(x_{i+1})$ and $P(x_{i+2})$. Locating the root of this quadratic closest to x_{i+2}, say x_{i+3}, the process is repeated using now the points x_{i+1}, x_{i+2}, and x_{i+3}.

The explicit formulas used are:

$$x_{i+3} = x_{i+2} + (x_{i+2} - x_{i+1})\, d_{i+3}$$

where

$$d_{i+3} = \frac{-2P(x_{i+2})\,(1+d_{i+2})}{b_{i+2} \pm \left\{b_{i+2}^2 - 4P(x_{i+2})d_{i+2}(1+d_{i+2})\left[P(x_i)d_{i+2} - P(x_{i+1})(1+d_{i+2}) + P(x_{i+2})\right]\right\}^{1/2}}$$

and

$$b_{i+2} = P(x_i)d_{i+2}^2 - P(x_{i+1})(1+d_{i+2})^2 + P(x_{i+2})(1+2d_{i+2})$$

The sign in the denominator is chosen in such a way so as to give d_{i+3} the smallest magnitude. Coupled with the starting procedure this finds the roots in an approximately ascending order of magnitude.

To start the process off, the following choice of values is made:

$$x_1 = -1$$

$$x_2 = 1$$

$$x_3 = 0$$

$$d_3 = -1/2$$

with the associated functional values approximating the polynomial $P(x)$ in the neighborhood of the origin:

$$P(x_1) \sim a_n - a_{n-1} + a_{n-2}$$

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reduced polynomials and finally the five values x_j, $P(x_j)$, $P'(x_j)$, x_{j+1}, and M, where

$$M = \left| \frac{P(x_j)}{x_{j+1} P'(x_j)} \right|$$

This latter information gives an indication of the relative accuracy of the approximation x_{j+1}. Thus one should expect a value of $M = 10^{-7}$ or smaller for roots which are accurate to 6 places or more. Larger values of M indicate the possibility of less significance. In the event either x_{j+1} or $P'(x_j)$ are equal to zero no value for M is punched and $x_{j+1} = x_j$.

Local convergence of the Muller process has been shown to be somewhat less than second order for simple roots. In the case of multiple roots the order of convergence approaches a first order process. In this case the accuracy in the calculated roots deteriorates rapidly.

Machine Time

The time, in seconds, taken to find the n roots of a polynomial and punch the results according to the format described can be estimated from the following table of representative problems.

Degree n	Entrance No. 1a	Entrance No. 1b	Entrance No. 2
5	14	20	8
7	23	32	13
14	55	106	35
16	83	154	59
32	270	-	222
64	843	-	740

```
D          00M00  00098                                  00142  00 00000 00000
D          01M00  00131                                  00203  00 00000 00000
D          02M00  00161                                  00241  00 00000 00000
D          00K00  00247                                  00367  00 00000 00000
D          F0000  00002                                  00002  00 00000 00000
D          C0000  00003                                  00003  00 00000 00000
D          00T00  00033                                  00041  00 00000 00000
00M00   MJ 00000  00000                                  00142  45 00000 00000
00M01   MJ 00000  00000          EXIT                    00143  45 00000 00000
00M02   MJ 00000  02M77          ENTRANCE 1              00144  45 00000 00356
00M03   TP 00K05  02M67          ENTRANCE 2              00145  11 00374 00344
00M04   SP 00M01  00015                                  00146  31 00143 00017
00M05   TU A0000  00M06                                  00147  15 20000 00150
00M06   TP 00000  A0000                                  00150  11 00000 20000
00M07   TU A0000  00M18                                  00151  15 20000 00164
00M08   TV A0000  00K07                                  00152  16 20000 00376
00M09   LA A0000  00016                                  00153  54 20000 00020
00M10   TP 00021  Q0000                                  00154  11 00025 10000
00M11   QS A0000  00M17                                  00155  53 20000 00163
00M12   AT 02M17  A0000                                  00156  35 00262 20000
00M13   QS A0000  01M05                                  00157  53 20000 00210
00M14   ST 00K06  A0000                                  00160  36 00375 20000
00M15   TU A0000  00M00                                  00161  15 20000 00142
00M16   RA 00M17  00K03                                  00162  21 00163 00372
00M17   RP 30000  00M19          TRANSFER                00163  75 30000 00165
00M18   TP 00000  00T15                                  00164  11 00000 00060
00M19   RS 00K07  00016                                  00165  23 00376 00020
00M20   TP 00K07  00T14                                  00166  11 00376 00057
00M21   MJ 00000  00M28                                  00167  45 00000 00176
00M22   TP 00013  00004                                  00170  11 00015 00004
00M23   TP 00T14  00031                                  00171  11 00057 00037
00M24 LDMP 00T15  00T06  B                               00172  14 32060 14047
00M25 ADNO 00T17  00000  BS                              00173  14 07062 00000
00M26   RA 00004  00K03                                  00174  21 00004 00372
00M27   IJ 00031  00M24                                  00175  41 00037 00172
00M28   RS 00M00  00K03                                  00176  23 00142 00372
00M29   TU 00M00  00004                                  00177  15 00142 00004
00M30   RS 01M05  00015                                  00200  23 00210 00017
00M31   TU 01M05  01M06                                  00201  15 00210 00211
00M32   RS 01M05  00015                                  00202  23 00210 00017
01M00 LDAD 00000  00004  B    B                          00203  14 32000 06004
01M01 SUST 00002  00T00  B       F0                      00204  14 12002 34041
01M02 ADAD 00002  00002  B    B                          00205  14 06002 06002
01M03   TP F0000  00T02             F1                   00206  11 00002 00043
01M04   TP C0000  00T03                                  00207  11 00003 00044
01M05   TP 00000  00T04                                  00210  11 00000 00045
01M06   TP 00000  00T05             F2                   00211  11 00000 00046
01M07   RP 10008  01M09                                  00212  75 10010 00214
01M08   TP 00013  00T06               S                  00213  11 00015 00047
01M09   TN 00K00  00T08                 E                00214  13 00367 00051
```

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```
01M10    TP 00K00 00T10          T
01M11    TN 00K01 00T12
01M12 PMNO 00000 00000        INITIAL
01M13    ZJ 01M15 01M14
01M14    TP 00K02 00T02        VALUES
01M15 LDMP 00T00 00T08
01M16 ADST 00T04 00023        E
01M17 MPST 00T08 00025        V
01M18 LDMP 00T02 00T10         A
01M19 STSU 00027 00023      S   L
01M20 LDPM 00T04 00000           U
01M21    ZJ 01M22 02M44           A
01M22 LDMP 00T04 00T10            T
01M23 ADNO F0000 00000             E
01M24    TN F0000 00029
01M25    TN C0000 00030
01M26 ADMP F0000 00T08        ROOT
01M27 MPLD 00023 00T04  S
01M28 SUMP 00027 00T10
01M29 ADMP 00025 F0000  S
01M30 ADRT 00023 00023      S
02M01    TN C0000 C0000     CONJUGATE
02M02 LDMP F0000 00025
02M03    SJ 02M04 02M06
02M04    TN 00023 00023
02M05    TN 00024 00024
02M06 LDAD 00025 00023      S DENOMINATOR
02M07 PMNO 00000 00000
02M08    ZJ 02M10 02M09
02M09    TP 00K01 00023
02M10 LDDV 00029 00023
02M11    TP F0000 00T08
02M12    TP C0000 00T09
02M13 MPST 00T12 00027
02M14 ADST 00T06 00023
02M15    TP 00K03 00004
02M16    TP 00T14 00031
02M17 NOLD 00T17 00T15
02M18 MPAD 00023 00T15    B  FORM
02M19    RA 00004 00K03       FI 1
02M20    IJ 00031 02M18
02M21    TP F0000 00025
02M22    TP C0000 00026
02M23 DVPM 00T04 00000        RATE OF
02M24    TJ 00K02 02M79        CHANGE IN
02M25    TP 00K00 F0000        FI 1
02M26    TP 00013 C0000
02M27 LDMP F0000 00T08      S
02M28    MJ 00000 02M13
02M29 ADNO 00T08 00000
02M30    TP F0000 00T10
02M31    TP 00T09 00T11
```

```
00215  11 00367 00053
00216  13 00370 00055
00217  14 24000 00000
00220  47 00222 00221
00221  11 00371 00043
00222  14 30041 14051
00223  14 04045 34027
00224  14 14051 34031
00225  14 30043 14053
00226  14 34033 11027
00227  14 30045 24000
00230  47 00231 00315
00231  14 30045 14053
00232  14 04002 00000
00233  13 00002 00035
00234  13 00003 00036
00235  14 04002 14051
00236  14 15027 30045
00237  14 10033 14053
00240  14 05031 14002
00241  14 04027 51027
00242  13 00003 00003
00243  14 30002 14031
00244  46 00245 00247
00245  13 00027 00027
00246  13 00030 00030
00247  14 30031 05027
00250  14 24000 00000
00251  47 00253 00252
00252  11 00370 00027
00253  14 30035 20027
00254  11 00002 00051
00255  11 00003 00052
00256  14 14055 34033
00257  14 04047 34027
00260  11 00372 00004
00261  11 00057 00037
00262  14 00062 30060
00263  14 14027 06060
00264  21 00004 00372
00265  41 00037 00263
00266  11 00002 00031
00267  11 00003 00032
00270  14 20045 24000
00271  42 00371 00360
00272  11 00367 00002
00273  11 00015 00003
00274  14 30002 15051
00275  45 00000 00256
00276  14 04051 00000
00277  11 00002 00053
00300  11 00052 00054
```

```
02M32    TP 00025 00T04                                  00301  11 00031 00045
02M33    TP 00026 00T05                                  00302  11 00032 00046
02M34 LDDV 00T12 00T06                                   00303  14 30055 20047
02M35 PMNO 00000 00000                                   00304  14 24000 00000
02M36    TJ 00K04 02M44          CONVERGED               00305  42 00373 00315
02M37    TP 02M34 A0000                                  00306  11 00303 20000
02M38    TU 00M06 02M39                                  00307  15 00150 00310
02M39    TJ 00000 01M15                                  00310  42 00000 00222
02M40 LDST 00T04 00008                                   00311  14 30045 34010
02M41 LDST 00T06 00006                                   00312  14 30047 34006
02M42 PDNO 00010 00000           ITERANT                 00313  14 74012 00000
02M43    MJ 00000 01M15                                  00314  45 00000 00222
02M44    TP 00T06 00006          LOAD                    00315  11 00047 00006
02M45    TP 00T07 00007            ROOT                  00316  11 00050 00007
02M46    TU 00M18 00004          SET B BOX               00317  15 00164 00004
02M47    TP 00K07 00031          SET INDEX               00320  11 00376 00037
02M48    TP 00013 00025                                  00321  11 00015 00031
02M49    TP 00013 00026                                  00322  11 00015 00032
02M50 LDST 00000 00023  B        FORM                    00323  14 32000 34027
02M51 LDMP 00025 00T06            RESIDUAL               00324  14 30031 14047
02M52 ADST 00023 00025              AND                  00325  14 04027 34031
02M53 LDMP 00023 00T06            DERIVATIVE             00326  14 30027 14047
02M54 ADST F0000 00023  B                                00327  14 06002 34027
02M55    RA 00004 00K03                                  00330  21 00004 00372
02M56    IJ 00031 02M51                                  00331  41 00037 00324
02M57    RP 30004 02M59                                  00332  75 30004 00334
02M58    TP 00023 00008                                  00333  11 00027 00010
02M59 LDPM 00025 00000          N                        00334  14 30031 24000
02M60    ZJ 02M61 02M65           E                      00335  47 00336 00342
02M61 LDNO 00023 00000              W                   00336  14 30027 00000
02M62 DVSU 00025 00T06  S             T                 00337  14 21031 10047
02M63    TN F0000 00T06                 O                00340  13 00002 00047
02M64    TN C0000 00T07                   N              00341  13 00003 00050
02M65    TU 00M00 00004           C                      00342  15 00142 00004
02M66 LDST 00T06 00004      B      Y                      00343  14 30047 36004
02M67 PDNO 00010 00000               C                  00344  14 74012 00000
02M68 STPM 00006 00000                 L                00345  14 34006 24000
02M69    ZJ 02M71 02M73                  E               00346  47 00350 00352
02M70    MJ 00000 02M74                                  00347  45 00000 00353
02M71 LDDV 00025 00T06                                   00350  14 30031 20047
02M72 PMNO 00008 00000  S                                00351  14 25010 00000
02M73 PDPD 00010 00010                                   00352  14 74012 74012
02M74    IJ 00T14 00M22                                  00353  41 00057 00170
02M75    RA 00M01 00016                                  00354  21 00143 00020
02M76    MJ 00000 00M01                                  00355  45 00000 00143
02M77    TP 02M70 02M67                                  00356  11 00347 00344
02M78    MJ 00000 00M04                                  00357  45 00000 00146
02M79    TP 00027 00T12                                  00360  11 00033 00055
02M80    TP 00028 00T13                                  00361  11 00034 00056
02M81    TP 00023 00T06                                  00362  11 00027 00047
```

```
02M82    TP 00024 00T07                                  00363  11 00030 00050
02M83    TP 00K01 F0000                                  00364  11 00370 00002
02M84    RP 30004 02M29                                  00365  75 30004 00276
02M85    TP 00T02 00T00                                  00366  11 00043 00041
00K00    05 00000 00000 -01 F    C                       00367  20 04000 00000
00K01    01 00000 00000     F    O                       00370  20 14000 00000
00K02    01 00000 00000   1 F      N                     00371  20 45000 00000
00K03    00 00002 00000             S                   00372  00 00002 00000
00K04    01 00000 00000 -04 F       T                   00373  16 36433 34272
00K05  PDNO 00010 00000                A                 00374  14 74012 00000
00K06    00 00004 00000                  N               00375  00 00004 00000
00K07    00 00000 00000                    TS            00376  00 00000 00000
START       00M00                                        00000  45 00000 00142
```

L. V. [illegible]
C. SWIFT

UNPACKED FLOATING POINT CARD OUTPUT

DESCRIPTION:

This routine writes up to five decimal point numbers on cards from either ES or MD

Drum address ,72013----72357 inc.

Number of instructions 270 octal

Constants 55 octal

Temporaries 76 octal

ES address (including temporaries) 01000--01442 inc.

Driver 71760--72012 inc.

The routine may be modified or may be used as a subroutine by the use of the driver, with ES stored starting at 74001.

All constants needed are included in the routine.

COMMAND SEQUENCE:

The subroutine is coded to start in cell 01000 and is entered by the write sequence

37	01001	01002
AB	UUUUU	VVVVV

In case of bull failure a start at PAK = 01000 will result in repeat of the interrupted instruction.

To use as a subroutine with the driver the sequence should be

37	71760	71761
AB	UUUUU	VVVVV

In case of bull failure a start at PAK = 72007 will restore ES and come to a 56 halt. Release of 56 stop will repeat interrupted instruction.

A. If A is equal to 4, 5, 6 or 7 the cards will not be numbered otherwise they will be numbered starting at one. Cell 01270 (72303) contains this counter and may be set at one less than the next positive card number desired.

B. Is not used.

UUUUU is the storage address of the first mantissa

VVVVV is the number of floating point numbers to be punched.

CARD FORM COLUMNS:

6, 21, 36, 51, 66 decimal point punched in card.

7-- 16, 22--31, 37--46, 52--61, 67--76 ten decimal digit mantissas

17, 32, 47, 62, 77 sign of the mantissas

18--19, 33--34, 48--49, 63--64, 78--79, exponents (power of ten) range -- 99 to 99

20, 35, 50, 65, 80 signs of exponent.

CODING NOTES:

No prime commands are included. 17 00000 72342 will advance a punch card.

In case of an unnormalized mantissa or an exponent with absolute value above 513 octal in any series to be punched, that number will be punched as negative zero. In addition an alarm listing of the first such address and mantissa will occur on the typewriter at the end of the last card and a 56 stop will occur which may be released to continue.

The maximum absolute value of exponents is 98 or 99 depending on the mantissa value.

The combined error of read in with IC011 and read out with IC012 will not exceed one in the tenth digit.

UNPACKED FLOATING POINT CARD OUTPUT

```
71760  00745  56 00000 30000
71761  00746  75 31777 71763     STORE
71762  00747  11 00001 74001       E S
71763  00750  75 30400 00752     ROUTINE
71764  00751  11 71760 00745       TO E S
71765  00752  31 00745 00000     SET
71766  00753  36 01310 72011      REPEAT
71767  00754  16 00745 00772     SET
71770  00755  21 00772 01310      EXIT
71771  00756  55 00745 20025     MODIFY
71772  00757  44 00761 00760      E S
71773  00760  32 00777 00000        ADDRESSES
71774  00761  55 20000 00017         TO STORAGE
71775  00762  37 00762 00763
71776  00763  16 20000 00764     ACQUIRE
71777  00764  71 01310 30000      CONTROL WORD
72000  00765  55 20000 00006     EXAMINE
72001  00766  37 00762 00757      FOR E S
72002  00767  55 20000 00017        ADDRESSES
72003  00770  37 01001 01006     TO SUBROUTINE
72004  00771  11 01270 72303     STORE CARD NUMBER
72005  00772  75 31777 30000     RESTORE
72006  00773  11 74001 00001       E S
72007  00774  75 31777 72011     RESTORE
72010  00775  11 74001 00001      E S
72011  00776  30 00000 00000        REPEAT
72012  00777  74 00000 00000     E S STORAGE
72013  01000  30 00000 0000*     REPEAT LAST INST
72014  01001  45 00000 30000     EXIT
72015  01002  16 01001 01005
72016  01003  21 01001 01310
72017  01004  36 01344 01000
```

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UNPACKED FLOATING POINT CARD OUTPUT

```
72020  01005  71 01310 30000
72021  01006  15 20000 01026     FIRST ADDRESS
72022  01007  13 20000 01347     FLAG
72023  01010  11 01310 01350     FLAG
72024  01011  31 20000 00025     EXTRACT
72025  01012  31 20000 00063      AND STORE
72026  01013  36 01310 01351       N-1
72027  01014  46 01001 01015     TEST FOR ZERO
72030  01015  17 00000 01327     PICK WRITE CARD
72031  01016  31 01351 00000
72032  01017  11 20000 01352     N-1 PER CARD
72033  01020  11 01325 10000     WRITE
72034  01021  42 01342 01024
72035  01022  11 01306 01352     5 PER CARD
72036  01023  11 01324 10000     WRITE AND PICK CARD
72037  01024  17 00000 10000     CARD INSTRUCTION
72040  01025  75 30012 01027     5 WORDS TO
72041  01026  11 30000 01353      STORAGE
72042  01027  75 10045 01031     CLEAR FOR
72043  01030  11 01307 01376      CARD IMAGE
72044  01031  15 01266 01050     SET ACQUISITION
72045  01032  11 01340 01374     BIT
72046  01033  11 01265 01375     BIT INSTRUCTION
72047  01034  41 01347 01047     IDENT NUMBER TEST
72050  01035  11 01332 01374     BIT
72051  01036  21 01270 01310     COUNT CARDS
72052  01037  42 01315 01041     SIZE OF WORD
72053  01040  31 01341 00000     SET 99999
72054  01041  32 01307 00043     INTEGER
72055  01042  32 01265 00000      TO
72056  01043  73 01315 01365       FRACTION
72057  01044  54 01365 00001         2 EXP 36
```

UNPACKED FLOATING POINT CARD OUTPUT

72060	01045	11	01306	01376	N-1 DIGITS
72061	01046	37	01200	01165	IDENT NUMBER
72062	01047	75	30002	01051	MANTISSA
72063	01050	11	30000	01365	AND EXPONENT
72064	01051	11	01365	01370	MANTISSA SIGN FLAG
72065	01052	54	01366	00030	EXPONENT
72066	01053	54	01366	00060	EXTENSION
72067	01054	12	20000	20000	EXPONENT
72070	01055	42	01301	01067	FLOATING TEST
72071	01056	41	01350	01062	FIRST TIME
72072	01057	11	01264	01370	MANTISSA FLAG
72073	01060	75	10002	01156	SET EQUAL
72074	01061	11	01307	01365	TO ZERO
72075	01062	13	01322	01350	SET ALARM FLAG
72076	01063	11	01026	01345	
72077	01064	15	01050	01065	ACQUIRE
72100	01065	11	30000	01346	MANTISSA
72101	01066	45	00000	01057	
72102	01067	11	01365	20000	
72103	01070	47	01071	01156	ZERO MANTISSA
72104	01071	46	01072	01073	
72105	01072	13	01365	01365	NEGATIVE MANTISSA
72106	01073	16	01323	01123	SET SHIFT TO 33
72107	01074	32	01307	00001	EXP 36
72110	01075	43	20000	01056	FLOATING TEST
72111	01076	11	01307	01373	CLEAR FOR DECIMAL EXP
72112	01077	11	01366	20000	EXPONENT
72113	01100	46	01101	01117	SIGN
72114	01101	23	01373	01342	10 EXP 5 ADJUSTMENT
72115	01102	11	01307	01372	CLEAR FOR 74
72116	01103	71	01315	01365	X 10 EXP 5
72117	01104	74	20000	01372	

UNPACKED FLOATING POINT CARD OUTPUT

```
72120  01105  11 20000 01365
72121  01106  46 01107 01114      TEST FOR ROUND
72122  01107  21 01365 01310      ROUND
72123  01110  43 20000 01114       MANTISSA
72124  01111  31 01365 00107         AND
72125  01112  11 20000 01365           ADJUST
72126  01113  21 01372 01310
72127  01114  21 01366 01372      ADJUST BSF
72130  01115  46 01101 01116      SIGN OF BSF
72131  01116  31 01366 00000      DIVIDE EXP
72132  01117  73 01323 01367       BY 33
72133  01120  11 20000 01366      EXPONENT REMAINDER
72134  01121  55 01365 00001      MANTISSA
72135  01122  45 00000 01152
72136  01123  31 01365 30000      MANTISSA SHIFT
72137  01124  11 20000 01371      STORE AR
72140  01125  34 20000 00044      ERASE
72141  01126  11 20000 01365      STORE AL
72142  01127  75 20013 01426      TEST FOR LARGER
72143  01130  42 01310 01131       POWER OF TEN
72144  01131  51 01330 10000
72145  01132  31 01311 00000      10 EXP 10
72146  01133  36 10000 10000
72147  01134  35 01373 01373      INCREASE EXP
72150  01135  31 10000 00017      N X 2 EXP 15
72151  01136  35 01363 01127
72152  01137  30 00000 0000       ACQUIRE DIVISOR
72153  01140  11 10000 01370
72154  [illegible]                 RESTORE
                                     A
                                   EXP 35
                                   EXP 36
```

UNPACKED FLOATING POINT CARD OUTPUT

```
72160  01145  31 20000 00001     DETERMINE
72161  01146  42 01372 01150      LAST
72162  01147  27 10000 01310       BIT
72163  01150  11 10000 01365     ANSWER X 2 EXP 36
72164  01151  37 01151 01152
72165  01152  41 01367 01123     HIGHER ORDER DIGIT
72166  01153  16 01366 01123     LOWER ORDER SHIFT
72167  01154  37 01151 01123     LOWER ORDER DIGIT
72170  01155  11 01373 01366     DECIMAL EXPONENT
72171  01156  21 01050 01326     STEP
72172  01157  21 01026 01326     STEP
72173  01160  37 01200 01174     SHIFT FOR PERIOD
72174  01161  12 01366 20000     EXPONENT
72175  01162  11 01333 01376     TALLY
72176  01163  73 01311 01372     DIGITS
72177  01164  11 20000 01371      OF EXP
72200  01165  31 01365 00002     EXTRACT
72201  01166  32 01365 00001      AND
72202  01167  11 20000 01365       POSITION
72203  01170  34 20000 00063        DIGIT
72204  01171  35 01375 01172     ASSEMBLE INST
72205  01172  30 00000 0000*     SET BIT
72206  01173  37 01173 01174
72207  01174  55 01374 00043     SHIFT BIT
72210  01175  44 01176 01177
72211  01176  21 01375 01334     ADVANCE FIELD
72212  01177  41 01376 01165     TEST FOR END
72213  01200  37 01200 01201
72214  01201  11 01370 10000
72215  01202  44 01203 01205
72216  01203  13 01331 20000
72217  01204  37 01173 01171     SIGN
```

UNPACKED FLOATING POINT CARD OUTPUT

```
72220  01205  55 01374 00043     SHIFT BIT
72221  01206  37 01206 01207
72222  01207  31 01372 00017     TENS DIGIT
72223  01210  37 01200 01171
72224  01211  31 01371 00017     UNITS DIGIT
72225  01212  37 01200 01171
72226  01213  11 01366 01370
72227  01214  37 01206 01201
72230  01215  37 01215 01216
72231  01216  41 01352 01047     WORDS PER CARD
72232  01217  11 01335 01371     SIT FOR 12 ROWS
72233  01220  21 01377 01336
72234  01221  21 01411 01336
72235  01222  21 01404 01336
72236  01223  21 01413 01337
72237  01224  21 01425 01337
72240  01225  21 01420 01337
72241  01226  16 01267 01233
72242  01227  16 01127 01234
72243  01230  15 01267 01231
72244  01231  55 30000 00010
72245  01232  77 00000 10000
72246  01233  77 10000 30000
72247  01234  77 10000 30000
72250  01235  23 01231 01331
72251  01236  23 01233 01310
72252  01237  23 01234 01310
72253  01240  41 01371 01231     TEST FOR END OF CARD
72254  01241  23 01351 01342     TEST FOR
72255  01242  46 01243 01016      END
72256  01243  41 01350 01001     FLOATING FLAG
72257  01244  75 10005 01246
```

UNPACKED FLOATING POINT CARD OUTPUT

```
72260  01245  61 00000 01302
72261  01246  11 01306 01371
72262  01247  55 01345 10011
72263  01250  31 01264 00000
72264  01251  52 01343 01252
72265  01252  30 00000 00000
72266  01253  55 10000 00003
72267  01254  41 01371 01250
72270  01255  37 01255 01256
72271  01256  55 01346 10003
72272  01257  61 00000 01306
72273  01260  11 01335 01371
72274  01261  37 01255 01250
72275  01262  56 00000 01001
72276  01263  55 01310 10001
72277  01264  61 00000 01271
72300  01265  21 01401 01374
72301  01266  00 01353 00000
72302  01267  00 01442 01412
72303  01270  00 00000          CARD COUNTER
72304  01271  00 00000 00037
72305  01272  00 00000 00052
72306  01273  00 00000 00074
72307  01274  00 00000 00*70
72310  01275  00 00000 00064
72311  01276  00 00000 00062
72312  01277  00 00000 00066
72313  01300  00 00000    72
72314  01301  00 00000 00513
72315  01302  00 00000 00*45
72316  01303  00 00000 00031
72317  01304  00 00000 00020
```

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UNPACKED FLOATING POINT CARD OUTPUT

72320	01305	00	00000	0***1
72321	01306	00	00000	00*04
72322	01307	00	00000	00 *
72323	01310	00	00000	1
72324	01311	00	00000	00012
72325	01312	00	00000	00144
72326	01313	00	00000	01750
72327	01314	00	00000	23420
72330	01315	00	00003	03240
72331	01316	00	00036	41100
72332	01317	00	00461	13200
72333	01320	00	05753	60400
72334	01321	00	73465	45000
72335	01322	11	24027	62000
72336	01323	00	00000	00041
72337	01324	00	00000	00112
72340	01325	00	00000	00102
72341	01326	00	00002	00000
72342	01327	00	00000	00110
72343	01330	00	00000	00 77
72344	01331	00	00001	00000
72345	01332	40	00000	00000
72346	01333	00	00000	00011
72347	01334	00	00014	00000
72350	01335	00	00000	00013
72351	01336	01	00001	00001
72352	01337	00	00100	00100
72353	01340	01	00000	00000
72354	01341	00	00003	03237
72355	01342	00	00000	00*05
72356	01343	00	00000	00 *7
72357	01344	00	00000	00 *2

ANALYSIS
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CONTINUOUS MATRIX MULTIPLIER USING FLIP III

This routine multiplies two matrices, takes this product times a third matrix, the resulting product times a fourth, etc. All input and output data is by means of six-field flip cards. The elements of any one of the matrices may be punched on cards with the elements of a row or a column in consecutive order with each row or column starting at the beginning of a flip card.* The multiplier assumes the matrix on the left is stored by rows and the one on the right is stored by columns. Even though one or both of the matrices may not be of this form on the cards, the multiplication may still be performed by using flags to indicate storage form different from the card form. A third flag is used to indicate a change in the form of the product if it is desired, and a fourth flag is used to indicate further multiplication. These flags are denoted by the symbols p_1, p_2, p_3, and p_4. Three parameters, m, n, and s, are necessary to furnish the routine with the size of the matrices.

To illustrate the use of the parameters and flags, suppose the product, ABC, of three matrices is wanted where the matrices have the following properties:

A : a m × n matrix, punched by columns on flip cards

B : a n × s matrix, punched by columns on flip cards

C : a s × t matrix, punched by rows on flip cards.

* The stop read indicator (a 12 - punch in column 1) must be on the last card for each matrix.

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The multiplication proceeds from the left, so AB is the first product formed, then this multiplies C.

Before reading matrix A, the routine reads three parameter cards. The first of these parameter cards contains "m" as the card number, the second contains "n" as the card number, and the third contains "s" as the card number. The third card also contains any of the four flags that need to be indicated. If flag p_1 is necessary, it appears as any number different from zero in field 1 and so on for the other three flags in the next three fields. Thus, for this multiplication $p_1 \neq 0$ since A needs to be changed in form before storage, $p_2 = 0$ since B does not need to be changed, $p_3 = 0$ since AB is multiplying C instead of the transpose of AB times C, and $p_4 \neq 0$ since the multiplication will not terminate with the product AB. After the product AB has been computed by columns, it is stored by rows in the position of the first matrix in the multiplier, and the routine is ready to receive C. However, a new parameter card must be read before reading C. This card contains the second dimension of C, i. e. "t", as the card number, nothing in field 1 since the first matrix in the multiplier has been properly stored, $p_2 \neq 0$ in field 2 since the form of C must be changed from cards to storage, $p_3 = 0$ since the product of ABC is wanted not its transpose, and $p_4 = 0$ since the multiplication is to terminate when ABC is formed.

To summarize,

p_1 { $= 0$ for first matrix punched by rows
{ $\neq 0$ for first matrix punched by columns

p_2 { $= 0$ for second matrix punched by columns
{ $\neq 0$ for second matrix punched by rows

p_3 { $= 0$ for the product to be used as formed
{ $\neq 0$ for the transpose of the product to be used

p_4 { = 0 for no further multiplication
{ ≠ 0 for continued multiplication

NOTE: If $p_4 = 0$, then p_3 controls the form of the output.

The final output is the product by columns for $p_3 = 0$, or is the transpose (of the product) by columns for $p_3 \neq 0$. In the routine, just prior to the final output, the only MS - 1 appears in the program. If a stop is made here and MJ - 1 is set, then the output is that specified by p_3 and also its transpose.

In a continuous multiplication, output of the intermediate products may be obtained. The only MS - 2 in the routine is just prior to the intermediate output. A stop at this point allows the operator to set the MJ 's which control the intermediate output as follows:

MJ 's	Output
none	none
1	{ product by columns for $p_3 = 0$, { transpose (of product) by columns for $p_3 \neq 0$.
2	Product regardless of p_3
3	Transpose (of Product) regardless of p_3
1 & 2	{ transpose (of product) for $p_3 = 0$ { Product for $p_3 \neq 0$.
1 & 3	Same as 1.
2 & 3	{ Product followed by transpose for $p_3 = 0$ { Transpose followed by product for $p_3 \neq 0$.
1, 2, & 3	Same as 1 & 2.

This routine, the working storage, the matrix storage and flip use

the entire ES storage and all of MD. The storage is allotted as follows:

00000 - 00077)
01477 - 01777 } Flip
70000 - 77777)

00100 - 00137 - Temporaries

00140 - 00157 - Constants

00160 - 00376 - Program

00377 - 01476 - Working storage

40000 - 40627 - Program

40630 - 50417 - 1st matrix

50420 - 60207 - 2nd matrix

60210 - 67777 - Product

Tests are built into the routine that give an alarm exit if the size of a matrix is too large for the multiplier. The following restrictions are imposed on m, n, s, k_1, k_2, & k_3 (see next page for definition of k_i 's):

$$1 \leq m, n, s \leq 192_{10}$$

$$1 \leq m \times k_2 \leq 3960 = 60(66) + 1$$

$$1 \leq k_2 \times s \leq 3960 = 60(66) + 1$$

$$1 \leq m \times k_3 \leq 3960 = 60(66) + 1$$

$$1 \leq k_1 \times s \leq 3960 = 60(66) + 1$$

Thus, the largest square matrix that can be handled is a 60×60 matrix, and the largest rectangular matrix is a 60×66. The largest square matrix is a 60×60 since a 61×61 would be handled on cards and in the memory as a 61×66 or 66×61 and the product $61 \times 66 = 4026$ which is greater than the 3960 number of elements allowed for each matrix.

A check sum is printed at the beginning of the program. This check sum is equal to 22420523 5612. A programmed Blotto is included in the routine. Setting (PAK) = 40620 and starting gives a Blotto of 00100 - 00377 and 40000 to 40637, which includes the temporaries, constants, and program in E.S. and entire program on M.D.

The program starts with (PAK) = 40000. Several continuous multiplication may be done by resetting (PAK) = 40000 at MS-0. However, either the cards should be loaded in the reading hopper when PAK is reset; or, all cards may be loaded beforehand if a blank card is placed between the cards for the separate continuous multiplications.

List of Symbols in Flow Chart and Code.

A	Matrix on left in product
B	Matrix on right in product
C	Product of A and B
a_{ij}	Element of A in ith row, jth column (refers to M.D. storage)
b_{jk}	Element of B in jth row, kth column (refers to M.D. storage)
c_{ik}	Element of C in ith row, kth column (refers to M.D. storage)
m	Number of rows of A, number of rows of C
n	Number of columns of A and number of rows of B
s	Number of columns of B, number of columns of C
k_1	m, if $m \equiv 0 \pmod 6$; lst multiple of 6 $>$ m if $m \not\equiv 0 \pmod 6$
k_2	n, if $n \equiv 0 \pmod 6$; lst multiple of 6 $>$ n if $n \not\equiv 0 \pmod 6$
k_3	s, if $s \equiv 0 \pmod 6$; lst multiple of 6 $>$ s if $s \not\equiv 0 \pmod 6$
p_1	non-zero for A changed from cards to storage, otherwise zero
p_2	non-zero for B changed from cards to storage, otherwise zero
p_3	non-zero for transpose of product wanted, otherwise zero

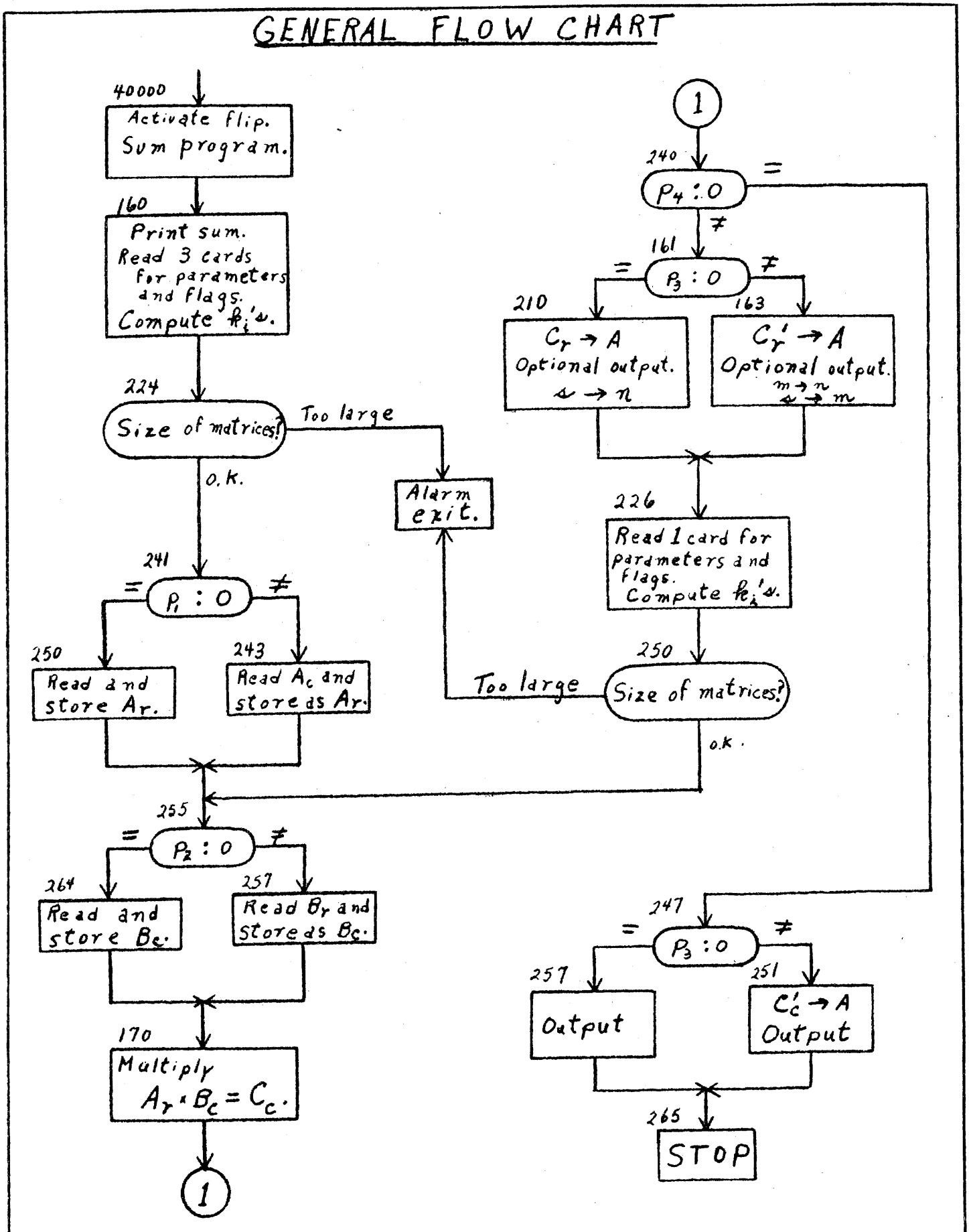
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p_4	non-zero for additional multiplication to do, otherwise zero
I_1	contents of a temporary storage cell in E. S.
d_{ij}	any matrix element on MD
δ_{ij}	any matrix element in ES after card read when p_1 or $p_2 \neq 0$
γ_j	one of a consecutive group of elements which is formed in ES before transfer to M.D. The group is a row of A or a column of B on card read with p_1 or $p_2 \neq 0$, is a column of C during multiplication, and is a row of C if $p_4 \neq 0$, $p_3 = 0$, or if $p_4 = 0$, $p_3 \neq 0$.
α_j	an element of the ith row of A
β_j	an element of the kth column of B
1 ( )	location of quantity in parenthesis
A_r, B_r, C_r	indicated matrix stored by rows
A_c, B_c, C_c	indicated matrix stored by columns

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GENERAL FLOW CHART



CONTINUOUS MATRIX MULTIPLIER

40000	45 00000 40001	40001 → (PAK)
40001	37 70160 70140	ACTIVATE FLIP
40002	00 00000 00000	FLAG
40003	31 40000 00000	CHECK
40004	75 20627 40006	SUM
40005	32 40001 00000	PROGRAM
40006	11 20000 10000	SUM → (Q)
40007	75 30237 00160	STARTER AND CARD READ
40010	11 40020 00140	TO ES, 160 → (PAK)
40011	00 00000 00000	
40012	00 00000 00000	
40013	00 00000 00000	
40014	00 00000 00000	
40015	00 00000 00000	
40016	00 00000 00000	
40017	00 00000 00000	
40020 00140	00 40630 40630	$\ell(a_{11}) \times 2^{15} + \ell(a_{11})$
40021 00141	00 50420 50420	$\ell(b_{11}) \times 2^{15} + \ell(b_{11})$
40022 00142	00 60210 60210	$\ell(c_{11}) \times 2^{15} + \ell(c_{11})$
40023 00143	00 00377 01177	$\ell(\delta_{11}) \times 2^{15} + \ell(\delta_{11})$
40024 00144	00 00106 00100	$\ell(m) \times 2^{15} + \ell(k_1)$
40025 00145	00 00000 00103	$\ell(k_1 \times 2^{15})$
40026 00146	00 07777 00000	4 DIGIT U-EXTRACTOR
40027 00147	00 00077 00000	2 DIGIT U-EXTRACTOR
40030 00150	00 00000 00006	6
40031 00151	00 00000 00572	378
40032 00152	00 00000 07571	3961
40033 00153	00 00000 00301	193
40034 00154	00 00000 00000	
40035 00155	00 00000 00000	
40036 00156	00 00000 00000	
40037 00157	00 00000 00000	

CONTINUOUS MATRIX MULTIPLIER

40040	00160	11	00057	00121	PRINT
40041	00161	61	00000	00042	
40042	00162	55	10000	00003	OF
40043	00163	51	00067	20000	
40044	00164	35	00042	00165	CHECK
40045	00165	30	00000	00000	
40046	00166	41	00121	00162	SUM
40047	00167	17	00000	73376	READY CARD REPRODUCER
40050	00170	1457	1010	0106	READ $m \rightarrow$ (106)
40051	00171	1457	1010	0107	READ $n \rightarrow$ (107)
40052	00172	1457	1010	0110	READ $s \rightarrow$ (110) FOLLOWED BY FLAGS
40053	00173	11	00106	20000	$m \rightarrow$ (A)
40054	00174	42	00153	00176	IS 193 > m ?
40055	00175	37	76000	76001	NO. ALARM EXIT
40056	00176	11	00107	20000	YES. $n \rightarrow$ (A)
40057	00177	42	00153	00201	IS 193 > n ?
40060	00200	37	76000	76001	NO. ALARM EXIT
40061	00201	11	00110	20000	YES. $s \rightarrow$ (A)
40062	00202	42	00153	00204	IS 193 > s ?
40063	00203	37	76000	76001	NO. ALARM EXIT
40064	00204	11	00041	00121	YES. SET INDEX
40065	00205	15	00144	00210	$\ell(m) \rightarrow \ell(m, n, \omega)$
40066	00206	16	00144	00215	$\ell(R_1) \rightarrow \ell(R_i)$
40067	00207	16	00145	00217	$\ell(R_1 \times 2^{15}) \rightarrow \ell(R_i \times 2^{15})$
40070	00210	11	30000	20000	m, n, OR $s \rightarrow$ (A)
40071	00211	73	00150	10000	(A)/6 $\rightarrow$ (Q), REM $\rightarrow$ (A)
40072	00212	47	00213	00214	IS (A) = 0 ?
40073	00213	21	10000	00074	NO. (Q) + 1 $\rightarrow$ (Q)
40074	00214	71	10000	00150	YES. (Q) × 6 $\rightarrow$ (A)
40075	00215	11	20000	30000	(R) $\rightarrow R_i$
40076	00216	54	20000	00017	(A) $\times 2^{15} \rightarrow$ (A)
40077	00217	11	20000	30000	(R) $\rightarrow R_i \times 2^{15}$

CONTINUOUS MATRIX MULTIPLIER

40100	00220	21	00210	00073	$\ell(m,n,\omega)+1 \rightarrow \ell(m,n,\omega)$
40101	00221	21	00215	00074	$\ell(k_i)+1 \rightarrow \ell(k_i)$
40102	00222	21	00217	00074	$\ell(k_2 \times 2^{15})+1 \rightarrow \ell(k_2 \times 2^{15})$
40103	00223	41	00121	00210	TEST INDEX
40104	00224	71	00106	00101	$m \times k_2 \rightarrow (A)$
40105	00225	42	00152	00227	IS 3961 $> m \times k_2$?
40106	00226	37	76000	76001	NO. ALARM EXIT
40107	00227	71	00101	00110	YES. $k_2 \times \omega \rightarrow$ (A)
40110	00230	42	00152	00232	IS 3961 $> k_2 \times \omega$?
40111	00231	37	76000	76001	NO. ALARM EXIT
40112	00232	71	00100	00110	YES. $k_1 \times \omega \rightarrow$ (A)
40113	00233	42	00152	00235	IS 3961 $> k_1 \times \omega$?
40114	00234	37	76000	76001	NO. ALARM EXIT
40115	00235	71	00106	00102	YES. $m \times k_3 \rightarrow$ (A)
40116	00236	42	00152	00240	IS 3961 $> m \times k_3$?
40117	00237	37	76000	76001	NO. ALARM EXIT
40120	00240	56	30000	00241	YES. MS←3
40121	00241	11	00111	20000	$\rho_1 \rightarrow$ (A)
40122	00242	47	00243	00250	IS $\rho_1 = 0$? YES. 250 $\rightarrow$ (PAK)
40123	00243	11	00100	00121	NO. $k_1 \rightarrow I_1$
40124	00244	11	00106	00122	$m \rightarrow I_2$
40125	00245	11	00140	00123	$\ell(a_{11}) \rightarrow I_3$
40126	00246	37	00300	00301	CHANGE A_C TO A_λ AND STORE
40127	00247	45	00000	00255	255 → (PAK)
40130	00250	16	00140	00251	$\ell(a_{11}) \rightarrow \ell(a_{ij})$
40131	00251	1457	0773	0000	READ 63 CARDS INTO $\ell(a_{ij})$ ETC.
40132	00252	21	00251	00151	$\ell(a_{ij}) + 378 \rightarrow \ell(a_{ij})$
40133	00253	11	00004	20000	(00004) → (A)
40134	00254	47	00255	00251	IS (A) = 0 ? YES. 251 → (PAK)
40135	00255	11	00112	20000	NO. $\rho_2 \rightarrow$ (A)
40136	00256	47	00257	00264	IS $\rho_2 = 0$? YES. 264 → (PAK)
40137	00257	11	00102	00121	NO. $k_3 \rightarrow I_1$

CONTINUOUS MATRIX MULTIPLIER

40140	00260	11	00110	00122	$A \rightarrow I_2$
40141	00261	11	00141	00123	$\ell(b_{11}) \rightarrow I_3$
40142	00262	37	00300	00301	CHANGE B_2 TO B_C AND STORE
40143	00263	45	00000	00274	$274 \rightarrow$ (PAK)
40144	00264	16	00141	00265	$\ell(b_{11}) \rightarrow \ell(b_{ij})$
40145	00265	1457	0773	0000	READ 63 CARDS INTO $\ell(b_{ij})$ ETC.
40146	00266	21	00265	00151	$\ell(b_{ij}) + 378 \rightarrow \ell(b_{ij})'$
40147	00267	11	00004	20000	(00004) $\rightarrow$ (A)
40150	00270	47	00274	00265	IS (A) = 0? YES. 265 $\rightarrow$ (PAK)
40151	00271	00	00000	00000	
40152	00272	00	00000	00000	
40153	00273	00	00000	00000	
40154	00274	75	30217	00170	NO. MULTIPLIER AND
40155	00275	11	40260	00160	FINAL OUTPUT TO ES
40156	00276	00	00000	00000	
40157	00277	00	00000	00000	
40160	00300	45	00000	30000	EXIT
40161	00301	11	00040	00127	$0 \rightarrow I_7$
40162	00302	11	00040	00131	$0 \rightarrow I_{11}$
40163	00303	55	00122	00017	$I_2 \times 2^{15} \rightarrow I_2$
40164	00304	11	00121	20000	$I_1 \rightarrow$ (A)
40165	00305	73	00150	00124	(A)/6 $\rightarrow I_4$
40166	00306	55	00121	00017	$I_1 \times 2^{15} \rightarrow I_1$
40167	00307	11	00064	20000	$63 \rightarrow$ (A)
40170	00310	73	00124	00125	(A)/$I_4 \rightarrow I_5$ AND (Q)
40171	00311	55	10000	00017	(Q) $\times 2^{15} \rightarrow$ (Q)
40172	00312	11	10000	00132	$I_5 \times 2^{15} \rightarrow I_{12}$
40173	00313	11	00107	20000	$n \rightarrow$ (A)
40174	00314	73	00125	10000	$n/I_5 \rightarrow$ (Q), REM $\rightarrow$ (A)
40175	00315	11	20000	00126	REM $\rightarrow I_6$
40176	00316	54	20000	00017	REM $\times 2^{15} \rightarrow$ (A)
40177	00317	11	20000	00133	$I_6 \times 2^{15} \rightarrow I_{13}$

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CONTINUOUS MATRIX MULTIPLIER

40200	00320	47	00323	00321	IS (A) = 0 ?
40201	00321	11	00125	00126	YES. $I_5 \rightarrow I_6$
40202	00322	11	00132	00133	$I_{12} \rightarrow I_{13}$
40203	00323	71	00124	00132	NO. $I_4 * I_{12} \rightarrow$ (A)
40204	00324	11	00147	10000	2 DIGIT U-EXTRACTOR → (Q)
40205	00325	53	20000	00327	SET NO. OF CARDS TO READ
40206	00326	53	00132	00364	SET NO OF r's TO TRANSFER TO MD
40207	00327	1457	0000	0377	READ PRESET NO. OF CARDS INTO ES
40210	00330	16	00123	00365	$\ell(d_{11}) \rightarrow \ell(d_{ij})$
40211	00331	21	00365	00131	$\ell(d_{11}) + I_{11} \rightarrow \ell(d_{ij})$
40212	00332	21	00131	00125	$I_{11} + I_5 \rightarrow I_{11}$
40213	00333	11	00004	20000	(00004) → (A)
40214	00334	47	00335	00352	IS (A) = 0 ? YES. 352 → (PAK)
40215	00335	11	00064	00127	NO. 63 → I_7
40216	00336	16	00143	00350	$\ell(r_1) \rightarrow \ell(r_{I_6+1})$
40217	00337	21	00350	00126	$\ell(r_1) + I_6 \rightarrow \ell(r_{I_6+1})$
40220	00340	31	00101	00000	$k_2 \rightarrow$ (R)
40221	00341	34	00107	00017	$(k_3 - m) \times 2^{15} \rightarrow$ (R)
40222	00342	11	20000	00124	(R) → I_4
40223	00343	11	00146	10000	4 DIGIT U-EXTRACTOR → (Q)
40224	00344	53	20000	00347	SET NO. OF r's TO BE ZERO
40225	00345	21	00124	00133	$I_4 * I_{13} \rightarrow I_4$
40226	00346	53	20000	00364	SET NO. OF r's TO TRANSFER TO MD
40227	00347	75	10000	00351	SET PROPER
40230	00350	11	00040	30000	r's = 0
40231	00351	11	00126	00125	$I_6 \rightarrow I_5$
40232	00352	11	00040	00130	0 → I_{10}
40233	00353	15	00143	00360	$\ell(\delta_{11}) \rightarrow \ell(\delta_{ij})$
40234	00354	21	00360	00130	$\ell(\delta_{11}) + I_{10} \rightarrow \ell(\delta_{ij})$
40235	00355	16	00143	00360	$\ell(r_1) \rightarrow \ell(r_j)$
40236	00356	11	00125	20000	$I_5 \rightarrow$ (A)
40237	00357	36	00074	00124	$I_5 - 1 \rightarrow I_4$

CONTINUOUS MATRIX MULTIPLIER

40240	00360	11	30000	30000	$\delta_{ij} \rightarrow r_j$
40241	00361	21	00360	00074	$\ell(r_j)+1 \rightarrow \ell(r_j)$
40242	00362	35	00121	00360	$\ell(\delta_{ij}) + I_1 \rightarrow \ell(\delta_{ij})$
40243	00363	41	00124	00360	TEST INDEX
40244	00364	75	30000	00366	SEND ALL
40245	00365	11	01177	30000	r_j's $\rightarrow d_{ij}$
40246	00366	21	00365	00101	$\ell(d_{ij}) + k_2 \rightarrow \ell(d_{ij})$
40247	00367	21	00130	00073	$I_{10} + 1 \times 2^{15} \rightarrow I_{10}$
40250	00370	42	00122	00353	TEST INDEX
40251	00371	11	00127	20000	$I_7 \rightarrow (A)$
40252	00372	47	00300	00327	TEST FOR MORE CARD READS
40253	00373	00	00000	00000	
40254	00374	00	00000	00000	
40255	00375	00	00000	00000	
40256	00376	00	00000	00000	
40257		00	00000	00000	
40260	00160	00	00000	00000	
40261	00161	00	00000	00000	
40262	00162	00	00000	00000	
40263	00163	00	00000	00000	
40264	00164	00	00000	00000	
40265	00165	00	00000	00000	
40266	00166	00	00000	00000	
40267	00167	00	00000	00000	
40270	00170	56	30000	00171	MS-3
40271	00171	16	00143	00203	$\ell(r_i) \rightarrow \ell(r_j)$
40272	00172	21	00203	00106	$\ell(r_i) + m \rightarrow \ell(r_{m+1})$
40273	00173	31	00100	00000	$k_1 \rightarrow (R)$
40274	00174	34	00106	00017	$(k_1 - m) \times 2^{15} \rightarrow (A)$
40275	00175	11	00146	10000	4 DIGIT U-EXTRACTOR $\rightarrow$ (Q)
40276	00176	53	20000	00202	SET NO. OF r's TO BE ZERO
40277	00177	53	00104	00210	SET NO. OF ROWS OF B_c

CONTINUOUS MATRIX MULTIPLIER

```
40300  00200  53 00104 00216   SET NO. OF COLUMNS OF A_ν
40301  00201  53 00103 00231   SET NO. OF ROWS OF C_c
40302  00202  75 10000 00204   SET PROPER
40303  00203  11 00040 30000            r_iν = 0
40304  00204  15 00141 00211   ℓ(b_11) → ℓ(b_jk)
40305  00205  16 00142 00232   ℓ(c_11) → ℓ(c_jk)
40306  00206  11 00110 20000   ν → (A)
40307  00207  36 00074 00121   ν - 1 → I_1
40310  00210 [75 30000 00212   SEND k th COLUMN OF
40311  00211  11 30000 00677            B_C TO ES
40312  00212  15 00140 00217   ℓ(a_11) → ℓ(a_ij)
40313  00213  16 00143 00225   ℓ(r_1) → ℓ(r_j)
40314  00214  11 00106 20000   m → (A)
40315  00215  36 00074 00122   m - 1 → I_2
40316  00216 [75 30000 00220   SEND i th ROW OF
40317  00217  11 30000 00377            A_λ TO ES
40320  00220  11 00101 20000   k_2 → (A)
40321  00221  36 00074 00123   k_2 - 1 → I_3
40322  00222  11 00040 20000    0 → (A)
40323  00223 [1423 4377 4677   (R) + α_j β_j → (R)
40324  00224  1440 0123 0223]  IS ℓ_1 < k_2 - 1 ? YES. 223 → (PAK)
40325  00225  11 20000 30000   NO (R) → r_j
40326  00226  21 00217 00104   ℓ(a_ij) + k_2 → ℓ(a_ij)
40327  00227  21 00225 00074   ℓ(r_i) + 1 → ℓ(r_i)
40330  00230  41 00122 00216]  TEST INDEX
40331  00231  75 30000 00233   SEND k th COLUMN OF
40332  00232  11 01177 30000            C_C TO MD
40333  00233  21 00232 00100   ℓ(c_ik) + k_1 → ℓ(c_ik)
40334  00234  21 00211 00104   ℓ(b_jk) + k_2 → ℓ(b_jk)
40335  00235  41 00121 00210]  TEST INDEX
40336  00236  56 30000 00237   MS-3
40337  00237  45 00000 00240    240 → (PAK)
```

CONTINUOUS MATRIX MULTIPLIER

```
40340  00240  11 00114 20000   P4 → (A)
40341  00241  47 00244 00246   IS P4 = 0 ?
40342  00242  00 00000 00000
40343  00243  00 00000 00000
40344  00244  75 30120 00160   NO. INTERMEDIATE OUTPUT
40345  00245  11 40500 00160         AND NEW SETUP TO ES
40346  00246  56 10000 00247   YES. MS-1
40347  00247  11 00113 20000   P3 → (A)
40350  00250  47 00251 00257   IS P3 = 0 ?
40351  00251  37 00301 00302   NO. Cc' → A
40352  00252  37 00350 00351   PUNCH Cc'
40353  00253  45 10000 00255   MJ-1. IF ON, 255 → (PAK)
40354  00254  45 00000 00264   264 → (PAK)
40355  00255  37 00340 00341   PUNCH Cc
40356  00256  45 00000 00264   264 → (PAK)
40357  00257  37 00340 00341   PUNCH Cc
40360  00260  45 10000 00262   MJ-1. IF ON, 262 → (PAK)
40361  00261  45 00000 00264   264 → (PAK)
40362  00262  37 00301 00302   Cc' → A
40363  00263  37 00350 00351   PUNCH Cc'
40364  00264  37 73374 73374   ADVANCE ALL CARDS PROCESSED
40365  00265  56 00000 40365   STOP
40366  00266  00 00000 00000
40367  00267  00 00000 00000
40370  00270  00 00000 00000
40371  00271  00 00000 00000
40372  00272  00 00000 00000
40373  00273  00 00000 00000
40374  00274  00 00000 00000
40375  00275  00 00000 00000
40376  00276  00 00000 00000
40377  00277  00 00000 00000
```

CONTINUOUS MATRIX MULTIPLIER

40400	00300	37	76000	76002	ALARM EXIT
40401	00301	45	00000	30000	EXIT
40402	00302	16	00143	00312	$\ell(r_i) \rightarrow \ell(r_j)$
40403	00303	21	00312	00110	$\ell(r_i) + \Delta \rightarrow \ell(r_{i+1})$
40404	00304	31	00102	00000	$k_3 \rightarrow (R)$
40405	00305	34	00110	00017	$(k_3 - \Delta) \times 2^{15} \rightarrow (R)$
40406	00306	11	00146	10000	4 DIGIT U-EXTRACTOR $\rightarrow$ (Q)
40407	00307	53	20000	00311	SET NO. OF r's TO BE ZERO
40410	00310	53	00105	00325	SET NO. OF ROWS OF C_c'
40411	00311	75	10000	00313	SET PROPER
40412	00312	11	00040	30000	r's = 0
40413	00313	11	00040	00122	$0 \rightarrow I_2$
40414	00314	15	00142	00321	$\ell(c_{11}) \rightarrow \ell(c_{ij})$
40415	00315	16	00140	00326	$\ell(a_{11}) \rightarrow \ell(a_{ij})$
40416	00316	11	00110	20000	$\Delta \rightarrow (A)$
40417	00317	36	00074	00121	$\Delta - 1 \rightarrow I_1$
40420	00320	16	00143	00321	$\ell(r_i) \rightarrow \ell(r_j)$
40421	00321	11	30000	30000	$c_{ij} \rightarrow r_j$
40422	00322	21	00321	00074	$\ell(r_j) + 1 \rightarrow \ell(r_j)$
40423	00323	35	00103	00321	$\ell(c_{ij}) + k_1 \rightarrow \ell(c_{ij})$
40424	00324	41	00121	00321	TEST INDEX
40425	00325	75	30000	00327	SEND i^{th} COLUMN OF
40426	00326	11	01177	30000	C_c' TO MD
40427	00327	21	00326	00102	$\ell(a_{ij}) + k_3 \rightarrow \ell(a_{ij})$
40430	00330	21	00122	00074	$I_2 + 1 \rightarrow I_2$
40431	00331	54	20000	00017	$(A) \times 2^{15} \rightarrow (A)$
40432	00332	15	00142	00321	$\ell(c_{11}) \rightarrow \ell(c_{ij})$
40433	00333	35	00321	00321	$\ell(c_{11}) + I_2 \rightarrow \ell(c_{ij})$
40434	00334	11	00122	20000	$I_2 \rightarrow (A)$
40435	00335	42	00106	00316	TEST INDEX
40436	00336	45	00000	00301	TO EXIT
40437	00337	00	00000	00000	

CONTINUOUS MATRIX MULTIPLIER

40440	00340	45	00000	30000	EXIT
40441	00341	71	00100	00110	$k_1 \times \omega \rightarrow (A)$
40442	00342	73	00150	20000	$(A)/6 \rightarrow (A)$
40443	00343	16	00142	00365	$\ell(c_{11}) \rightarrow \ell(d_{ij})$
40444	00344	37	00360	00361	PUNCH C_c
40445	00345	17	00000	00077	BLANK CARD IN OUTPUT
40446	00346	45	00000	00340	TO EXIT
40447	00347	00	00000	00000	
40450	00350	45	00000	30000	EXIT
40451	00351	71	00102	00106	$m \times k_3 \rightarrow (A)$
40452	00352	73	00150	20000	$(A)/6 \rightarrow (A)$
40453	00353	16	00140	00365	$\ell(a_{11}) \rightarrow \ell(d_{ij})$
40454	00354	37	00360	00361	PUNCH C_c'
40455	00355	17	00000	00077	BLANK CARD IN OUTPUT
40456	00356	45	00000	00350	TO EXIT
40457	00357	00	00000	00000	
40460	00360	45	00000	30000	EXIT
40461	00361	42	00064	00371	IS $63 > (A)$?. YES. 371 $\rightarrow$ (PAK)
40462	00362	73	00064	00122	NO. $(A)/63 \rightarrow I_2$. REM $\rightarrow (A)$
40463	00363	11	20000	00121	$(A) \rightarrow I_1$
40464	00364	23	00122	00074	$I_2 - 1 \rightarrow I_2$
40465	00365	1456	0773	0000	PUNCH 63 CARDS STARTING AT $\ell(d_{ij})$
40466	00366	21	00365	00151	$\ell(d_{ij}) + 378 \rightarrow \ell(d_{ij})$
40467	00367	41	00122	00365	TEST INDEX
40470	00370	11	00121	20000	$I_2 \rightarrow (A)$
40471	00371	16	00365	00375	$\ell(d_{ij}) \rightarrow \ell(d_{ij})$
40472	00372	54	20000	00017	$(A) \times 2^{15} \rightarrow (A)$
40473	00373	11	00147	10000	2 DIGIT U-EXTRACTOR $\rightarrow$ (Q)
40474	00374	53	20000	00375	SET NO. CARDS TO PUNCH
40475	00375	1456	0003	0000	PUNCH CARDS
40476	00376	45	00000	00360	TO EXIT
40477		00	00000	00000	

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CONTINUOUS MATRIX MULTIPLIER

```
40500  00160  56 20000 00161   MS-2
40501  00161  11 00113 20000   P3 → (A)
40502  00162  47 00163 00210   IS P3 = 0?  YES, 210 → (PAK)
40503  00163  45 10000 00167   NO, MJ-1, IF ON 167 → (PAK)
40504  00164  45 30000 00173   MJ-3, IF ON 173 → (PAK)
40505  00165  45 20000 00177   MJ-2, IF ON 177 → (PAK)
40506  00166  45 00000 00200     200 → (PAK)
40507  00167  45 20000 00177   MJ-2, IF ON 177 → (PAK)
40510  00170  37 00301 00302   C'c → A
40511  00171  37 00350 00351   PUNCH C'c
40512  00172  45 00000 00200   200 → (PAK)
40513  00173  37 00301 00302   C'c → A
40514  00174  37 00350 00351   PUNCH C'c
40515  00175  45 20000 00177   MJ-2, IF ON 177 → (PAK)
40516  00176  45 00000 00200   200 → (PAK)
40517  00177  37 00340 00341   PUNCH Cc
40520  00200  71 00103 00110   ϕ1 x ϕ2 x 2^15 → (A)
40521  00201  11 00146 10000   4 DIGIT U-EXTRACTOR → (Q)
40522  00202  53 20000 00203   SET NO. OF ELEMENTS OF Cc
40523  00203  75 30000 00205   SEND
40524  00204  11 60210 40630       Cc → A
40525  00205  11 00106 00107   m → n
40526  00206  11 00110 00106   ℓ → m
40527  00207  45 00000 00225   225 → (PAK)
40530  00210  37 00301 00302   C'c → A
40531  00211  45 10000 00215   MJ-1, IF ON 215 → (PAK)
40532  00212  45 20000 00220   MJ-2, IF ON 220 → (PAK)
40533  00213  45 30000 00223   MJ-3, IF ON 223 → (PAK)
40534  00214  45 00000 00224   224 → (PAK)
40535  00215  45 20000 00223   MJ-2, IF ON 223 → (PAK)
40536  00216  37 00340 00341   PUNCH Cc
40537  00217  45 00000 00224   224 → (PAK)
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CONTINUOUS MATRIX MULTIPLIER

40540	00220	37	00340	00341	PUNCH C_C
40541	00221	45	30000	00223	MJ-3, IF ON 223 → (PAK)
40542	00222	45	00000	00224	224 → (PAK)
40543	00223	37	00350	00351	PUNCH C_C'
40544	00224	11	00110	00107	$\omega \rightarrow n$
40545	00225	56	30000	00226	MS-3
40546	00226	1457	1010	0110	READ NEW PARAMETER AND FLAGS
40547	00227	45	00000	00230	230 → (PAK)
40550	00230	11	00041	00121	SET INDEX
40551	00231	15	00144	00234	$\ell(m) \rightarrow \ell(m, n, \omega)$
40552	00232	16	00144	00241	$\ell(k_1) \rightarrow \ell(k_i)$
40553	00233	16	00145	00243	$\ell(k_1 \times 2^{15}) \rightarrow \ell(k_i \times 2^{15})$
40554	00234	11	30000	20000	m, n, OR $\omega \rightarrow$ (A)
40555	00235	73	00150	10000	(A)/6 → (Q), REM → (A)
40556	00236	47	00237	00240	IS REM = 0?
40557	00237	21	10000	00074	NO. (Q)+1 → (Q)
40560	00240	71	10000	00150	YES. (Q)×6 → (A)
40561	00241	11	20000	30000	(R) → k_i
40562	00242	54	20000	00017	(A) × 2^{15} → (A)
40563	00243	11	20000	30000	(R) → $k_i \times 2^{15}$
40564	00244	21	00234	00073	$\ell(m, n, \omega) + 1 \rightarrow \ell(m, n, \omega)$
40565	00245	21	00241	00074	$\ell(k_i) + 1 \rightarrow \ell(k_i)$
40566	00246	21	00243	00074	$\ell(k_i \times 2^{15}) + 1 \rightarrow \ell(k_i \times 2^{15})$
40567	00247	41	00121	00234	TEST INDEX
40570	00250	71	00101	00110	$k_2 \times \omega \rightarrow$ (A)
40571	00251	42	00152	00253	IS 3961 > $k_2 \times \omega$?
40572	00252	37	76000	76001	NO. ALARM EXIT
40573	00253	71	00100	00110	YES. $k_1 \times \omega \rightarrow$ (A)
40574	00254	42	00152	00256	IS 3961 > $k_1 \times \omega$?
40575	00255	37	76000	76001	NO. ALARM EXIT
40576	00256	71	00102	00106	YES. $m \times k_3 \rightarrow$ (A)
40577	00257	42	00152	00261	IS 3961 > $m \times k_3$?

CONTINUOUS MATRIX MULTIPLIER

```
40600  00260  37 76000 76001   NO. ALARM EXIT.
40601  00261  11 00110 20000   YES. ↓ → (A)
40602  00262  42 00153 00270   IS 193 > ↓ ? YES, 270 → (PAK)
40603  00263  37 76000 76001   NO. ALARM EXIT
40604  00264  00 00000 00000
40605  00265  00 00000 00000
40606  00266  00 00000 00000
40607  00267  00 00000 00000
40610  00270  75 30120 00255   NEW MATRIX CARD
40611  00271  11 40135 00255         READ TO ES
40612  00272  00 00000 00000
40613  00273  00 00000 00000
40614  00274  00 00000 00000
40615  00275  00 00000 00000
40616  00276  00 00000 00000
40617  00277  00 00000 00000
40620         37 70563 70567   BLOTTOS
40621         00 00100 00377         ES AND
40622         00 40000 40637            MD.
40623         56 00000 40623   STOP
40624         00 00000 00000
40625         00 00000 00000
40626         00 00000 00000
40627         00 00000 00000
```

ANALYSIS
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CONTINUOUS MATRIX MULTIPLIER USING SINGLE OR MULTI-PRECISION ARITHMETIC

This routine multiplies two matrices, take this product or its transpose times a third matrix, the resulting product or its transpose times a fourth, etc. All input and output data is by means of cards with five floating decimal numbers per card (see IC-004 for card format). The elements of any one of the matrices may be punched on cards with the elements of a row or a column in consecutive order with or without each row or column starting at the beginning of a new card.* The input assumes all matrices are punched on the cards by columns in packed form (i.e., no spaces are left on the cards between the last element of one column and the first element of the next). However, the routine will handle matrices punched by rows and/or in unpacked form. Flags punched as numbers on cards are used to indicate the form of the matrices on the cards. Flags are also used to indicate the use of single or multi-precision arithmetic, the use of the transpose of any of the products, and the continuation of the multiplication. Three parameters are necessary to furnish the routine with the size of the matrices. The flags are denoted by the symbols P_0 to P_6 and the parameters by m, n, and s.

* The stop read indicator (a 12-punch in column 1) must be on the last card for each matrix.

The flags and parameters are punched as the mantissas on the parameter cards and are read into the memory as fixed point integers (see I C - 011). Two parameters, m and n, and three flags, P_0, P_1, and P_2, are on the first of two parameter cards while s and P_3 to P_6 are on the second card. The parameters and flags are defined as follows and appear on the cards in this order:

FIRST CARD

m number of rows of the first matrix

n number of columns of the first matrix (also, number of rows of the second)

P_0 =0 for single-precision arithmetic

≠0 for multi-precision arithmetic

P_1 =0 for first matrix punched packed

≠0 for first matrix punched unpacked

P_2 =0 for first matrix punched by columns

≠0 for first matrix punched by rows

SECOND CARD

s number of columns of the second matrix

P_3 =0 for second matrix punched packed

≠0 for second matrix punched unpacked

P_4 =0 for second matrix punched by columns

≠0 for second matrix punched by rows

P_5 =0 for product to be used

≠0 for transpose of product to be used

P_6 =0 for no further multiplication

≠0 for continued multiplication

Examination of this card format reveals that before any multiplication both parameter cards must be used while only the second card is necessary before each matrix in a continued product.

To illustrate the use of the parameters and flags, suppose the product, ABC, of three matrices is wanted using single-precision arithmetic where the matrices have the following properties:

A: m by n, punched packed by rows

B: n by s, punched unpacked by columns

C: s by t, punched unpacked by rows

The multiplication proceeds from the left so AB is the first product formed then this product multiplies C. The first input cards contains as mantissas m,n,0,0, and non-zero. The second input card contains as mantissas s, non-zero, 0, 0, and non-zero. The cards for A and B are the next input cards then one parameter card followed by the cards for C. The input card before C contains as mantissas t, non-zero, non-zero, 0 and 0. No blank cards appear in the input. The last card of each matrix contains a 12-punch in column one to indicate the end of that matrix.

Output of the intermediate products and the final product is controlled by the MJ and MS switches. The intermediate output is preceded by the only MS-2 and followed by the only MS-3. Setting (PAK) = 00176 at MS-3 and starting will give additional intermediate output if the desired MJ switches are set. The final output is preceded by the only MS-1 and followed by MS-0. Starting at MS-0 will give additional final output if the desired MJ switches are set. If no MJ switches are set when the final product is formed, the typewriter prints "SET MJ-S FOR OUTPUT" before stopping at MS-0.

Setting the MJ's and starting will give the final output. All output is by columns with the column and row indices of the first element on each card indicated as the card number (see IC-004). The form of the output as controlled by the MJ switches is as follows:

MJ's	Output for $P_5=0$	Output for $P_5\neq0$
none	none	none
1	product packed	transpose packed
2	product unpacked	transpose unpacked
1 and 3	transpose packed	product packed
2 and 3	transpose unpacked	product unpacked
1 and 2	same as 1	same as 1
1, 2, and 3	same as 1 and 3	same as 1 and 3
3	none	none

This routine, the working storage, the matrix storage, and the service routines use the entire ES and most of MD storage. The storage is allotted as follows:

00000 - 00070	temporaries
00071 - 00147	constants
00150 - 00457	program
00460 - 01777	working storage
40000 - 41377	program
41400 - 41477	available
41500 - 54637	first matrix
54640 - 67777	second matrix and product
70000 - 77777	service routines, IC - 004, and IC - 011.

Tests in the routine will give an alarm exit if the size of a matrix is too large for the storage space provided. The following

restrictions are imposed on the size of the matrices:

1. No dimension greater than decimal 120.
2. The number of elements in any matrix not greater than 2860 (this includes the zeros in an unpacked form.)

Thus, the largest square matrix that can be handled is a 53 by 53 packed or a 52 by 52 unpacked since an unpacked form would be handled on cards as a 52 by 55 containing 2860 elements including the zeros. (Note: even though the matrix is unpacked and the storage limitations require consideration of this, the input dimensions on the parameter cards are the packed dimensions.)

A check sum, equal to 012345670123, is printed at the beginning of the program after reading the paper tape. This represents the sum of this routine, IC-004, and IC-011, all of which are loaded by paper tape. A programmed Blotto is included in the code. Setting (PAK) =41,370 and starting gives a Blotto of 00000-00457 and 40000-41377 which includes the temporaries, constants, and program in E.S. and entire program on MD.

The program starts with (PAK) =40,000. Several continuous multiplications may be done by resetting (PAK) =40,000 at MS-0. However, a blank card must be placed between the cards for the separate continuous multiplications unless the reading hopper is loaded when PAK is reset. The check sum obtained when PAK is reset is not the same as that obtained after reading the paper tape.

PX 71900-10-(182)

CONTINUOUS MATRIX MULTIPLIER

```
40000          45 00000 40001
40001          31 40000 00000   CHECK
40002          75 21377 41374       SUM
40003          32 40001 00000       PROGRAM.
40004          11 20000 10000
40005          17 00000 72433   PRIME BULL.
40006          75 30370 00150   PROGRAM
40007          11 40010 00070       TO ES.
40010  00070   00 00000 00000
40011  00071   00 00000 00110   DEC. 72.
40012  00072   40 00000 00000   SIGN MASK.
40013  00073   00 00000 00003
40014  00074   00 00000 00001
40015  00075   77 77777 70000   MANTISSA AND EXPONENT MASK.
40016  00076   77 77777 77777   NEGATIVE ZERO.
40017  00077   00 00000 00152   DEC. 106.
40020  00100   00 00000 00045   DEC. 37.
40021  00101   00 00000 00042   DEC. 34.
40022  00102   00 00000 04000   DEC. 2048.
40023  00103   77 77777 74000   DEC.-2047.
40024  00104   00 00000 00072   DEC. 58.
40025  00105   00 00000 00021   DEC. 17.
40026  00106   00 07777 00000   4-DIGIT U-EXTRACTOR.
40027  00107   00 41500 41500   START OF A.
40030  00110   00 54640 54640   START OF B.
40031  00111   00 00460 00460   START OF
40032  00112   00 01040 01040       ES WORKING
40033  00113   00 01420 01420       STORAGES.
40034  00114   00 00002 00000
40035  00115   00 00000 77777   V-EXTRACTOR.
40036  00116   00 00000 00002
40037  00117   47 45242 00145   FLEX CODE
```

CONTINUOUS MATRIX MULTIPLIER

```
40040  00120  07 32562 40404        FOR--
40041  00121  03 12040 33426        SET MJ-S
40042  00122  15 34010 45701        FOR OUTPUT.
40043  00123  00 00000 00013   DEC. 11.
40044  00124  00 00000 00007
40045  00125  00 00000 00005
40046  00126  00 00000 00004
40047  00127  61 00000 00130   ZERO PRINT ORDER.
40050  00130  00 00000 00037   FLEX
40051  00131  00 00000 00052
40052  00132  00 00000 00074        CODES
40053  00133  00 00000 00070
40054  00134  00 00000 00064        FOR
40055  00135  00 00000 00062
40056  00136  00 00000 00066        0-7.
40057  00137  00 00000 00072
40060  00140  00 00000 00171   DEC. 121.
40061  00141  00 00000 05455   DEC. 2861.
40062  00142  00 00300 00300   START OF ES STORAGE
40063  00143  00 00000 00442   DEC. 290.
40064  00144  00 00000 00043   DEC. 35.
40065  00145  00 00000 00044   DEC. 36.
40066  00146  00 00000 00235   DEC. 157.
40067  00147  00 00000 00000
40070  00150  11 00123 00001   PRINT OF
40071  00151  61 00000 00100
40072  00152  55 10000 00003        CHECK
40073  00153  51 00124 20000
40074  00154  35 00127 00155        SUM.
40075  00155  30 00000 00000
40076  00156  41 00001 00152
40077  00157  37 72400 72401   READ
```

CONTINUOUS MATRIX MULTIPLIER

```
40100  00160  04 00021 00012        PARAMETER CARDS.
40101  00161  11 00023 00060   STORE
40102  00162  11 00026 00023        PARAMETERS
40103  00163  11 00032 00026        CONSECUTIVELY.
40104  00164  11 00021 20000
40105  00165  42 00140 00167   TEST
40106  00166  37 76000 76001
40107  00167  11 00022 20000        SIZE
40110  00170  42 00140 00172
40111  00171  37 76000 76001        OF
40112  00172  11 00023 20000
40113  00173  42 00140 00175        PARAMETERS.
40114  00174  37 76000 76001
40115  00175  75 30003 00177   DOUBLE
40116  00176  11 00021 00032
40117  00177  75 30003 00201        PARAMETERS.
40120  00200  21 00032 00021
40121  00201  75 30003 00203   SCALE
40122  00202  11 00021 00035
40123  00203  75 20003 00205        PARAMETERS.
40124  00204  55 00035 00020
40125  00205  75 30003 00207   DECREASE
40126  00206  11 00021 00041
40127  00207  75 20003 00211        PARAMETERS BY 1.
40130  00210  23 00041 00074
40131  00211  75 30003 00213   SCALE
40132  00212  11 00021 00052
40133  00213  75 20003 00215        PARAMETERS.
40134  00214  55 00052 00017
40135  00215  75 30003 00217   FIND
40136  00216  11 00021 00044
40137  00217  11 00021 20000        FIRST
```

CONTINUOUS MATRIX MULTIPLIER

```
40140  00220  73 00125 10000
40141  00221  47 00222 00224        MUTIPLE
40142  00222  71 10000 00125
40143  00223  35 00125 00044        OF 5
40144  00224  11 00022 20000
40145  00225  73 00125 10000        GREATER
40146  00226  47 00227 00231
40147  00227  71 10000 00125        THEN
40150  00230  35 00125 00045
40151  00231  11 00023 20000        OR EQUAL
40152  00232  73 00125 10000
40153  00233  47 00234 00236        TO
40154  00234  71 10000 00125
40155  00235  35 00125 00046        PARAMETERS.
40156  00236  75 30003 00240
40157  00237  11 00044 00047   DOUBLE
40160  00240  75 30003 00242
40161  00241  21 00047 00044        MULTIPLES.
40162  00242  75 30003 00244
40163  00243  11 00044 00055   SCALE
40164  00244  75 20003 00246
40165  00245  55 00055 00017        MULTIPLES.
40166  00246  71 00021 00045
40167  00247  42 00141 00251
40170  00250  37 76000 76001   TEST
40171  00251  71 00045 00023
40172  00252  42 00141 00254        SIZES
40173  00253  37 76000 76001
40174  00254  71 00044 00023        OF
40175  00255  42 00141 00257
40176  00256  37 76000 76001        MATRICES.
40177  00257  71 00046 00021
```

CONTINUOUS MATRIX MULTIPLIER

```
40200  00260  42 00141 00262
40201  00261  37 76000 76001
40202  00262  11 00070 20000   TEST FOR
40203  00263  47 00305 00264       READ OF A.
40204  00264  11 00025 20000   TEST FOR
40205  00265  47 00266 00276       CHANGE IN FORM OF A.
40206  00266  37 72400 72401   READ A
40207  00267  00 41500 05544       ONTO MD.
40210  00270  11 00024 20000   TEST FOR
40211  00271  47 00272 00305       UNPACKING A.
40212  00272  11 00041 00001
40213  00273  11 00107 00002
40214  00274  37 00351 00352   PACK A.
40215  00275  45 00000 00305
40216  00276  11 00021 00004   CHANGE
40217  00277  11 00035 00002
40220  00300  11 00107 00003       A AND
40221  00301  11 00024 20000
40222  00302  47 00303 00304       STORE
40223  00303  11 00044 00004
40224  00304  37 40400 40402       ON MD.
40225  00305  11 00030 20000   TEST FOR
40226  00306  47 00317 00307       CHANGE IN FORM OF B.
40227  00307  37 72400 72401   READ B
40230  00310  00 54640 05544       ONTO MD.
40231  00311  11 00027 20000   TEST FOR
40232  00312  47 00313 00326       UNPACKING B.
40233  00313  11 00043 00001
40234  00314  11 00110 00002
40235  00315  37 00351 00352   PACK B.
40236  00316  45 00000 00326
40237  00317  11 00023 00004   CHANGE
```

CONTINUOUS MATRIX MULTIPLIER

```
40240  00320  11 00037 00002      B AND
40241  00321  11 00110 00003
40242  00322  11 00027 20000      STORE
40243  00323  47 00324 00325
40244  00324  11 00046 00004      ON MD.
40245  00325  37 40400 40402
40246  00326  45 00000 00327
40247  00327  11 00036 00040  TEST FOR
40250  00330  11 00022 20000
40251  00331  42 00021 00333      SPACING OF B.
40252  00332  45 00000 00341
40253  00333  11 00110 00001  SPACE
40254  00334  11 00033 00002
40255  00335  11 00032 00003      COLUMNS
40256  00336  11 00023 00004
40257  00337  37 00371 00372      OF B.
40260  00340  11 00035 00040
40261  00341  75 30060 00343  MULTIPLIER
40262  00342  11 40540 00150      TO ES.
40263  00343  11 00060 20000  TEST FOR
40264  00344  47 00347 00345      ARITHMETIC.
40265  00345  75 30100 00150  SINGLE PRECISION
40266  00346  11 40620 00230      TO ES.
40267  00347  75 30150 00150  MULTI-PRECISION
40270  00350  11 40720 00230      TO ES.
40271  00351  45 00000 30000  EXIT-PACKING SUBROUTINE.
40272  00352  11 00106 10000
40273  00353  53 00036 00363  SET
40274  00354  53 00036 00365
40275  00355  23 00001 00074      INITIAL
40276  00356  15 00002 00364
40277  00357  16 00002 00366      CONDITIONS.
```

CONTINUOUS MATRIX MULTIPLIER

```
40300  00360  31 00056 00001   ADVANCE
40301  00361  35 00364 00364        ADDRESSES.
40302  00362  21 00366 00033
40303  00363  75 30000 00365   UNPACKED
40304  00364  11 30000 01420        ROW TO ES.
40305  00365  75 30000 00367   PACKED
40306  00366  11 01420 30000        ROW TO MD.
40307  00367  41 00001 00360
40310  00370  45 00000 00351
40311  00371  45 00000 30000   EXIT-UNPACKING SUBROUTINE.
40312  00372  11 00002 20000
40313  00373  43 00003 00375   TEST
40314  00374  45 00000 00403
40315  00375  13 00076 00005        FOR
40316  00376  13 00076 00006
40317  00377  15 00001 00005        NEEDED
40320  00400  16 00001 00006
40321  00401  54 00006 00017        UNPACKING.
40322  00402  43 00005 00371
40323  00403  11 00003 00005
40324  00404  55 00005 00017   SET
40325  00405  55 00002 00017
40326  00406  21 00004 00074        LOCATIONS
40327  00407  15 00001 00431
40330  00410  16 00001 00433        OF LAST
40331  00411  71 00002 00004
40332  00412  35 00431 00431        COLUMN
40333  00413  71 00003 00004
40334  00414  35 00433 00433        OR ROW.
40335  00415  11 00106 10000
40336  00416  53 00002 00430   SET
40337  00417  53 00005 00432
```

CONTINUOUS MATRIX MULTIPLIER

```
40340  00420  23 00005 00002        NUMBER
40341  00421  53 20000 00426
40342  00422  11 00002 20000        OF ELEMENTS IN
40343  00423  52 00113 20000
40344  00424  55 20000 00025        ROW OR COLUMN.
40345  00425  16 20000 00427
40346  00426  75 10000 00430   SET EXTRA
40347  00427  13 00076 30000        ELEMENTS TO ZERO.
40350  00430  75 30000 00432   PACKED ROW OR
40351  00431  11 30000 01420        COLUMN TO ES.
40352  00432  75 30000 00434   UNPACKED ROW OR
40353  00433  11 01420 30000        COLUMN TO MD.
40354  00434  23 00431 00002   RETARD
40355  00435  23 00433 00003        ADDRESSES.
40356  00436  41 00004 00430
40357  00437  45 00000 00371
40360  00440  00 00000 00000
40361  00441  00 00000 00000
40362  00442  00 00000 00000
40363  00443  00 00000 00000
40364  00444  00 00000 00000
40365  00445  00 00000 00000
40366  00446  00 00000 00000
40367  00447  00 00000 00000
40370  00450  00 00000 00000
40371  00451  00 00000 00000
40372  00452  00 00000 00000
40373  00453  00 00000 00000
40374  00454  00 00000 00000
40375  00455  00 00000 00000
40376  00456  00 00000 00000
40377  00457  00 00000 00000
```

CONTINUOUS MATRIX MULTIPLIER

```
40400  00150  75 30160 30000  EXIT-CHANGE FORM SUBROUTINE.
40401  00151  11 40220 00300  RELOAD ES.
40402  00152  75 30140 00154  LOAD
40403  00153  11 40400 00150      ES.
40404  00154  13 00076 00011
40405  00155  11 00143 20000  FIND
40406  00156  73 00004 00005
40407  00157  71 00004 00005      NUMBER
40410  00160  11 20000 00020
40411  00161  73 00125 00016      OF COLUMNS
40412  00162  11 20000 00015
40413  00163  11 00132 00017      OR ROWS
40414  00164  55 00004 00020
40415  00165  11 00022 20000      PER READ.
40416  00166  73 00005 10000
40417  00167  11 20000 00006
40420  00170  47 00172 00171
40421  00171  11 00005 00006  PRESET
40422  00172  31 00005 00020
40423  00173  11 00106 10000      INDICES
40424  00174  53 20000 00233
40425  00175  11 00115 10000      AND
40426  00176  53 00020 00205
40427  00177  13 00076 00001      TRANSFERS.
40430  00200  11 00015 20000  TEST FOR
40431  00201  47 00202 00204      CARD READ TYPE.
40432  00202  37 00242 00243  READ
40433  00203  45 00000 00206      PRESET
40434  00204  37 72400 72401      NUMBER
40435  00205  00 00300 00000      OF CARDS.
40436  00206  16 00003 00234  PRESET
40437  00207  21 00234 00011      ADDRESSES
```

CONTINUOUS MATRIX MULTIPLIER

```
40440  00210  31 00005 00001        AND
40441  00211  35 00011 00011        INDICES.
40442  00212  11 00001 20000   TEST FOR
40443  00213  47 00214 00220        END OF MATRIX.
40444  00214  11 00106 10000   SET FOR
40445  00215  31 00006 00020        LAST
40446  00216  53 20000 00233        CARD
40447  00217  11 00006 00005        READ.
40450  00220  13 00076 00010   SET COUNTER.
40451  00221  15 00142 00227   PRESET
40452  00222  21 00227 00010        ADDRESSES
40453  00223  16 00113 00227        AND
40454  00224  11 00005 20000        INDICES.
40455  00225  36 00074 00007
40456  00226  75 30002 00230   PUT ROW OR
40457  00227  11 30000 30000        COLUMN
40460  00230  21 00227 00116        ELEMENTS
40461  00231  35 00004 00227        IN ORDER.
40462  00232  41 00007 00226
40463  00233  75 30000 00235   STORE
40464  00234  11 01420 30000        ROW OR
40465  00235  21 00234 00033        COLUMN
40466  00236  21 00010 00114        ON MD.
40467  00237  42 00002 00221
40470  00240  11 00001 20000   TEST FOR
40471  00241  47 00150 00200        LAST CARD READ
40472  00242  45 00000 30000
40473  00243  11 00017 20000   TEST FOR
40474  00244  73 00125 10000        NEED OF
40475  00245  15 00142 00273        ENTIRE
40476  00246  47 00247 00267        LAST CARD.
40477  00247  11 20000 00014
```

CONTINUOUS MATRIX MULTIPLIER

```
40500  00250  54 20000 00020   PRESET
40501  00251  11 00106 10000
40502  00252  53 20000 00260       ADDRESSES.
40503  00253  15 00142 00261
40504  00254  31 00020 00020       TRANSFERS.
40505  00255  35 00261 00261
40506  00256  31 00014 00020       AND INDICES
40507  00257  35 00273 00273
40510  00260  75 30000 00262   PLACE ELEMENTS
40511  00261  11 30000 00300       FROM PREVIOUS READ.
40512  00262  11 00014 20000   TEST FOR NUMBER
40513  00263  42 00015 00267       OF CARDS TO READ.
40514  00264  71 00125 00016   PRESET NUMBER
40515  00265  16 20000 00273       OF NUMBERS.
40516  00266  45 00000 00272
40517  00267  71 00125 00016   PRESET NUMBER
40520  00270  35 00125 20000       OF NUMBERS.
40521  00271  16 20000 00273
40522  00272  37 72400 72401   READ
40523  00273  00 30000 00000       CARDS.
40524  00274  23 00017 00015   PREPARE FOR NEW READ.
40525  00275  45 00000 00242
40526  00276  00 00000 00000
40527  00277  00 00000 00000
40530  00300  00 00000 00000
40531  00301  00 00000 00000
40532  00302  00 00000 00000
40533  00303  00 00000 00000
40534  00304  00 00000 00000
40535  00305  00 00000 00000
40536  00306  00 00000 00000
40537  00307  00 00000 00000
```

CONTINUOUS MATRIX MULTIPLIER

```
40540  00150  45 00000 00151
40541  00151  11 00106 10000   PRESET
40542  00152  53 00035 00211       REPEATS,
40543  00153  53 00036 00160       ADDRESSES,
40544  00154  53 00036 00165       AND
40545  00155  15 00110 00161       INDICES.
40546  00156  16 00110 00212
40547  00157  11 00043 00061
40550  00160  75 30000 00162   ONE COLUMN
40551  00161  11 30000 01040       OF B TO ES.
40552  00162  15 00107 00166   PRESET
40553  00163  16 00113 00205       ADDRESSES
40554  00164  11 00041 00001       AND INDICES.
40555  00165  75 30000 00167   ONE ROW OF
40556  00166  11 30000 00460       A TO ES.
40557  00167  15 00111 00175   PRESET
40560  00170  15 00112 00177       ADDRESSES
40561  00171  11 00042 00002       AND INDICES.
40562  00172  13 00076 00015   ZERO
40563  00173  13 00076 00016       TO RESULT.
40564  00174  75 30002 00176   COMPUTE
40565  00175  11 30000 00011       ONE ELEMENT
40566  00176  75 30002 00200       OF A COLUMN
40567  00177  11 30000 00013       OF C.
40570  00200  37 00231 00232
40571  00201  21 00175 00114   ADVANCE
40572  00202  21 00177 00114       ADDRESSES.
40573  00203  41 00002 00174
40574  00204  75 30002 00206   STORE COMPUTED
40575  00205  11 00015 30000       ELEMENT.
40576  00206  21 00166 00036   ADVANCE
40577  00207  21 00205 00116       ADDRESSES.
```

CONTINUOUS MATRIX MULTIPLIER

```
40600  00210  41 00001 00165
40601  00211  75 30000 00213   ONE COLUMN
40602  00212  11 01420 30000       OF C TO MD.
40603  00213  21 00212 00032   ADVANCE
40604  00214  21 00161 00040       ADDRESSES.
40605  00215  41 00061 00160
40606  00216  75 30310 00150   OUTPUT
40607  00217  11 41070 00150       PROGRAM TO ES.
40610  00220  00 00000 00000
40611  00221  00 00000 00000
40612  00222  00 00000 00000
40613  00223  00 00000 00000
40614  00224  00 00000 00000
40615  00225  00 00000 00000
40616  00226  00 00000 00000
40617  00227  00 00000 00000
40620  00230  37 76000 76002   SINGLE PRECISION
40621  00231  45 00000 30000       ARITHMETIC—SEE ZM-527.
40622  00232  16 00146 00320   SET FOR ACCUMULATE MULTIPLY.
40623  00233  75 30002 00265   STORE
40624  00234  11 00015 00017       SUM.
40625  00235  11 00012 00016   ADD ENTRANCE.
40626  00236  23 10000 10000   CLEAR A AND B.
40627  00237  16 10000 00257   ERASE SHIFT.
40630  00240  43 00013 00257   Y ZERO TEST.
40631  00241  43 00011 00255   X ZERO TEST.
40632  00242  23 00012 00014   EXPONENT DIFFERENCE.
40633  00243  12 20000 20000
40634  00244  42 00145 00247   36 COMPARSION.
40635  00245  41 00012 00257   Y. OR X.
40636  00246  45 00000 00255
40637  00247  16 20000 00257   SET SHIFT.
```

CONTINUOUS MATRIX MULTIPLIER

```
40640  00250  41 00012 00253   Y OR X.
40641  00251  11 00011 10000   X TO Q.
40642  00252  45 00000 00256
40643  00253  11 00013 10000   Y TO Q.
40644  00254  75 00001 00257
40645  00255  11 00014 00016   Y EXPONENT.
40646  00256  11 00013 00011   Y TO X.
40647  00257  54 00011 30000   SHIFT X.
40650  00260  35 10000 00015
40651  00261  45 00000 00272   TO NORMALIZE.
40652  00262  23 00016 00145   A LEFT
40653  00263  54 00015 00044       NOT SIGNIFICANT.
40654  00264  47 00273 00313   ZERO TEST.
40655  00265  11 00014 20000   MULTIPLY ENTRANCE.
40656  00266  35 00012 20000   ADD EXPONENTS.
40657  00267  36 00144 00016
40660  00270  71 00013 00011   FORM PRODUCT.
40661  00271  11 20000 00015   TEST
40662  00272  43 20000 00262       EXTENTION.
40663  00273  13 00076 00005   CLEAR FOR SF.
40664  00274  11 00074 10000   POSITIVE FLAG.
40665  00275  46 00276 00277   SIGN TEST.
40666  00276  13 10000 10000   NEGATIVE FLAG.
40667  00277  11 10000 00006   FOR ROUNDING.
40670  00300  74 20000 00005   SCALE FACTOR.
40671  00301  11 20000 00015
40672  00302  46 00303 00304   ADJUST
40673  00303  13 10000 10000       FOR SIGN.
40674  00304  21 00016 00005   ADJUST FOR SF.
40675  00305  44 00306 00313
40676  00306  21 00015 00006   ROUND.
40677  00307  43 20000 00313   OVERFLOW TEST.
```

CONTINUOUS MATRIX MULTIPLIER

```
40700  00310  32 00147 00107   ADJUST
40701  00311  11 20000 00015       FOR
40702  00312  21 00016 00074       OVERFLOW.
40703  00313  11 00015 20000   ZERO
40704  00314  47 00316 00315       TEST.
40705  00315  11 20000 00016   ERASE EXPONENT.
40706  00316  75 30004 00320   SET FOR
40707  00317  11 00015 00011       ADD.
40710  00320  37 00320 00321   TO ADD OR EXIT.
40711  00321  45 00000 00231
40712  00322  00 00000 00000
40713  00323  00 00000 00000
40714  00324  00 00000 00000
40715  00325  00 00000 00000
40716  00326  00 00000 00000
40717  00327  00 00000 00000
40720  00230  37 76000 76002   MULTI-PRECISION
40721  00231  45 00000 30000       ARITHMETIC--SEE CA-006.
40722  00232  75 30002 00246   STORE
40723  00233  11 00015 00017       SUM.
40724  00234  75 10002 00301   ZERO TO
40725  00235  13 00076 00015       MULTIPLY RESULT.
40726  00236  42 00102 00240   TEST EXPONENT.
40727  00237  45 00000 00230   ALARM.
40730  00240  42 00103 00234   TEST EXPONENT.
40731  00241  13 00075 10000   STORE
40732  00242  53 20000 00016       EXPONENT.
40733  00243  11 00072 10000   STORE
40734  00244  53 00015 00016       SIGN.
40735  00245  45 00000 30000   TO ADD OR EXIT.
40736  00246  71 00012 00013   MULTIPLY ENTRANCE.
40737  00247  72 00011 00014   FORM
```

CONTINUOUS MATRIX MULTIPLIER

```
40740  00250  54 20000 00044        LOW
40741  00251  11 20000 20000        ORDER
40742  00252  54 20000 00001        PRODUCT.
40743  00253  72 00011 00013   ADD HIGHER ORDER.
40744  00254  37 00300 00271   NORMALIZE.
40745  00255  23 00005 00074
40746  00256  31 00012 00030   STORE
40747  00257  11 20000 00003
40750  00260  54 00003 00060        EXPONENTS.
40751  00261  31 00014 00030
40752  00262  11 20000 00010
40753  00263  54 00010 00060
40754  00264  37 00264 00265
40755  00265  21 00005 00003   CORRECT
40756  00266  35 00010 20000        EXPONENT.
40757  00267  37 00245 00236   TEST, STORE EXP, SIGN.
40760  00270  45 00000 00301   TO ADD.
40761  00271  47 00272 00234   ZERO TEST.
40762  00272  13 00076 00005   STORE ZERO.
40763  00273  74 20000 00005   NORMALIZE
40764  00274  11 20000 00015        AND
40765  00275  54 20000 00043        STORE
40766  00276  11 20000 00016        RESULT.
40767  00277  23 00005 00101
40770  00300  45 00000 30000
40771  00301  75 30004 00303   ADD EXTRANCE.
40772  00302  11 00015 00011
40773  00303  11 00013 20000
40774  00304  47 00305 00231   ZERO TEST.
40775  00305  11 00011 20000
40776  00306  47 00311 00307   ZERO TEST.
40777  00307  75 30002 00231   ZERO TO
```

CONTINUOUS MATRIX MULTIPLIER

```
41000  00310  11 00013 00015       RESULT.
41001  00311  37 00264 00256   STORE EXPONENTS.
41002  00312  11 00003 20000   SUBTRACT
41003  00313  36 00010 20000       EXPONENTS.
41004  00314  46 00315 00322   NEGATIVE TEST.
41005  00315  11 00013 00005
41006  00316  11 00014 00006   STORE
41007  00317  11 00010 00003
41010  00320  75 30002 00326       LARGER NUMBER.
41011  00321  11 00011 00007
41012  00322  11 00011 00005   STORE
41013  00323  11 00012 00006
41014  00324  11 00013 00007       LARGER NUMBER.
41015  00325  11 00014 00010
41016  00326  12 20000 20000   STORE
41017  00327  13 20000 00015       EXPONENT DIFFERENCE.
41020  00330  42 00101 00341   34 COMPARISON.
41021  00331  42 00104 00334   58 COMPARISON.
41022  00332  75 30002 00231   LARGER
41023  00333  11 00005 00015       TO RESULT.
41024  00334  21 00015 00077
41025  00335  16 20000 00347   SET
41026  00336  13 00076 00004
41027  00337  11 00007 00010       SHIFT.
41030  00340  45 00000 00347
41031  00341  21 00015 00101   SET
41032  00342  16 20000 00344
41033  00343  11 00074 00004       SHIFT.
41034  00344  55 00004 30000   SHIFT CORRECTION.
41035  00345  35 00100 20000   SET
41036  00346  16 20000 00347       SHIFT.
41037  00347  54 00010 30000   SHIFT MANTISSA.
```

CONTINUOUS MATRIX MULTIPLIER

```
41040  00350  54 00006 00107
41041  00351  54 00005 20042   SHIFT
41042  00352  35 00006 20000       MANTISSA
41043  00353  72 00004 00007       AND
41044  00354  35 00010 20000       ADD.
41045  00355  47 00360 00356
41046  00356  75 10002 00231   ZERO TO
41047  00357  13 00076 00015       RESULT.
41050  00360  37 00300 00272   NORMALIZE.
41051  00361  42 00073 00364   EXPONENT
41052  00362  42 00105 00356       TESTS.
41053  00363  36 00071 20000   CORRECT
41054  00364  35 00003 00003       EXPONENT.
41055  00365  42 00102 00367   EXPONENT TEST.
41056  00366  45 00000 00230
41057  00367  42 00103 00356   EXPONENT TEST.
41060  00370  37 00245 00241   STORE EXPONENT, SIGN.
41061  00371  45 00000 00231
41062  00372  00 00000 00000
41063  00373  00 00000 00000
41064  00374  00 00000 00000
41065  00375  00 00000 00000
41066  00376  00 00000 00000
41067  00377  00 00000 00000
41070  00150  45 00000 00151
41071  00151  11 00026 20000   TEST
41072  00152  47 00175 00153       CONTINUOUS FLAG.
41073  00153  56 10000 00154
41074  00154  45 10000 00173   TEST
41075  00155  45 20000 00173       MJ SWITCHES.
41076  00156  11 00073 00001
41077  00157  11 00071 20000   TYPES—
```

CONTINUOUS MATRIX MULTIPLIER

```
41100  00160  32 00124 00017
41101  00161  15 20000 00162        SET
41102  00162  11 30000 10000
41103  00163  11 00125 00002        MJ-S
41104  00164  61 00000 10000
41105  00165  55 10000 00006        FOR
41106  00166  41 00002 00164
41107  00167  31 00074 00017        OUTPUT.
41110  00170  35 00162 00162
41111  00171  41 00001 00162
41112  00172  56 00000 00154
41113  00173  37 00220 00221   OUTPUT.
41114  00174  56 00000 00154
41115  00175  56 20000 00176
41116  00176  45 10000 00201   TEST
41117  00177  45 20000 00201        MJ SWITCHES.
41120  00200  45 00000 00202
41121  00201  37 00220 00221   OUTPUT.
41122  00202  56 30000 00203
41123  00203  11 00031 20000   TEST FOR
41124  00204  47 00210 00205        TRANSPOSE
41125  00205  37 00272 00273        AND SEND
41126  00206  11 00023 00022        TO POSITION.
41127  00207  45 00000 00213
41130  00210  37 00316 00317   PRODUCT
41131  00211  11 00021 00022        TO POSITION.
41132  00212  11 00023 00021
41133  00213  11 00115 00070
41134  00214  37 72400 72401   READ NEW
41135  00215  04 00026 00005        PARAMETER CARD.
41136  00216  75 30310 00162   LOAD
41137  00217  11 40070 00150        ES.
```

CONTINUOUS MATRIX MULTIPLIER

```
41140  00220  45 00000 30000   EXIT-OUTPUT SUBROUTINE.
41141  00221  11 00031 20000   TEST FOR
41142  00222  47 00263 00223       TRANSPOSE.
41143  00223  45 10000 00245   TEST
41144  00224  45 20000 00226       MJ SWITCHES.
41145  00225  45 00000 00220
41146  00226  45 30000 00236
41147  00227  37 00335 00336   FORM PRODUCT UNPACKED.
41150  00230  15 00054 00234   SET
41151  00231  16 00044 00234       PARAMETERS.
41152  00232  37 70440 70443   PUNCH.
41153  00233  00 41500 00000
41154  00234  00 00000 00000
41155  00235  45 00000 00220
41156  00236  37 00345 00346   FORM TRANSPOSE UNPACKED.
41157  00237  15 00052 00243   SET
41160  00240  16 00046 00243       PARAMETERS.
41161  00241  37 70440 70443   PUNCH.
41162  00242  00 41500 00000
41163  00243  00 00000 00000
41164  00244  45 00000 00220
41165  00245  45 30000 00254
41166  00246  15 00054 00252   SET
41167  00247  16 00021 00252       PARAMETERS.
41170  00250  37 70440 70443   PUNCH PRODUCT PACKED.
41171  00251  00 54640 00000
41172  00252  00 00000 00000
41173  00253  45 00000 00220
41174  00254  37 00272 00273   FORM TRANSPOSE PACKED.
41175  00255  15 00052 00261   SET
41176  00256  16 00023 00261       PARAMETERS.
41177  00257  37 70440 70443   PUNCH.
```

CONTINUOUS MATRIX MULTIPLIER

```
41200  00260  00 41500 00000
41201  00261  00 00000 00000
41202  00262  45 00000 00220
41203  00263  45 10000 00270   TEST
41204  00264  45 20000 00266       MJ SWITCHES.
41205  00265  45 00000 00220
41206  00266  45 30000 00227   PUNCH PRODUCT UNPACKED.
41207  00267  45 00000 00236   PUNCH TRANSPOSE UNPACKED.
41210  00270  45 30000 00246   PUNCH PRODUCT PACKED.
41211  00271  45 00000 00254   PUNCH TRANSPOSE PACKED.
41212  00272  45 00000 30000   EXIT-FORM TRANSPOSE SUBROUTINE.
41213  00273  11 00106 10000   PRESET
41214  00274  53 00037 00310
41215  00275  13 00076 00002       INDICES
41216  00276  16 00107 00311
41217  00277  15 00110 00304       AND
41220  00300  21 00304 00002
41221  00301  11 00043 00001       ADDRESSES.
41222  00302  16 00113 00304
41223  00303  75 30002 00305   ONE ELEMENT
41224  00304  11 30000 30000       OF PRODUCT TO ES.
41225  00305  21 00304 00116   ADVANCE
41226  00306  35 00035 00304       ADDRESSES.
41227  00307  41 00001 00303
41230  00310  75 30000 00312   ONE COLUMN
41231  00311  11 01420 30000       OF TRANSPOSE TO MD.
41232  00312  21 00311 00034   ADVANCE
41233  00313  21 00002 00114       ADDRESSES.
41234  00314  42 00035 00277
41235  00315  45 00000 00272
41236  00316  45 00000 30000   EXIT-STORE PRODUCT SUBROUTINE.
41237  00317  11 00106 10000   PRESET
```

CONTINUOUS MATRIX MULTIPLIER

```
41240  00320  53 00035 00325      REPEATS.
41241  00321  53 00035 00327      INDICES.
41242  00322  11 00043 00001      AND
41243  00323  15 00110 00326      ADDRESSES.
41244  00324  16 00107 00330
41245  00325  75 30000 00327  ONE COLUMN
41246  00326  11 30000 01420      TO ES.
41247  00327  75 30000 00331  ONE COLUMN
41250  00330  11 01420 30000      TO MD.
41251  00331  21 00326 00035  ADVANCE
41252  00332  21 00330 00032      ADDRESSES.
41253  00333  41 00001 00325
41254  00334  45 00000 00316
41255  00335  45 00000 30000  EXIT-UNPACKING PRODUCT SUBROUTINE.
41256  00336  15 00110 00001  PRESET
41257  00337  16 00107 00001      ADDRESSES
41260  00340  11 00032 00002      AND
41261  00341  11 00047 00003      INDICES.
41262  00342  11 00023 00004
41263  00343  37 00371 00372  UNPACK PRODUCT.
41264  00344  45 00000 00335
41265  00345  45 00000 30000  EXIT-UNPACKING TRANSPOSE SUBROUTINE.
41266  00346  37 00272 00273  STORE TRANSPOSE
41267  00347  11 00107 00001  PRESET
41270  00350  11 00034 00002      ADDRESSES
41271  00351  11 00051 00003      AND
41272  00352  11 00021 00004      INDICES.
41273  00353  37 00371 00372  UNPACK PRODUCT.
41274  00354  45 00000 00345
41275  00355  00 00000 00000
41276  00356  00 00000 00000
41277  00357  00 00000 00000
```

CONTINUOUS MATRIX MULTIPLIER

```
41300  00360  00 00000 00000
41301  00361  00 00000 00000
41302  00362  00 00000 00000
41303  00363  00 00000 00000
41304  00364  00 00000 00000
41305  00365  00 00000 00000
41306  00366  00 00000 00000
41307  00367  00 00000 00000
41310  00370  00 00000 00000
41311  00371  45 00000 30000   EXIT-UNPACKING SUBROUTINE.
41312  00372  11 00002 20000
41313  00373  43 00003 00375   TEST
41314  00374  45 00000 00403
41315  00375  13 00076 00005       FOR
41316  00376  13 00076 00006
41317  00377  15 00001 00005       NEEDED
41320  00400  16 00001 00006
41321  00401  54 00006 00017       UNPACKING.
41322  00402  43 00005 00371
41323  00403  11 00003 00005
41324  00404  55 00005 00017   SET
41325  00405  55 00002 00017
41326  00406  21 00004 00074       LOCATIONS
41327  00407  15 00001 00431
41330  00410  16 00001 00433       OF LAST
41331  00411  71 00002 00004
41332  00412  35 00431 00431       COLUMN
41333  00413  71 00003 00004
41334  00414  35 00433 00433       OR ROW.
41335  00415  11 00106 10000
41336  00416  53 00002 00430   SET
41337  00417  53 00005 00432
```

CONTINUOUS MATRIX MULTIPLIER

```
41340  00420  23 00005 00002        NUMBER
41341  00421  53 20000 00426
41342  00422  11 00002 20000        OF ELEMENTS IN
41343  00423  52 00113 20000
41344  00424  55 20000 00025        ROW OR COLUMN.
41345  00425  16 20000 00427
41346  00426  75 10000 00430   SET EXTRA
41347  00427  13 00076 30000        ELEMENTS TO ZERO.
41350  00430  75 30000 00432   PACKED ROW OR
41351  00431  11 30000 01420        COLUMN TO ES.
41352  00432  75 30000 00434   UNPACKED ROW OR
41353  00433  11 01420 30000        COLUMN TO MD.
41354  00434  23 00431 00002   RETARD
41355  00435  23 00433 00003        ADDRESSES.
41356  00436  41 00004 00430
41357  00437  45 00000 00371
41360  00440  00 00000 00000
41361  00441  00 00000 00000
41362  00442  00 00000 00000
41363  00443  00 00000 00000
41364  00444  00 00000 00000
41365  00445  00 00000 00000
41366  00446  00 00000 00000
41367  00447  27 64146 06130   FOR CONVENIENT CHECK SUM.
41370  00450  37 77763 77767   BLOTTOS
41371  00451  00 00000 00457        ES
41372  00452  00 40000 41377        AND
41373  00453  56 00000 41373        MD.
41374  00454  75 20550 41376   SUMS
41375  00455  32 70440 00000        IC-004
41376  00456  75 20352 40004        AND
41377  00457  32 72400 00000        IC-011.
```

CONTINUOUS MATRIX MULTIPLIER

SEE IC-004 FOR CODE OF 70440-71207.

SEE IC-011 FOR CODE OF 72400-72751 EXCEPT FOR THE FOLLOWING CHANGE WHICH STORES THE FLAG FOR THE STOP READ INDICATOR IN CELL 00001 AFTER ES HAS BEEN RESTORED.

72532 01074 11 01255 74001

DIVISION San Diego

MODEL ALL

REPORT ZM-527

DATE 8/29/56

TITLE

S P U R

Single precision unpacked rounded floating point package for ERA-1103 Computers

Part I Operation Specifications

PREPARED BY L Barton

GROUP Digital Computing Lab.

REFERENCE

CHECKED BY C. J. Swift
Donn Parker
Dick Bielsker

APPROVED BY

NO. OF PAGES 22

NO. OF DIAGRAMS 0

REVISIONS

NO.	DATE	BY	CHANGE	PAGES AFFECTED

GO 241A

PX 71900-10-(183)

SINGLE PRECISION UNPACKED ROUNDED FLOATING POINT PACKAGE

I Brief Specifications

Occupies

ES	00000, 00001
	01500 to 01777 inclusive
MD	76000 to 77777 some parts open
	74000 to 75777 (E. S. image)

Registers

P	01764, 01765
B	01766, 01767
C	01770, 01771
S	01772, 01773
R	01774, 01775
b_1	01776,
b_2	01777

Constants used and available

01750 00 00000 00000
01751 00 00000 00001
01752 00 00000 00002
01753 00 00002 00000
01754 00 00000 00043
01755 00 00000 00044
01756 00 00000 00177
01757 00 00000 01777

Activation

37 76000 76001 (stored package to E.S.)
17 00000 77413 (initially prime cards)

Two address commands

14 CC XXXX YYYY

Addition (CC)

00 Y + X to R

04 R + Y + X to R

20 Y + X to R, Y

24 R + Y + X to R, Y

Subtraction (CC)

01 Y - X to R

05 R + Y - X to R

21 Y - X to R, Y

25 R + Y - X to R,Y

Multiplication (CC)

02 Y · X to R

06 R + Y · X to R

22 Y · X to R, Y

26 R + Y · X to R, Y

Division (CC)

03 Y/X to R

07 R + Y/X to R

23 Y/X to R, Y

27 R + Y/X to R, Y

Threshold jump 17 If X is greater than R jump to Y; otherwise continue with the next instruction, In either case R original will be unchanged in R, S, and B. (CAUTION; due to rounding a jump may occur either way when X approaches R, if X and R were calculated by different operations)

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One address commands

14 CC K NN YYYYY (The rightmost bit of K is used with NN, the leftmost two bits of K are used as tags for the Y address. Refer to detailed command explanations for details.

Index jumps with modification of index counter registers b (1 or 2)

(CC)

76 with b 1

77 with b 2

Add 2 to the contents of b (1 or 2). If N is greater than one half of b (1 or 2) jump to Y a nd leave b (1 or 2) advanced. Otherwise set b (1 or 2) equal to zero and continue with the next instruction. The effect is to go through the loop N + 1 times with the test at the end of the loop or N times with the test at the entrance to the loop.

Polynomial (CC)

75 Compute the polynomial $A_0 + A_1X + A_2X^2 + \ldots + A_nX^n$;

Where:

X, as a floating point number, must be prestored in register P.

Y is the address of the last constant, A_n, where the constants are floating point numbers stored each in two cells-mantissa, exponent-consecutively,

$A_0, A_1, A_2, \ldots, A_n$.

N is the degree of the equation.

The answer appears in R.

If N is less than one no operation will be performed.

Card instructions (CC)

57 Read N cards into cells consecutively starting at Y.

56 Punch N cards from cells consecutively starting at Y.

More detailed instructions and options available are given in the detailed instructions. The contents of register C cannot be punched by a 14 instruction.

In case of Bull failure set PAK equal, to

77430 for read, or

77007 for write.

ES will be restored followed by a 56 stop with V address that of the interrupted card instruction.

Sum

A sum is stored at 77777. Entrance at 77371 will calculate a new sum over the area 76000 to 77776 inclusive; place the new sum in the Q register; place the difference between the new sum and the stored sum in the accumulator, and come to a 56 00000 77377 stop. Restarting computer will replace the stored sum with the calculated sum and terminate with a 56 00000 30000 stop. In general when no changes have been made in the tape a zero difference in the accumulator indicates the routine is correctly stored on the Magnetic Drum.

II Detailed Specifications

This is an unpacked floating point package including card input and output, addition, subtraction, multiplication, division, two index registers and normalization; all with rounding. The floating point number representation is defined in the 1103 storage as follows;

$N = M \cdot 2^e$ where $1/2 \leqslant |m| < 1$ and $0 \leqslant |e| < 2^{35}$

M is scaled 35, e is scaled 0, where M is in the first of two consecutive cells and e in the second.

Examples:

1 = 200000000000 000000000001

or 377777777777 000000000000

-1 = 577777777777 000000000001

- 10 = 314631463146 777777777776

The card input and output will only handle a maximum decimal exponent of 99.

The number should be normalized at all times to gain the maximum accuracy because 35 bits are used in a normalized mantissa. However, the addition, subtraction, and multiplication operations will handle floating numbers not normalized and give normalized answers which are correct to a lesser number of places. The division operation requires a normalized divisor or will go to the alarm exit, where it will alarm print the divisor and halt with a 56 stop. A restart will then finish the current instruction using an incorrect answer, and No fault will be caused by a non-normalized dividend which will give a non-normalized quotient correct to a lesser number of places.

The number whose mantissa is in the accumulator scaled 35 and whose exponent is in 01775 will be normalized by the return jump 37 01741 01712.

The mantissa of the answer will be duplicated in 01774 and the accumulator, with the exponent in 01775, i.e. the normalized number will be left in R as for arithmetic operation answers.

To attempt greater convenience of programming subroutines and simpler explanation of operation; a core package, to operate from 01500 to 01777 inclusive, is independent of any subroutines used. The intention is that any subroutine may be easily assembled to use with it. It includes rounded operations for accuracy and the fundamental arithmetic operations. These last arithmetic operations can be used with interpretive instructions for normal programs or with return jump instructions for greater speed in loops and especially for construction of subroutines.

The package starts with a self contained arithmetic unit from 01633 to 01775 inclusive which will perform addition, subtraction, multiplication, division, and normalization operation on specified registers by return jump instructions. From 01500 to 01632 inclusive is an interpretive system which uses the smaller arithmetic package. From 77400 to 77751 on the drum is a card input, self contained and operated either by return jump instructions of by the interpretive system. From 76760 to 77357 is a similar card output. The package requires

00000 45 00000 ( )

00001 45 00000 01547

01500 - 01777 inclusive, package operation

76000 - 77777 inclusive for package and subroutine storage.

74000 - 75777 inclusive, ES image during some operations as for example card

input and output.

To attempt greater convenience of programming subroutines and simpler explanation of operation; a core package, to operate from 01500 to 01777 inclusive, is independent of any subroutines used. The intention is that any subroutine may be easily assembled to use with it. It includes rounded operations for accuracy and the fundamental arithmetic operations. These last arithmetic operations can be used with interpretive instructions for normal programs or with return jump instructions for greater speed in loops and especially for construction of subroutines.

The package starts with a self contained arithmetic unit from 01633 to 01775 inclusive which will perform addition, subtraction, multiplication, division, and normalization operating on specified registers by return jump instructions. From 01500 to 01632 inclusive is an interpretive system which uses the smaller arithmetic package. From 77400 to 77751 on the drum is a card input, self contained and operated either by return jump instructions of by the interpretive system. From 76760 to 77357 is a similar card output.

The package requires

00000 45 00000 ( )

00001 45 00000 01547

01500 - 01777 inclusive, package operation

76000 - 77777 inclusive for package and subroutine storage.

74000 - 75777 inclusive, ES image during some operations as for example card input and output.

The tape reads into cells 76000 - 77777 inclusive 37 76000 76001 transfers from drum storage to E.S. cells 00000, 00001, and 01500

to 01757 inclusive and clears cells 01760 to 01777 for registers. 17 00000 77413 will prime read and punch cards initially and succeeding card movements will be automatic.

00002 - 01477 inclusive remain available for any program or added subroutines.

Registers

01764 P for storage of an
01765 operand for iteration
01766 B for storage of the
01767 (X) operand
01770 C for storage of the
01771 (Y) operand
01772 S for storage of an
01773 operand for iteration
01774 R The answer for storage of result
01775
01776 b 1 Index Registers for
01777 b 2 address modificat

Secondary registers

01760 I contains the current or ~~the~~ ~~instructive~~ (14) instruction
01761 N is used as a counter, receives N from single address instructions
01762 Used as temporaries
01763 in normalization and arithmetic operations (except division)

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Commands

Two address commands

14 CC XXXX YYYY

14 is the interpretive code

CC is the pseudo command code

XXXX (excluding the leftmost two bits) is the address of the operand placed in register B.

YYYY (excluding the leftmost two bits) is the address of the operand placed in register C.

The first (leftmost) bit of XXXX or YYYY is called a tag. If a one, it will cause a temporary addition of the contents of index register b 1 to that address during operation.

After the operation the instruction resumes its original unaltered form.

The second (next) bit, if one, will add the contents of index register b 2 but otherwise operate as described for b 1. Both may be used in the same operation.

One address commands

14 CC KNN YYYYY

14 is the interpretive (1103) code.

CC is the pseudo command code

K is divided into two parts.

The leftmost 2 bits are used as tags on the Y address.

The first (leftmost) bit of K if a one will cause a temporary addition of the contents of index register b 1 to the Y address during operation. After the operation the instruction resumes its original unaltered form. The second (next) bit if a one will add the contents

of index register b 2 but otherwise operate as above for b 1. Both tags may be used in the same operation.

The third (rightmost) bit of K will be used with NN as a number N. NN with the third bit of K is the number N placed in register N and usually used as a counter. Its maximum size is 177 octal or 127 decimal.

YYYYY is the address of the number placed in register C.

Commands and Registers

14 00 XXXX YYYY

Y + X to R

or 37 01741 01656

C + B to R

14 01 XXXX YYYY

Y - X to R

or 37 01741 01655

C - B to R

14 02 XXXX YYYY

Y . X to R

or 37 01741 01706

C • B to R

14 03 XXXX YYYY

Y/X to R

or 37 01741 01633

C/B to R

Registers

R final will be duplicated in C and the double extension of the R final mantissa will also be in the accumulator

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P will be unchanged

For 14 type instructions

R initial will be in S and B

For 37 type instructions

S will be unchanged and duplicated in B.

Commands and Registers

14 04 XXXX YYYY

R initial + Y + X to R

14 05 XXXX YYYY

R initial + Y - X to R

14 06 XXXX YYYY

R initial + Y • X to R

or 37 01741 01617

S + Y • X to R

14 07 XXXX YYYY

R initial + Y/X to R

Registers

R final will be duplicated in C and the double extension of the R final mantissa will also be in the accumulator

P will be unchanged

For 14 type instructions

R initial will be in S and B

For 37 type instructions

S will be unchanged and duplicated in B

Commands and Registers

14 20 XXXX YYYY

Y + X to R, Y

or 37 01746 01656

C + B to R, see footnote*

14 21 XXXX YYYY

Y - X to R, Y

or 37 01746 01655

C - B to R, see footnote*

14 22 XXXX YYYY

Y * X to R, Y

or 37 01746 01706

C * B to R, see footnote*

14 23 XXXX YYYY

Y/X to R, Y

or 37 01746 01633

C/B to R, see footnote*

Registers

P will be unchanged

For 14 type instructions

R final will be duplicated in C and Y and the double extension of the R final mantissa will also be in the accumulator.

R initial will be in S and B

For 37 type instructions

* R final will be duplicated in C and also at the "Y" address taken from the last 14 instruction used and located in the V portion of cell 01744 (where it is subject to modification by the programmer)

The double extension of the final mantissa will also be in the accumulator.

S will be unchanged and duplicated in B.

Commands and Registers

14 24 XXXX YYYY

R + Y + X to R, Y

14 25 XXXX YYYY

R + Y - X to R, Y

14 26 XXXX YYYY

R + Y * X to R, Y

or 37 01746 01617

S + C * B to R, *

14 27 XXXX YYYY

R + Y/X to R, Y

Registers

P will be unchanged

For 14 type instructions

R final will be duplicated in C and Y and the double extension of the R final mantissa will also be in the accumulator.

R initial will be in S and B

For 37 type instructions

*R final will be duplicated in C and also at the "Y" address taken from the last 14 instruction used and located in the V portion of Cell 01744 (where it is subject to modification by the programmer) The double extension of the R final mantissa will also be in the accumulator S will be unchanged and duplicated in B.

Commands and Registers

Threshold jump

14 17 XXXX YYYY

If X is greater than R jump to Y; otherwise continue with the next instruction (caution - due to rounding a jump may occur either way when X approaches R if X and R have been calculated by different operations)

R initial will be unchanged in R, S, and B

R - X will be in C and the mantissa of R - X will be in the accumulator

P will be unchanged.

Index jumps with modification of b index registers

14 76 KNN YYYYY with b 1

14 77 KNN YYYYY with b 2

Add 2 to the contents of b 1 or b 2. If N (last bit of K with NN from instruction is greater than b1 or b2 jump to y and leave b1 or b2 advanced.

Otherwise set b1 or b2 equal to zero and continue with the next instruction.

The contents of Y (2 cells) will be placed in register C.

N (from the last bit of K and NN) will be placed in register N and remain unchanged

R initial will be duplicated in S

R, P, and B will be unchanged.

Polynomial

14 75 KNN YYYYY

Compute the polynomial $A_0 + A_1X + A_2X^2 + \cdots + A_nX^n$; Where:

X must be prestored in register P

Y is the address of the last constant, A_N, where the constants are floating point numbers stored each in two cells - mantissa, exponent - consecutively, A_0, A_1, + ··· + A_N.

N is the degree of the equation.

The answer appears in R.

If N is less than one, no operation will be performed.

R and C will contain the answer.

S and B will contain A_0

P will contain X

N will be zero

The double extension of the mantissa of the answer will also be in the accumulator.

Commands and Registers

Card Instructions

14 57 KNN YYYYY

Read N cards (N is NN with the rightmost bit of K) into cells consecutively starting at Y in normalized floating point form.

14 56 KNN YYYYY

Punch N cards (N is NN with the rightmost bit of K) from cells consecutively starting at Y where numbers are stored in normalized floating point form.

Registers

Register N will contain the number N unchanged.

Register C will contain the first word stored at Y. In the case of read or punch this will be the contents of Y before read or punch - R, S, P, and B will be unchanged. Register C cannot be punched by a 14 instruction since Y is placed in C at the start of all 14 interpretations.

Return jump card options

Card read

37 77400 77401

AB UUUUU VVVVV

A. If a is equal to 4,5,6 or 7 do not print sum, otherwise print a sum which is characteristic of those cards.

B. If B is equal to 4,5,6 or 7 read in mantissas as integers to the zero scale factor, and store them in single consecutive cells. Ignore all exponents. Otherwise read in and store normal flosting point numbers in normalized form.

UUUUU Address for storage of the first data word.

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VVVVV Number of floating point numbers to be read or with option number of mantissas stored as integers.

Card output

37 76760 76761

AB UUUUU VVVVV

A. If A is equal to 4,5,6 or 7 the cards will not be numbered, otherwise they will be numbered starting at one. Cell 77303 contains this counter and may be set at one less than the next positive card number desired.

B Is not used.

UUUUU Is the storage address of the first mantissa

VVVVV Is the number of floating point numbers to be punched.

Coding Notes

In case of Bull failure set PAK equal to:

77430 for read, or

77007 for write.

ES will be restored followed by a 56 stop with the V address that of the interrupted card instruction.

If cards are not primed at start of program:

17 00000 77433 will advance one read card.

17 00000 77342 will advance one punch card

17 00000 77413 will advance one read card and one punch card

If the mantissa is zero after any arithmetic operation the exponent will be set equal to zero. During card read the exponent of a zero mantissa will be retained.

In punching or writing cards if an un-normalized mantissa or an exponent with absolute value above 513 octal in any series is to be punched, that number will be punched as negative zero. In this last case an alarm printing (nf) of the address of the first such number in any card instruction and its mantissa will be made on the typewriter but the program will continue. The maximum absolute value of exponents punched on cards is 98 or 99 depending on the mantissa value.

In reading cards a punch in column number one and row number twelve of any card will act as a flag and terminate the read instruction at the end of that card with a normal return to the program. If N is exhausted first an exit will occur. If it is desired to read a large number of cards with only a flag termination without regard to N, change the instruction at address 77445 to 11 01006 01314

Card Form Columns:

6, 21, 36, 51, 66 decimal point punched in card

7 - 16, 22-31, 37-46, 52-61, 67-76, ten decimal digit mantissas.

17, 32, 47, 62 77 sign of the mantissas.

18 - 19, 33 - 34, 48 - 49, 63 - 64, 78 - 79, exponents (power of ten) range - 99 to 99

20, 35, 50, 65, 80 signs of exponent.

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Codes and Exits Available For Subroutines

Two address references from E. S. Whiffletree

Code	U Address of	V Address of
10, 30*		01632
11, 31*	01632	
12, 32*		01631
13, 33*	01631	
14, 34*		01627
15, 35*	01627	
16, 36*		01626

Note that the 10 to 17 series will set to prevent storage of the result in Y.

One address references from E. S. Whiffletree

Code	U address of	V Address of
60, 61, 62, 63		01527
64, 65, 66, 67	01527	
70		01505
71	01505	
72		01504
73	01504	
74		01531

One address references from drum Whiffletree

Code	U address of	V address of
40		76122
41	76122	
42		76121
43	76121	

Code	U Address of	V Address of
44		76117
45	76117	
46		76116
47	76116	
50		76113
51	76113	
52		76112
53	76112	
54		76110
55	76110	

The drum whiffletree stores E. S., transfers itself to E. S., and jumps to the chosen address.

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SPUR ACCURACY TESTS:

20,000 Operations

07,21:

	Octal
Number in	246033531747 / 777777777774
Number out	246033536705 / 777777777774

	Decimal
Number in	.8108108108 01-
Number out	.8108109027 01-

04,01:

	Octal
Number in	400000000012 / 000000000005
Number out	400000077460 / 000000000005

	Decimal
Number in	.3199999998 - 02
Number out	.3199996967 - 02

03,22

	Octal
Number in	207002533507 / 000000000000
Number out	207002543105 / 000000000000

	Decimal
Number in	.5273641890 00
Number out	.5273643007 00

8th degree palynomial:	Exact	Computed
	1330157	1330156.999
	231285	231284.9999
	24835	24834.99999

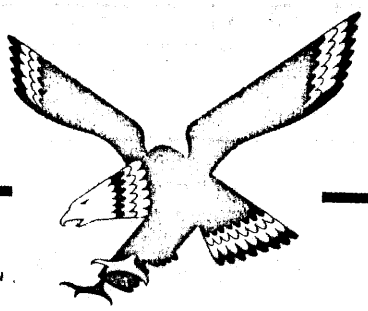
SPUR time tests;

	Command	Time (Milliseconds)
14/	00	3.84
	04	5.69
	20	3.95
	24	5.73
	01	3.80
	05	5.74
	21	3.90
	25	5.80
	02	3.49
	06	5.33
	22	3.48
	26	5.28
	03	3.65
	07	5.45
	23	3.71
	27	5.60
	17	3.81
	76	1.47
	77	1.47
	75	27.0 (For 8th degree poly.)

37 01746 01706 (Comparable to 1422) 1.73 m.s.

37 01741 01633 (Comparable to 1403) 1.74 m.s.

PX 71900-10-(183)



CONVAIR

A DIVISION OF GENERAL DYNAMICS CORPORATION

SAN DIEGO

REPORT ZM 527-II

DATE 9-6-56

MODEL All

TITLE

S P U R

Single Precision Unpacked Rounded
Floating Point Package for

ERA 1103 Computer

Part II Codes

PREPARED BY L. W. Barton

GROUP Digital Computing Lab.

REFERENCE

CHECKED BY C. J. Swift, D. Parker
D. Bielsker

APPROVED BY

NO. OF PAGES 27

NO. OF DIAGRAMS

REVISIONS

NO.	DATE	BY	CHANGE	PAGES AFFECTED

FORM 1612A-4

SPUR ACTIVATION

```
76000  01760  45 00000 30000   EXIT
76001  01761  11 76012 00000   SET F 0
76002  01762  11 76013 00001   SET F 1
76003  01763  75 30020 01765      THIS TO
76004  01764  11 76000 01760           ES
76005  01765  75 30260 01767      SPUR TO
76006  01766  11 76500 01500           ES
76007  01767  16 01760 01770   SET EXIT
76010  01770  75 10020 30000      CLEAR
76011  01771  11 01750 01760         EXIT
76012  01772  45 00000 00700   F 0
76013  01773  45 00000 01547   F 1
```

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SPUR DRUM WHIFFLE TREE

```
76100          75 31777 76102      STORE
76101          11 00001 74001        ES
76102          75 30045 00004      THIS TO
76103          11 76104 00004        ES
76104  00004   44 00005 00014    WHIFFLETREE
76105  00005   44 00006 00011
76106  00006   44 00007 00010
76107  00007   44 00023 00036    CARD   READ WRITE
76110  00010   44 30000 30000    55 54
76111  00011   44 00012 00013
76112  00012   44 30000 30000    53 52
76113  00013   44 30000 30000    55 50
76114  00014   44 00015 00020
76115  00015   44 00016 00017
76116  00016   44 30000 30000    47 46
76117  00017   44 30000 30000    45 44
76120  00020   44 00021 00022
76121  00021   44 30000 30000    43 42
76122  00022   44 30000 30000    41 40
76123  00023   75 30352 00025      CARD READ
76124  00024   11 77400 00742        TO ES
76125  00025   16 01746 00770   SET EXIT
76126  00026   16 01746 00742      SET
76127  00027   31 00742 00000        FAULT
76130  00030   36 01264 77432            REPEAT
76131  00031   31 01761 00002      ASSEMBLE
76132  00032   35 01761 00742        PARAMETER
76133  00033   15 01601 00742            WORD
76134  00034   16 00032 00763   SET ACQUISITION
76135  00035   45 00000 00762
76136  00036   75 30400 00040      CARD WRITE
76137  00037   11 76760 00745        TO ES
```

```
76140  00040  16 01746 00772   SET EXIT
76141  00041  16 01746 00745      SET
76142  00042  31 00745 00000         FAULT
76143  00043  36 01310 77011            REPEAT
76144  00044  31 01761 00002      ASSEMBLE
76145  00045  35 01761 00745         PARAMETER
76146  00046  15 01601 00745            WORD
76147  00047  16 00045 00764   SET ACQUISITION
76150  00050  45 00000 00764
```

SPUR ES PACKAGE

76500	01500	44	30064	30060	
76501	01501	44	01516	01530	
76502	01502	44	01501	01503	
76503	01503	44	01504	01505	
76504	01504	44	30073	30072	
76505	01505	44	30071	30070	
76506	01506	44	01502	01500	
76507	01507	11	01750	01770	ONE ADDRESS INST.
76510	01510	16	01760	01770	ADDRESS
76511	01511	55	10000	00016	
76512	01512	51	01756	01761	NUMBER N
76513	01513	55	01760	10014	
76514	01514	37	01603	01570	SET ADDRESS TAGS
76515	01515	44	01506	76100	ES OR MD
76516	01516	15	01527	01524	SET
76517	01517	16	01564	01526	b_1
76520	01520	44	01521	01523	
76521	01521	15	01541	01524	SET
76522	01522	16	01566	01526	b_2
76523	01523	55	01761	10001	2 N
76524	01524	21	30000	01752	$b_i + 2$
76525	01525	42	10000	01747	JUMP TO Y
76526	01526	11	01750	30000	CLEAR
76527	01527	45	01776	01746	JUMP TO NI
76530	01530	15	01601	01537	SET Y ADDRESS
76531	01531	44	01533	30074	
76532	01532	37	01742	01617	ACCUMULATE MULT.
76533	01533	11	01764	01766	X FOR
76534	01534	11	01765	01767	MULT.
76535	01535	23	01537	01753	STEP
76536	01536	75	30002	01540	CONSTANT
76537	01537	11	30000	01772	A_i FOR ADD

```
76540  01540  41 01761 01532   TEST DEGREE
76541  01541  45 01777 01745
76542  01542  11 01774 01770
76543  01543  11 01775 01771
76544  01544  37 01741 01655   R SUB X TO R
76545  01545  75 30002 01616      REPLACE
76546  01546  11 01772 01774         R
76547  01547  16 00000 01746   INTERPRET ENTRANCE
76550  01550  31 00000 00000
76551  01551  34 01751 00017
76552  01552  15 20000 01553
76553  01553  11 30000 01760   STORE INST.
76554  01554  55 01760 10006
76555  01555  44 01507 01556   ONE OR TWO ADDRESS
76556  01556  11 01760 10000
76557  01557  51 01757 01770   Y ADDRESS
76560  01560  55 10000 00030
76561  01561  51 01757 01766   X ADDRESS
76562  01562  55 01760 10014
76563  01563  44 01564 01565
76564  01564  21 01766 01776   X  B1
76565  01565  44 01566 01567
76566  01566  21 01766 01777   X  B2
76567  01567  55 10000 00012
76570  01570  44 01571 01572   ENT FROM ONE AD
76571  01571  21 01770 01776   Y  B1
76572  01572  44 01573 01574
76573  01573  21 01770 01777   Y  B2
76574  01574  16 01770 01747      SET
76575  01575  16 01770 01744         Y JUMP
76576  01576  31 01770 00017            AND
76577  01577  15 20000 01601                TRANSFERS
```

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```
76600  01600  75 30002 01602      Y TO
76601  01601  11 30000 01770         OP C
76602  01602  55 01760 10007
76603  01603  37 01603 01604   EXIT FOR ONE AD
76604  01604  11 01774 01772      R TO
76605  01605  11 01775 01773         S
76606  01606  44 01610 01607
76607  01607  21 01742 01752   NO TRANSMIT
76610  01610  31 01766 00017
76611  01611  15 20000 01613
76612  01612  75 30002 01614      X TO
76613  01613  11 30000 01766         OP B
76614  01614  44 01624 01615
76615  01615  44 01620 01621
76616  01616  46 01747 01746   Y OR N1 JUMP
76617  01617  75 00001 01706   JUMP TO MULT
76620  01620  16 01623 01741   SET FOR ACCUMULATE
76621  01621  44 01622 01623
76622  01622  44 01633 01706   DIVIDE  MULT.
76623  01623  44 01655 01656   SUB., ADD.
76624  01624  44 01625 01630
76625  01625  44 01626 01627
76626  01626  44 01542 30016   TJ, 16
76627  01627  44 30015 30014   15, 14
76630  01630  44 01631 01632
76631  01631  44 30013 30012   13, 12
76632  01632  44 30011 30010   11, 10
76633  01633  54 01766 20001      TEST FOR DIVISOR  DIVISION
76634  01634  43 20000 77752         ZERO OR UNNORMALIZED
76635  01635  11 01771 20000      EXPONENT
76636  01636  36 01767 01775         DIFFERENCE
76637  01637  12 01770 20000      COMPARE
```

```
76640  01640  12 01766 10000        MANTISSA
76641  01641  36 10000 20000           SIZE
76642  01642  46 01643 01645
76643  01643  54 01770 20043     SHIFT
76644  01644  45 00000 01647        OR ADJUST
76645  01645  21 01775 01751           EXPONENT
76646  01646  54 01770 20042              AND SHIFT
76647  01647  73 01766 01774  DIVIDE
76650  01650  32 01750 00001     TEST
76651  01651  12 01767 10000        FOR
76652  01652  42 10000 01734           ROUND
76653  01653  21 01774 01751  ROUND
76654  01654  45 00000 01730
76655  01655  13 01766 01766  SUBTRACTION
76656  01656  11 01767 01775  ADDITION
76657  01657  23 10000 10000  CLEAR A, Q
76660  01660  16 10000 01700  ERASE SHIFT
76661  01661  43 01770 01700  Y ZERO TEST
76662  01662  43 01766 01676  X ZERO TEST
76663  01663  23 01767 01771  EXPONENT DIFFERENCE
76664  01664  12 20000 20000
76665  01665  42 01755 01670  36 COMPARISON
76666  01666  41 01767 01700  Y OR X
76667  01667  45 00000 01676
76670  01670  16 20000 01700  SET SHIFT
76671  01671  41 01767 01674  Y OR X
76672  01672  11 01766 10000  X TO Q
76673  01673  45 00000 01677
76674  01674  11 01770 10000  Y TO Q
76675  01675  75 00001 01700
76676  01676  11 01771 01775  Y EXP
76677  01677  11 01770 01766  Y TO X
```

```
76700  01700  54 01766 30000   SHIFT X
76701  01701  35 10000 01774
76702  01702  45 00000 01713   TO NORMALIZE
76703  01703  23 01775 01755      A LEFT
76704  01704  54 01774 00044         NOT SIGNIFICANT
76705  01705  47 01714 01734   ZERO TEST
76706  01706  11 01771 20000   MULTIPLICATION
76707  01707  35 01767 20000   ADD EXPONENTS
76710  01710  36 01754 01775
76711  01711  71 01770 01766   PRODUCT
76712  01712  11 20000 01774     TEST
76713  01713  43 20000 01703          EXTENTION
76714  01714  11 01750 01762   CLEAR FOR SF
76715  01715  11 01751 10000   POS. FLAG
76716  01716  46 01717 01720   SIGN
76717  01717  13 10000 10000   NEG. FLAG
76720  01720  11 10000 01763   FOR ROUNDING
76721  01721  74 20000 01762   SCALE FACTOR
76722  01722  11 20000 01774
76723  01723  46 01724 01725      ADJUST
76724  01724  13 10000 10000         FOR SIGN
76725  01725  21 01775 01762   ADJUST FOR SF
76726  01726  44 01727 01734
76727  01727  21 01774 01763   ROUND
76730  01730  43 20000 01734   OVERFLOW TEST
76731  01731  32 01750 00107      ADJUST
76732  01732  11 20000 01774         FOR
76733  01733  21 01775 01751            OVERFLOW
76734  01734  11 01774 20000      ZERO
76735  01735  47 01737 01736         TEST
76736  01736  11 20000 01775   ERASE EXPONENT
76737  01737  75 30004 01741   SET FOR
```

```
76740  01740  11 01772 01766   ITERATION
76741  01741  37 01741 01742   FOR ITERATION
76742  01742  37 01742 01743   FOR BYPASS
76743  01743  75 30002 01745      STORE
76744  01744  11 01774 01774       R TO Y
76745  01745  45 00000 01746   FOR TRACE
76746  01746  45 00000 30000   TO NEXT INST.
76747  01747  45 00000 30000   TO Y
76750  01750  00 00000 00000   CONSTANTS
76751  01751  00 00000 00001
76752  01752  00 00000 00002
76753  01753  00 00002 00000
76754  01754  00 00000 00043
76755  01755  00 00000 00044
76756  01756  00 00000 00177
76757  01757  00 00000 01777   CONSTANTS
       01760  00 00000 00000     I FOR INSTRUCTION
       01761  00 00000 00000     N COUNTER
       01762  00 00000 00000     TEMPORARY
       01763  00 00000 00000     TEMPORARY
       01764  00 00000 00000     P FOR OPERAND
       01765  00 00000 00000      STORAGE FOR ITERATION
       01766  00 00000 00000     B FO
       01767  00 00000 00000      X OPERAND
       01770  00 00000 00000     C FOR
       01771  00 00000 00000      Y OPERAND
       01772  00 00000 00000     S FOR OPERAND
       01773  00 00000 00000      STORAGE FOR ITERATION
       01774  00 00000 00000     R FOR
       01775  00 00000 00000      THE RESULT
       01776  00 00000 00000      1 INDEX
       01777  00 00000 00000      2   REGISTERS
```

SPUR CARD OUTPUT

```
76760  00745  56 00000 30000
76761  00746  75 31777 76763     STORE
76762  00747  11 00001 74001       E S
76763  00750  75 30400 00752     ROUTINE
76764  00751  11 76760 00745       TO E S
76765  00752  31 00745 00000     SET
76766  00753  36 01310 77011      REPEAT
76767  00754  16 00745 00772     SET
76770  00755  21 00772 01310      EXIT
76771  00756  55 00745 20025     MODIFY
76772  00757  44 00761 00760      E S
76773  00760  32 00777 00000       ADDRESSES
76774  00761  55 20000 00017         TO STORAGE
76775  00762  37 00762 00763
76776  00763  16 20000 00764     ACQUIRE
76777  00764  71 01310 30000      CONTROL WORD
77000  00765  55 20000 00006     EXAMINE
77001  00766  37 00762 00757      FOR E S
77002  00767  55 20000 00017       ADDRESSES
77003  00770  37 01001 01006     TO SUBROUTINE
77004  00771  11 01270 77303     STORE CARD NUMBER
77005  00772  75 31777 30000     RESTORE
77006  00773  11 74001 00001       E S
77007  00774  75 31777 77011     RESTORE
77010  00775  11 74001 00001      E S
77011  00776  30 00000 00000       REPEAT
77012  00777  74 00000 00000     E S STORAGE
77013  01000  30 00000 00000     REPEAT LAST INST
77014  01001  45 00000 30000     EXIT
77015  01002  16 01001 01005
77016  01003  21 01001 01310
77017  01004  36 01344 01000
```

```
77020  01005  71 01310 30000
77021  01006  15 20000 01026     FIRST ADDRESS
77022  01007  13 20000 01347     FLAG
77023  01010  11 01310 01350     FLAG
77024  01011  31 20000 00025     EXTRACT
77025  01012  31 20000 00063      AND STORE
77026  01013  36 01310 01351       N-1
77027  01014  46 01001 01015     TEST FOR ZERO
77030  01015  17 00000 01327     PICK WRITE CARD
77031  01016  31 01351 00000
77032  01017  11 20000 01352     N-1 PER CARD
77033  01020  11 01325 10000     WRITE
77034  01021  42 01342 01024
77035  01022  11 01305 01352     5 PER CARD
77036  01023  11 01324 10000     WRITE AND PICK CARD
77037  01024  17 00000 10000     CARD INSTRUCTION
77040  01025  75 30012 01027     5 WORDS TO
77041  01026  11 30000 01353      STORAGE
77042  01027  75 10045 01031     CLEAR FOR
77043  01030  11 01307 01376      CARD IMAGE
77044  01031  15 01266 01050     SET ACQUISITION
77045  01032  11 01340 01374     BIT
77046  01033  11 01265 01375     BIT INSTRUCTION
77047  01034  41 01347 01047     IDENT NUMBER TEST
77050  01035  11 01332 01374     BIT
77051  01036  21 01270 01310     COUNT CARDS
77052  01037  42 01315 01041     SIZE OF WORD
77053  01040  31 01341 00000     SET 99999
77054  01041  32 01307 00043     INTEGER
77055  01042  32 01265 00000      TO
77056  01043  73 01315 01365       FRACTION
77057  01044  54 01365 00001       2 EXP 36
```

```
77060  01045  11 01305 01376    N-1 DIGITS
77061  01046  37 01200 01165    IDENT NUMBER
77062  01047  75 30002 01053    MANTISSA
77063  01050  11 30000 01365     AND EXPONENT
77064  01051  11 01307 01366    ZERO EXPONENT
77065  01052  45 00000 01156
77066  01053  11 01365 01370    MANTISSA SIGN FLAG
77067  01054  12 01366 20000    EXPONENT
77070  01055  42 01301 01067     FLOATING TEST
77071  01056  41 01350 01062    FIRST TIME
77072  01057  11 01264 01370    MANTISSA FLAG
77073  01060  75 10002 01156    SET EQUAL
77074  01061  11 01307 01365     TO ZERO
77075  01062  13 01322 01350    SET ALARM FLAG
77076  01063  11 01026 01345
77077  01064  15 01050 01065    ACQUIRE
77100  01065  11 30000 01346     MANTISSA
77101  01066  45 00000 01057
77102  01067  21 01365 01307
77103  01070  47 01071 01051    ZERO MANTISSA
77104  01071  46 01072 01073
77105  01072  13 01365 01365    NEGATIVE MANTISSA
77106  01073  16 01323 01123    SET SHIFT TO 33
77107  01074  32 01307 00001    EXP 36
77110  01075  43 20000 01056    FLOATING TEST
77111  01076  11 01307 01373    CLEAR FOR DECIMAL EXP
77112  01077  11 01366 20000    EXPONENT
77113  01100  46 01101 01117     SIGN
77114  01101  23 01373 01342    10 EXP 5 ADJUSTMENT
77115  01102  11 01307 01372    CLEAR FOR 74
77116  01103  71 01315 01365    X 10 EXP 5
77117  01104  74 20000 01372
```

```
77120  01105  11 20000 01365
77121  01106  46 01107 01114    TEST FOR ROUND
77122  01107  21 01365 01310    ROUND
77123  01110  43 20000 01114     MANTISSA
77124  01111  31 01365 00107      AND
77125  01112  11 20000 01365       ADJUST
77126  01113  21 01372 01310
77127  01114  21 01366 01372    ADJUST BSF
77130  01115  46 01101 01116    SIGN OF BSF
77131  01116  31 01366 00000    DIVIDE EXP
77132  01117  73 01323 01367     BY 33
77133  01120  11 20000 01366    EXPONENT REMAINDER
77134  01121  55 01365 00001    MANTISSA
77135  01122  45 00000 01152
77136  01123  31 01365 30000    MANTISSA SHIFT
77137  01124  11 20000 01371    STORE AR
77140  01125  34 20000 00044    ERASE
77141  01126  11 20000 01365    STORE AL
77142  01127  75 20013 01426    TEST FOR LARGER
77143  01130  42 01310 01131     POWER OF TEN
77144  01131  51 01330 10000
77145  01132  31 01311 00000    10 EXP 10
77146  01133  36 10000 10000
77147  01134  35 01373 01373    INCREASE EXP
77150  01135  31 10000 00017    N X 2 EXP 15
77151  01136  35 01263 01137
77152  01137  30 00000 00000    ACQUIRE DIVISOR
77153  01140  11 10000 01372
77154  01141  31 01365 00044    RESTORE
77155  01142  32 01371 00000       A
77156  01143  73 10000 10000    2 EXP 35
77157  01144  55 10000 00001    2 EXP 36
```

```
77160  01145  31 20000 00001     DETERMINE
77161  01146  42 01372 01150      LAST
77162  01147  27 10000 01310       BIT
77163  01150  11 10000 01365     ANSWER X 2 EXP 36
77164  01151  37 01151 01152
77165  01152  41 01367 01123     HIGHER ORDER DIGIT
77166  01153  16 01366 01123     LOWER ORDER SHIFT
77167  01154  37 01151 01123     LOWER ORDER DIGIT
77170  01155  11 01373 01366     DECIMAL EXPONENT
77171  01156  21 01050 01326     STEP
77172  01157  21 01026 01326     STEP
77173  01160  37 01200 01174     SHIFT FOR PERIOD
77174  01161  12 01366 20000     EXPONENT
77175  01162  11 01333 01376     TALLY
77176  01163  73 01311 01372     DIGITS
77177  01164  11 20000 01371      OF EXP
77200  01165  31 01365 00002     EXTRACT
77201  01166  32 01365 00001      AND
77202  01167  11 20000 01365       POSITION
77203  01170  34 20000 00063         DIGIT
77204  01171  35 01375 01172     ASSEMBLE INST
77205  01172  30 00000 00000     SET BIT
77206  01173  37 01173 01174
77207  01174  55 01374 00043     SHIFT BIT
77210  01175  44 01176 01177
77211  01176  21 01375 01334     ADVANCE FIELD
77212  01177  41 01376 01165     TEST FOR END
77213  01200  37 01200 01201
77214  01201  11 01370 10000
77215  01202  44 01203 01205
77216  01203  13 01331 20000
77217  01204  37 01173 01171     SIGN
```

```
77220  01205  55 01374 00043     SHIFT BIT
77221  01206  37 01206 01207
77222  01207  31 01372 00017     TENS DIGIT
77223  01210  37 01200 01171
77224  01211  31 01371 00017     UNITS DIGIT
77225  01212  37 01200 01171
77226  01213  11 01366 01370
77227  01214  37 01206 01201
77230  01215  37 01215 01216
77231  01216  41 01352 01047     WORDS PER CARD
77232  01217  11 01335 01371     SIT FOR 12 ROWS
77233  01220  21 01377 01336
77234  01221  21 01411 01336
77235  01222  21 01404 01336
77236  01223  21 01413 01337
77237  01224  21 01425 01337
77240  01225  21 01420 01337
77241  01226  16 01267 01233
77242  01227  16 01127 01234
77243  01230  15 01267 01231
77244  01231  55 30000 00010
77245  01232  77 00000 10000
77246  01233  77 10000 30000
77247  01234  77 10000 30000
77250  01235  23 01231 01331
77251  01236  23 01233 01310
77252  01237  23 01234 01310
77253  01240  41 01371 01231     TEST FOR END OF CARD
77254  01241  23 01351 01342     TEST FOR
77255  01242  46 01243 01016      END
77256  01243  41 01350 01001     FLOATING FLAG
77257  01244  75 10004 01246
```

```
77260  01245  61 00000 01302
77261  01246  11 01305 01371
77262  01247  55 01345 10011
77263  01250  31 01264 00000
77264  01251  52 01343 01252
77265  01252  30 00000 00000
77266  01253  55 10000 00003
77267  01254  41 01371 01250
77270  01255  37 01255 01256
77271  01256  55 01346 10003
77272  01257  61 00000 01305
77273  01260  11 01335 01371
77274  01261  37 01255 01250
77275  01262  45 00000 01001
77276  01263  55 01310 10001
77277  01264  61 00000 01271
77300  01265  21 01401 01374
77301  01266  00 01353 00000
77302  01267  00 01442 01412
77303  01270  00 00000 00000      CARD COUNTER
77304  01271  00 00000 00037
77305  01272  00 00000 00052
77306  01273  00 00000 00074
77307  01274  00 00000 00070
77310  01275  00 00000 00064
77311  01276  00 00000 00062
77312  01277  00 00000 00066
77313  01300  00 00000 00072
77314  01301  00 00000 00513
77315  01302  00 00000 00045
77316  01303  00 00000 00006
77317  01304  00 00000 00026
```

77320	01305	00	00000	00004	
77321	01306	00	00000	00143	EXCESS
77322	01307	00	00000	00000	
77323	01310	00	00000	00001	
77324	01311	00	00000	00012	
77325	01312	00	00000	00144	
77326	01313	00	00000	01750	
77327	01314	00	00000	23420	
77330	01315	00	00003	03240	
77331	01316	00	00036	41100	
77332	01317	00	00461	13200	
77333	01320	00	05753	60400	
77334	01321	00	73465	45000	
77335	01322	11	24027	62000	
77336	01323	00	00000	00041	
77337	01324	00	00000	00112	
77340	01325	00	00000	00102	
77341	01326	00	00002	00000	
77342	01F27	00	00000	00110	
77343	01330	00	00000	00077	
77344	01331	00	00001	00000	
77345	01332	40	00000	00000	
77346	01333	00	00000	00011	
77347	01334	00	00014	00000	
77350	01335	00	00000	00013	
77351	01336	01	00001	00001	
77352	01337	00	00100	00100	
77353	01340	01	00000	00000	
77354	01341	00	00003	03237	
77355	01342	00	00000	00005	
77356	01343	00	00000	00007	
77357	01344	00	00000	00002	

SPUR SUM AND MT INSTRUCTION

```
70000          45 00000 70006     SROK FROM MT 3
70001          45 00000 70100     FLIP FROM MT 3
70002          45 00000 71404     SPUR FROM MT 3
70003          45 00000 77371     SUM SPUR
70004          45 00000 77376     CHANGE SUPUR SUM
70005          45 00000 70071     ERA MAINT. FROM MT 3
77371          31 70000 00000     START SUM
77372          75 23777 77374
77373          32 70001 00000
77374          75 21777 71400
77375          32 76000 00000
77376          75 00001 77371     CHANGE
77377          11 10000 77777      SUM
71400          34 77303 00000     REMOVE
71401          34 77400 00000      VARIABLE
71402          75 20013 71426       FROM
71403          34 76110 00000         SUM
71404          11 71423 00000     SET F
71405          75 31777 71407     STORE
71406          11 00001 74001      ES
71407          75 30015 00411     THIS
71410          11 71411 00411      TO ES
71411  00411  64 30001 00000     READ ONE BLOCK
71412  00412  11 00000 20000     TEST FOR
71413  00413  43 00425 00421      ZERO BLOCK
71414  00414  31 71424 00052     PRINT
71415  00415  61 00000 20000      TAPE
71416  00416  34 20000 00006        ALARM
71417  00417  47 00415 00420
71420  00420  56 00000 00411     TRY AGAIN
71421  00421  66 30400 00000     ADVANCE TO SPUR
71422  00422  64 30001 00000     READ IN FIRST BLOCK
```

77320	01305	00	00000	00004	
77321	01306	00	00000	00143	EXCESS
77322	01307	00	00000	00000	
77323	01310	00	00000	00001	
77324	01311	00	00000	00012	
77325	01312	00	00000	00144	
77326	01313	00	00000	01750	
77327	01314	00	00000	23420	
77330	01315	00	00003	03240	
77331	01316	00	00036	41100	
77332	01317	00	00461	13200	
77333	01320	00	05753	60400	
77334	01321	00	73465	45000	
77335	01322	11	24027	62000	
77336	01323	00	00000	00041	
77337	01324	00	00000	00112	
77340	01325	00	00000	00102	
77341	01326	00	00002	00000	
77342	01F27	00	00000	00110	
77343	01330	00	00000	00077	
77344	01331	00	00001	00000	
77345	01332	40	00000	00000	
77346	01333	00	00000	00011	
77347	01334	00	00014	00000	
77350	01335	00	00000	00013	
77351	01336	01	00001	00001	
77352	01337	00	00100	00100	
77353	01340	01	00000	00000	
77354	01341	00	00003	03237	
77355	01342	00	00000	00005	
77356	01343	00	00000	00007	
77357	01344	00	00000	00002	

SPUR SUM AND MT INSTRUCTION

```
70000          45 00000 70006     SROK FROM MT 3
70001          45 00000 70100     FLIP FROM MT 3
70002          45 00000 71404     SPUR FROM MT 3
70003          45 00000 77371     SUM SPUR
70004          45 00000 77376     CHANGE SUPUR SUM
70005          45 00000 70071     ERA MAINT. FROM MT 3
77371          31 70000 00000     START SUM
77372          75 23777 77374
77373          32 70001 00000
77374          75 21777 71400
77375          32 76000 00000
77376          75 00001 77371     CHANGE
77377          11 10000 77777      SUM
71400          34 77303 00000     REMOVE
71401          34 77400 00000      VARIABLE
71402          75 20013 71426       FROM
71403          34 76110 00000         SUM
71404          11 71423 00000     SET F
71405          75 31777 71407     STORE
71406          11 00001 74001      ES
71407          75 30015 00411     THIS
71410          11 71411 00411      TO ES
71411  00411  64 30001 00000     READ ONE BLOCK
71412  00412  11 00000 20000     TEST FOR
71413  00413  43 00425 00421      ZERO BLOCK
71414  00414  31 71424 00052     PRINT
71415  00415  61 00000 20000      TAPE
71416  00416  34 20000 00006        ALARM
71417  00417  47 00415 00420
71420  00420  56 00000 00411     TRY AGAIN
71421  00421  66 30400 00000     ADVANCE TO SPUR
71422  00422  64 30001 00000     READ IN FIRST BLOCK
```

```
71423   00423   45 00000 00002     JUMP TO FIRST BLOCK
71424   00424   45 01301 52056     FLEX TAPE
71425   00425   45 07777 00002     LOCATOR ON ZERO BLOCK
71426           34 77432 00000     FURTHER
71427           34 76760 00000      SUM
71430           34 77011 00000       ADJUSTMENTS
71431           11 20000 20000
71432           11 20000 10000     SUM TO Q
71433           36 77777 20000     SUBTRACT STORED
71434           47 71435 71445      SUM, TEST
71435           31 71466 00052     SPUR FOR PRINT
71436           61 00000 20000     PRINT
71437           34 20000 00006      WORD
71440           47 71436 71441
71441           37 71441 71442     SWITCH
71442           31 71470 00052     PRINT
71443           37 71441 71436      NO SUM
71444           56 10000 71404     TO READ FROM MT
71445           37 71441 71435     PRINT SPUR
71446           31 71467 00052     PRINT
71447           37 71441 71436      SUM OK
71450           56 00000 71451     TO CLEAR
71451           75 17000 71453     START CLEAR
71452           11 20000 40000
71453           75 17000 71455
71454           11 20000 47000
71455           75 17000 71457
71456           11 20000 56000
71457           75 13000 71472
71460           11 20000 65000
71461           75 11777 71463
71462           11 20000 00001
```

```
71463    31 71471 00052     PRINT
71464    37 71441 71436      CLEAR
71465    57 00000 00000
71466    45 24153 41204     FLEX SPUR
71467    24 34070 40336     FLEX SUM OK
71470    06 03042 43407     FLEX NO SUM
71471    04 16112 03012     FLEX CLEAR
71472    75 12000 71461   CLEAR 74000
71473    11 20000 74000       75777
```

SPUR CARD INPUT

```
77400  00742  56 00000 30000     EXIT
77401  00743  75 31777 77403     STORE
77402  00744  11 00001 74001       ES
77403  00745  75 30352 00747     ROUTINE
77404  00746  11 77400 00742      TO ES
77405  00747  11 00742 20000     SET
77406  00750  36 01264 77432      REPEAT
77407  00751  35 01305 20000     SET
77410  00752  16 20000 00770      EXIT
77411  00753  55 00742 20025     TEST FOR
77412  00754  44 00757 00756      ES
77413  00755  00 00000 00114       ADDRESSES
77414  00756  32 00776 00000     ADDRESS MODIFICATION
77415  00757  55 20000 00017
77416  00760  37 00760 00761
77417  00761  16 20000 00763     SET ACQUISITION
77420  00762  11 00777 01024     ERASE INSTRUCTION
77421  00763  71 01264 30000     ACQUIRE CONTROL WORD
77422  00764  55 20000 00006
77423  00765  37 00760 00754     X
77424  00766  55 20000 00017
77425  00767  37 01001 01004     TP SIBRPITOME
77426  00770  75 31777 30000     RESTORE E S
77427  00771  11 74001 00001      AND EXIT
77430  00772  75 31777 77432     RESTORE E S
77431  00773  11 74001 00001      AND
77432  00774  30 00000 00000       REPEAT
77433  00775  02 00000 00104
77434  00776  74 00000 00000
77435  00777  11 00000 00000
77436  01000  30 00000 00000     REPEAT
77437  01001  45 00000 30000     EXIT
```

```
77440  01002  16 01001 01003
77441  01003  71 01264 30000    ACQUIRE CONTROL WORD
77442  01004  13 20000 01352    PRINT SUM FLAG
77443  01005  11 01263 01314    CLEAR
77444  01006  11 01263 01315      CELLS
77445  01007  16 20000 01314    NUMBER OF WORDS   N
77446  01010  55 20000 00003
77447  01011  13 20000 01351    READ AS INTEGER FLAG
77450  01012  31 01255 00000    SET FINAL
77451  01013  35 01277 01227     TRANSFER
77452  01014  11 01305 01356    SET TRANSFER
77453  01015  11 01265 01357      STEPS
77454  01016  44 01017 01022
77455  01017  23 01227 01313    MODIFICATINNS
77456  01020  11 01264 01356     FOR INTEGER
77457  01021  23 01357 01261      STORAGE
77460  01022  55 10000 00021    SET DATA
77461  01023  16 10000 01230     STORAGE
77462  01024  21 01001 01264    SET EXIT
77463  01025  36 01305 01000    SET REPEAT
77464  01026  23 01314 01264    N-1
77465  01027  46 01001 01030    EXIT IF N   0
77466  01030  41 01352 01032    SUM TEST
77467  01031  61 00000 01303    CARRIAGE RETURN
77470  01032  17 00000 01300    READ AND PICK CARC
77471  01033  11 01260 01350    LINE DIGIT   9
77472  01034  16 01256 01224    SET TEMPORARY STORAGE
77473  01035  75 10011 01037    CLEAR
77474  01036  11 01263 01316    MATRIX
77475  01037  76 00000 01361
77476  01040  76 10000 10000
77477  01041  76 10000 01360
```

```
77500  01042  37 01042 01043
77501  01043  54 01361 00034
77502  01044  11 01257 01054     SET 1ST STORAGE
77503  01045  11 01304 01327     SET INDEX   3
77504  01046  31 01306 00024     2 EXP 35
77505  01047  32 01263 00004     SHIFT 4
77506  01050  44 01051 01052     TEST BIT   0
77507  01051  32 01350 00000     ADD LINE DIGIT
77510  01052  46 01053 01047     TEST DIGITS   9
77511  01053  31 20000 00000     CLEAR A LEFT
77512  01054  30 00000 00000     STORE MATRIX WORD
77513  01055  21 01054 01307     STEP STORAGE
77514  01056  41 01327 01046     4 TIMES
77515  01057  37 01057 01060
77516  01060  11 01360 10000
77517  01061  37 01057 01045
77520  01062  11 01361 10000
77521  01063  37 01057 01046
77522  01064  37 01064 01065
77523  01065  23 01350 01264     REDUCE LINE DIGIT
77524  01066  46 01067 01037     TEST FOR 11 ROW
77525  01067  11 01264 01350
77526  01070  37 01064 01037     11 ROW
77527  01071  37 01042 01037     12 ROW, DUMMY
77530  01072  44 01073 01075     TEST EXIT FLAG
77531  01073  11 01302 01314     OVERRIDE INDEX
77532  01074  11 01255 01350     SET FLAG
77533  01075  31 01314 00000     N-1 REMAINDER
77534  01076  42 01261 01100     TEST LAST CARD
77535  01077  17 00000 01300     READ AND PICK CARD
77536  01100  11 01302 01332     SET INDEX FOR WORD CHANGE
77537  01101  15 01257 01123     SET FOR 1ST EXTRACTION
```

```
77540  01102  55 01316 00024    SHIFT FOR IDENT NUMBER
77541  01103  11 01302 01347    SET FOR 5 DATA WORDS
77542  01104  31 01304 00000    TEST FOR
77543  01105  42 01314 01115      LESS THAN
77544  01106  11 01314 01347      5 WORDS
77545  01107  31 01314 00017    N-1
77546  01110  35 01306 10000    TEST FOR
77547  01111  41 01351 01113      INTEGER
77550  01112  55 10000 00001        OPTION
77551  01113  31 01255 00000    SET SMALLER
77552  01114  35 10000 01227      STORAGE
77553  01115  37 01124 01120    SPACE FOR PERIOD
77554  01116  11 01260 01331    SET TALLY   9
77555  01117  11 01263 01327    CLEAR
77556  01120  41 01332 01123    TEST TO
77557  01121  21 01123 01306     CHANGE MATRIX
77560  01122  11 01262 01332      WORD
77561  01123  55 30000 00004    PSSITION DIGIT
77562  01124  37 01124 01125
77563  01125  31 01327 00002    N X 10
77564  01126  32 01327 00001     ADD
77565  01127  52 01301 01327      DIGIT
77566  01130  41 01331 01120    TEST N COMPLETE
77567  01131  11 01327 01334    SET EXPONENT FOR N   3
77570  01132  37 01124 01120     ACQUIRE
77571  01133  51 01301 20000     SZ¤PN
77572  01134  11 01265 01330      FLAG
77573  01135  47 01136 01140    TEST SIGN
77574  01136  13 01327 01334    SET EXPONENT FOR N   0
77575  01137  13 01265 01330    -FLAG
77576  01140  37 01140 01141
77577  01141  11 01327 01354    MANTISSA X 10 EXP 10
```

77600	01142	11	01330	01355	MANTISSA FLAG
77601	01143	11	01264	01331	SET TALLY
77602	01144	37	01140	01117	EXPONENT INFORMATION
77603	01145	41	01351	01217	TEST INTEGER OPTION
77604	01146	11	01263	01333	CLEAR
77605	01147	11	01354	20000	TEST N
77606	01150	47	01151	01223	FOR 0
77607	01151	23	01327	01330	EXPONENT
77610	01152	12	20000	20000	ADJUSTMENT
77611	01153	73	01265	01353	TENS DIGIT
77612	01154	31	20000	00017	UNITS DIGIT
77613	01155	35	01254	01215	UNITS POWER
77614	01156	11	20000	01251	OF 10
77615	01157	23	01334	01265	ADJUST EXPONENT
77616	01160	11	01276	01327	10 EXP 10
77617	01161	11	01310	01334	ADJUST AXPONENT
77620	01162	46	01214	01250	SIGN OF EXPONENT
77621	01163	23	01334	01311	ADJUST EXPONENT
77622	01164	31	01354	00000	N
77623	01165	73	01327	01333	N ADJUSTMENT
77624	01166	31	20000	00043	FOR NEGATIVE
77625	01167	73	01327	10000	EXPONENT
77626	01170	55	10000	00001	DETERMINE
77627	01171	32	01263	00001	LAST
77630	01172	42	01327	01174	BIT
77631	01173	27	10000	01264	OF N
77632	01174	31	10000	00044	ASSEMBLE
77633	01175	32	01333	00044	M
77634	01176	11	01263	01331	CLEAR
77635	01177	74	20000	01331	SCALE FACTOR N
77636	01200	11	20000	01354	STORE N
77637	01201	46	01202	01207	TEST FOR ROUNDING

```
77640  01202  21 01354 01264     ROUND
77641  01203  43 20000 01207     ADJUST FOR
77642  01204  32 01263 00107      OVERFLOW
77643  01205  11 20000 01354       IF
77644  01206  21 01334 01264        NECESSARY
77645  01207  31 01331 00000     ADJUST
77646  01210  42 01303 01212
77647  01211  23 01334 01312      SCALE
77650  01212  21 01334 01331       FACTOR
77651  01213  37 01213 01214
77652  01214  41 01353 01163     TEST TENS DIGIT
77653  01215  30 00000 00000     POWER FOR UNITS DIGIT
77654  01216  37 01213 01163     ADJUST FOR UNITS DIGIT
77655  01217  11 01354 01333     N
77656  01220  41 01355 01222     SIGN OF N
77657  01221  13 01333 01333     NEGATIVE
77660  01222  21 01315 01333     SUM
77661  01223  75 30002 01225     STORE
77662  01224  11 01333 30000      TEMPORARY
77663  01225  21 01224 01356     STEP STORAGE
77664  01226  41 01347 01115     TEST END OF CARD
77665  01227  30 00000 00000     FINAL
77666  01230  11 01335 30000      STORAGE
77667  01231  21 01230 01357     STEP
77670  01232  23 01314 01261     TEST FOR
77671  01233  46 01234 01033      END
77672  01234  41 01352 01001     TEST PRINT SUM
77673  01235  31 01263 00000     CLEAR
77674  01236  75 00006 01240     SUM
77675  01237  32 01315 00014
77676  01240  31 20000 00030
77677  01241  32 01264 00004
```

```
77700  01242  61 00000 20000
77701  01243  34 20000 00000
77702  01244  47 01241 01001     PRINTING
77703  01245  71 01354 01327    ADJUSTMENT
77704  01246  37 01213 01176     OF N
77705  01247  37 01247 01250      AND
77706  01250  41 01353 01245       EXPONENT
77707  01251  30 00000 00000        FOR
77710  01252  37 01247 01245         POSITIVE
77711  01253  45 00000 01217           SCALE FACTOR
77712  01254  11 01264 01327    CONSTANTS
77713  01255  75 30000 01231
77714  01256  00 00000 01335
77715  01257  35 01316 01316
77716  01260  00 00000 00011
77717  01261  00 00000 00005
77720  01262  00 00000 00010
77721  01263  00 00000 00000
77722  01264  00 00000 00001
77723  01265  00 00000 00012
77724  01266  00 00000 00144
77725  01267  00 00000 01750
77726  01270  00 00000 23420
77727  01271  00 00003 03240
77730  01272  00 00036 41100
77731  01273  00 00461 13200
77732  01274  00 05753 60400
77733  01275  00 73465 45000
77734  01276  11 24027 62000
77735  01277  00 00012 00000
77736  01300  00 00000 00105
77737  01301  00 00000 00017
```

77740	01302	00	00000	00004
77741	01303	00	00000	00045
77742	01304	00	00000	00003
77743	01305	00	00000	00002
77744	01306	00	00001	00000
77745	01307	00	00001	00001
77746	01310	00	00000	00043
77747	01311	00	00000	00044
77750	01312	00	00000	00110
77751	01313	00	00005	00000

SPUR DIVISION AND GENERAL ALARMS

77752		75	30700	77754	STORE PART
77753		11	01100	75100	OF E.S.
77754		75	30021	01100	THIS TO
77755		11	77756	01100	E.S.
77756	01100	75	30200	01102	PART OF
77757	01101	11	77213	01200	CARD ROUTINE
77760	01102	31	01746	00000	ADDRESS
77761	01103	36	01310	10000	OF
77762	01104	55	10000	00030	INST.
77763	01105	11	01305	01371	5 DIGITS
77764	01106	61	00000	01302	CAR. RET.
77765	01107	37	01255	01250	ADDRESS
77766	01110	61	00000	01305	SPACE
77767	01111	31	01355	00052	PRINT
77770	01112	61	00000	20000	
77771	01113	34	20000	00006	LABEL
77772	01114	47	01112	01115	
77773	01115	61	00000	01311	DIVISOR
77774	01116	11	01766	10000	
77775	01117	37	01351	01346	DIVISOR MANTISSA
77776	01120	45	00000	01345	TO CONTINUE
77360	01345	55	01760	10003	INSTRUCTION
77361	01346	11	01335	01371	12 DIGITS
77362	01347	61	00000	01305	SPACE
77363	01350	37	01255	01250	Q OCTAL
77364	01351	37	01351	01352	
77365	01352	75	30700	76061	RESTORE
77366	01353	11	75100	01100	ES
77367	01354	56	00000	01741	EXCESS
77370	01355	22	14171	42403	FLEX CODE
76014		75	30021	76016	PART
76015		11	77756	01100	OF

```
76016          75 30200 76022      DIVISION
76017          11 77213 01200       ALARM
76020          75 30700 76014     STORE
76021          11 01100 75100      ES
76022          75 30035 01137     THIS
76023          11 76024 01115      TO ES
76024  01115  61 00000 01142     PRINT LETTER
76025  01116  21 01115 01751     STEP
76026  01117  55 01760 10003     PRINT
76027  01120  37 01351 01346      REGISTER
76030  01121  21 01117 01151     STEP
76031  01122  37 01122 01123     SWITCH
76032  01123  61 00000 01302     CAR. RET.
76033  01124  37 01124 01125     SWITCH
76034  01125  37 01124 01115     PRINT N
76035  01126  21 01117 01150     STEP
76036  01127  37 01122 01115     PRINT
76037  01130  37 01124 01117      B
76040  01131  37 01131 01132     SWITCH
76041  01132  37 01131 01127     PRINT C
76042  01133  21 01117 01753     STEP
76043  01134  37 01131 01127     PRINT R
76044  01135  37 01131 01127     PRINT BOXES
76045  01136  45 00000 01352
76046  01137  11 01141 01355     SET FLEX ALARM
76047  01140  45 00000 01102
76050  01141  30 11301 20745     FLEX ALARM
76051  01142  00 00000 00014
76052  01143  00 00000 00006
76053  01144  00 00000 00023
76054  01145  00 00000 00016
76055  01146  00 00000 00012
```

76056	01147	00	00000	00001	
76057	01150	00	00004	00000	
76060	01151	00	00001	00000	
76061		37	01741	01741	SET NO ACCUMULATE
76062		37	01742	01742	SET STORE IN Y
76063		56	00000	01746	RETURN TO N. I.

SFUR SROK ALARM

```
72000    45 00000 72000
72001    16 72026 72022
72002    11 20000 00000
72003    61 00000 72047
72004    55 72012 00005
72005    55 72012 00011    SET FOR 5 DIGITS
72006    55 72012 00012    SET FOR 2 DIGITS
72007    34 20000 00003    OCTAL
72010    32 72037 00000
72011    11 20000 72012     PRINT
72012    00 01000 10001
72013    44 72014 72007       LOOP
72014    11 10000 72012    RESTORE FLAG
72015    61 00000 72021    SPACE
72016    37 72016 72017    SWITCH
72017    31 00000 00044
72020    11 72000 00000    SET JUMP
72021    37 72016 72004    PRINT
72022    37 72022 72023    SWITCH
72023    31 72000 00017    FOR MAIN
72024    15 20000 72025     ROUTINE AD
72025    16 72000 00000    SET JUMP
72026    15 72023 72025    RESTORE
72027    16 72027 72000    RESTORE
72030    31 72042 00047
72031    37 72016 72047    PRINT  ALARM
72032    41 00000 72033    ADJUST ADDRESS
72033    31 20000 00071
72034    37 72016 72005    PRINT 5 DIGITS
72035    56 00000 00000
72036    00 00000          EXCESS
72037    61 00000 72037
```

```
72040          00 00000    52
72041          00 00000 00 74
72042          43 01130 12070
72043          00 00000 00 64
72044          00 00000 00062
72045          00 00000 00 66
72046          00 00000 00 72
72047          61 00000 20045      FLEX
72050          34 20000 00006       PRINT
72051          47 72047 72015        LOOP
```

SPUR PAPERTAPE DUMP

```
73234    37 73234 73235    EXIT
73235    45 00000 73265    AUTO FLEX
73236    45 00000 73270    AUTO BIOCTAL
73237    45 00000 73273    MANUAL FLEX
73240    45 00000 73277    MANUAL BIOCTAL
73241    11 00000 74000
73242    11 73235 00000
73243    75 30152 73245
73244    11 00001 74001
73245    75 30064 73247
73246    11 73302 00006
73247    11 10000 73300
73250    11 20000 00151
73251    54 20000 00044
73252    11 20000 00152
73253    37 73253 73254
73254    11 73300 10000
73255    31 00152 00044
73256    32 00151 00000
73257    11 00010 73275
73260    11 00010 73300
73261    75 30152 73263    RESTORE
73262    11 74001 00001     ES
73263    11 74000 00000
73264    45 00000 73234    TO EXIT
73265    37 73253 73241    STORE IMAGE
73266    75 30057 00041    FLEX
73267    11 73366 00072     PROGRAM
73270    37 73253 73241    STORE IMAGE
73271    75 30040 00120    BIOCTAL
73272    11 73445 00072     PROGRAM
73273    11 10000 73275    PARAMETER WD.
```

```
73274          37 73234 73265     SET EXIT
73275          00 00000           P.W. STORAGE
73276          56 00000 73237     MANUAL FLEX.
73277          37 73234 73270     SET EXIT
73300          00 0000            Q
73301          56 00000 73240     MANUAL BIOCT.
73302  00006   00 00001 00000
73303  00007   00 00000 00007
73304  00010   00 00000 00000
73305  00011   00 00000 00001
73306  00012   00 00000 00002
73307  00013   00 00000 00004
73310  00014   00 00152 00000
73311  00015   00 74000 00000
73312  00016   63 00000 00017
73313  00017   00 00000 00037     FLEX 0
73314  00020   00 00000 00052
73315  00021   00 00000 00074
73316  00022   00 00000 00070
73317  00023   00 00000 00064
73320  00024   00 00000 00062
73321  00025   00 00000 00066
73322  00026   00 00000 00072
73323  00027   00 00000 00045     CAR. RET.
73324  00030   00 00000 00043     STOP CODE
73325  00031   00 00000 00075
73326  00032   00 00000 00132
73327  00033   00 00000 02000
73330  00034   00 00000 40000
73331  00035   11 00010 00001     CHECK ADDRESS
73332  00036   45 00000 00072     JUMP TO PUNCH
73333  00037   11 00034 00001     40000
```

```
73334  00040  45 00000 00072   JUMP TO PUNCH
73335  00041  75 00010 00043   LEADER
73336  00042  63 00000 00010
73337  00043  31 73234 00017   PARAMETER ADDRESS
73340  00044  11 20000 00001
73341  00045  31 00014 00000   PARAMETER
73342  00046  42 00001 00050    ADDRESS
73343  00047  21 00001 00015     IN IMAGE
73344  00050  15 00001 00051
73345  00051  11 30051 10000   PARAMETER
73346  00052  11 00010 00001   CLEAR
73347  00053  11 00010 00003    TEMPORARIES
73350  00054  15 10000 00003   AD. OF FIRST WD.
73351  00055  11 00003 00004
73352  00056  16 10000 00001   AD. OF LAST WD.
73353  00057  44 73254 00060
73354  00060  44 73254 00061   PAR. INST.
73355  00061  44 73254 00062
73356  00062  21 73234 00011   STEP
73357  00063  31 00001 00017   LAST AD.
73360  00064  34 00003 00071    FIRST AD.
73361  00065  11 20000 00002     NO. OF WDS.
73362  00066  46 00043 00067   PAR. END
73363  00067  21 00001 00011   STEP
73364  00070  43 00033 00035   2000 TO ZERO
73365  00071  43 00006 00037   10000 TO 40000
73366  00072  55 10000 00002
73367  00073  44 00074 00075   NO STOP PUNCH
73370  00074  16 00042 00135
73371  00075  31 00014 00000   CURRENT WORD
73372  00076  42 00004 00102    IN IMAGE
73373  00077  21 00003 00015   ADJUST FOR IMAGE
```

```
73374  00100  16 00031 00127
73375  00101  45 00000 00103
73376  00102  16 00101 00127
73377  00103  11 00004 10000     CURRENT AD.
73400  00104  56 10000 00105
73401  00105  55 10000 00006
73402  00106  37 00150 00142     5 DIGITS
73403  00107  15 00003 00110     CURRENT
73404  00110  31 30110 00000      WORD
73405  00111  43 00010 00121     OMIT PUNCHING
73406  00112  75 00002 00114     2 SPACES
73407  00113  63 00000 00013
73410  00114  11 20000 10000     CURRENT WD.
73411  00115  11 00011 00005
73412  00116  37 00150 00143     2 DIGITS
73413  00117  37 00150 00141     5 DIGITS
73414  00120  37 00150 00141     5 DIGITS
73415  00121  41 00140 00124     32 WDS.
73416  00122  11 00017 00140     RESTORE TALLY
73417  00123  63 00000 00027     CAR.
73420  00124  63 00000 00027      RET.
73421  00125  21 00004 00006     STEP
73422  00126  11 00004 00003
73423  00127  41 00002 30127     END
73424  00130  16 00032 00127
73425  00131  11 00017 00002
73426  00132  31 00140 00000
73427  00133  43 00017 00135
73430  00134  45 00000 00121
73431  00135  63 00000 00030
73432  00136  11 73431 00135
73433  00137  45 00000 00041     TO NEXT PAR.
```

```
73434  00140  00 00000 00037    TALLY
73435  00141  63 00000 00013    SPACE
73436  00142  11 00013 00005    SET TALLY
73437  00143  55 10000 00003
73440  00144  51 00007 20000    EXTRACT DIGIT
73441  00145  35 00016 00146
73442  00146  00 00000 00000    PUNCH DIGIT
73443  00147  41 00005 00143
73444  00150  45 00000 30150    EXIT
73445  00072  63 10000 00010    7TH LEVEL
73446  00073  11 00004 10000    PUNCH
73447  00074  55 10000 00025     INSERT
73450  00075  37 00130 00122      ADDRESS
73451  00076  37 00130 00122
73452  00077  31 00014 00000    IN
73453  00100  42 00004 00104     IMAGE
73454  00101  21 00003 00015    ADJUST
73455  00102  16 00131 00113
73456  00103  45 00000 00105
73457  00104  16 00103 00113
73460  00105  15 00003 00106    CURRENT ADDRESS
73461  00106  11 30000 10000    PUNCH
73462  00107  11 00013 00005     CURRENT
73463  00110  37 00130 00123      WORD
73464  00111  21 00004 00006    STEP
73465  00112  11 00004 00003
73466  00113  41 00002 30113    END
73467  00114  11 00012 00005
73470  00115  11 00001 10000    CHECK
73471  00116  37 00130 00123     ADDRESS
73472  00117  37 00130 00123
73473  00120  75 00310 00041    PUNCH
```

```
73474  00121  63 00000 00010      LEADER
73475  00122  11 00011 00005
73476  00123  55 10000 00006      PUNCH
73477  00124  63 00000 10000       2
73500  00125  41 00005 00123        DIGITS
73501  00126  55 10000 00006
73502  00127  63 10000 10000
73503  00130  56 10000 30130
73504  00131  00 00000 00077
```

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SUPER OTTO SPUR

72052	01000	45	00000	01013
72053	01001	47	01002	01004
72054	01002	35	01304	01172
72055	01003	45	00000	01171
72056	01004	55	00022	00043
72057	01005	53	10000	00004
72060	01006	53	10000	00013
72061	01007	45	00000	01173
72062	01010	56	00000	01010
72063	01011	11	01316	10000
72064	01012	37	01273	01266
72065	01013	45	30000	01016
72066	01014	75	00002	01020
72067	01015	17	00000	01332
72070	01016	75	00276	01020
72071	01017	63	00000	01314
72072	01020	45	10000	01042
72073	01021	11	01317	10000
72074	01022	37	01273	01266
72075	01023	11	01320	10000
72076	01024	37	01273	01267
72077	01025	11	40000	00003
72100	01026	11	01275	40000
72101	01027	57	00000	00000
72102	01030	11	00003	40000
72103	01031	15	01332	01033
72104	01032	15	01333	01034
72105	01033	11	30000	10000
72106	01034	31	30000	00000
72107	01035	56	10000	01036
72110	01036	11	10000	00017

72111	01037	11	20000	00020
72112	01040	37	01261	01262
72113	01041	44	72441	01044
72114	01042	23	10000	10000
72115	01043	56	00000	01036
72116	01044	61	00000	01340
72117	01045	11	01334	00023
72120	01046	11	00020	10000
72121	01047	61	00000	01340
72122	01050	37	01261	01264
72123	01051	11	00017	10000
72124	01052	51	01355	20000
72125	01053	73	01345	00003
72126	01054	36	10000	00025
72127	01055	11	00003	20000
72130	01056	42	01335	01070
72131	01057	11	00017	00026
72132	01060	11	01276	01110
72133	01061	11	01312	01202
72134	01062	55	00017	10005
72135	01063	44	01064	01075
72136	01064	11	01277	01114
72137	01065	11	01300	01210
72140	01066	75	20002	01101
72141	01067	55	00026	00006
72142	01070	11	00017	00027
72143	01071	21	00017	01336
72144	01072	11	01301	01110
72145	01073	11	01302	01202
72146	01074	45	00000	01076
72147	01075	11	00020	00027

72150	01076	11	01303	01114
72151	01077	11	01313	01210
72152	01100	45	00000	01066
72153	01101	45	30000	01175
72154	01102	15	00017	01107
72155	01103	75	30014	01105
72156	01104	23	00003	00003
72157	01105	11	01311	00000
72160	01106	17	00000	01333
72161	01107	11	30000	00030
72162	01110	11	00026	30000
72163	01111	11	01337	00022
72164	01112	11	01340	00023
72165	01113	37	01174	01166
72166	01114	11	00027	30000
72167	01115	11	01341	00022
72170	01116	11	01340	00023
72171	01117	37	01174	01166
72172	01120	45	20000	01152
72173	01121	11	00030	00021
72174	01122	11	01342	00022
72175	01123	11	01337	00023
72176	01124	37	01174	01166
72177	01125	11	01337	00024
72200	01126	55	00022	00043
72201	01127	11	01340	00023
72202	01130	37	01174	01166
72203	01131	41	00024	01126
72204	01132	11	01343	00024
72205	01133	16	01305	01135
72206	01134	77	00000	01314

72207	01135	77	10000	30000
72210	01136	77	10000	01314
72211	01137	23	01135	01337
72212	01140	41	00024	01134
72213	01141	56	20000	01142
72214	01142	41	00025	01147
72215	01143	17	00000	01332
72216	01144	45	10000	01043
72217	01145	75	20002	01033
72220	01146	21	01033	01344
72221	01147	21	01107	01345
72222	01150	75	20002	01103
72223	01151	21	00026	01346
72224	01152	11	00030	10000
72225	01153	51	01347	20000
72226	01154	43	01350	01156
72227	01155	45	00000	01121
72230	01156	11	00030	00021
72231	01157	11	01342	00022
72232	01160	11	01351	00024
72233	01161	11	01352	00023
72234	01162	37	01174	01166
72235	01163	55	00022	00043
72236	01164	41	00024	01161
72237	01165	45	00000	01132
72240	01166	55	00021	00003
72241	01167	51	01353	20000
72242	01170	45	00000	01001
72243	01171	55	00022	00043
72244	01172	53	01321	30000
72245	01173	41	00023	01166

```
72246  01174  45 00000 01174
72247  01175  15 00017 01200
72250  01176  75 00036 01200
72251  01177  63 00000 01314
72252  01200  11 30000 00030
72253  01201  63 00000 01307
72254  01202  11 00026 30000
72255  01203  37 01261 01250
72256  01204  75 00002 01210
72257  01205  63 00000 01340
72260  01206  75 00007 01210
72261  01207  63 00000 01340
72262  01210  11 00027 30000
72263  01211  37 01261 01250
72264  01212  75 00002 01216
72265  01213  63 00000 01340
72266  01214  75 00007 01216
72267  01215  63 00000 01340
72270  01216  45 20000 01235
72271  01217  11 00030 10000
72272  01220  11 01337 00023
72273  01221  37 01261 01253
72274  01222  63 00000 01340
72275  01223  37 01261 01250
72276  01224  63 00000 01340
72277  01225  37 01261 01250
72300  01226  56 20000 01227
72301  01227  41 00025 01232
72302  01230  75 00003 01144
72303  01231  63 00000 01307
72304  01232  21 01200 01345
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72305	01233	75	20002	01200
72306	01234	21	00026	01346
72307	01235	11	00030	10000
72310	01236	51	01347	20000
72311	01237	43	01350	01241
72312	01240	45	00000	01217
72313	01241	11	01351	00024
72314	01242	11	00030	10000
72315	01243	11	01352	00023
72316	01244	37	01261	01253
72317	01245	63	00000	01340
72320	01246	41	00024	01243
72321	01247	45	00000	01226
72322	01250	11	01340	00023
72323	01251	45	00000	01253
72324	01252	11	01343	00023
72325	01253	15	01305	01256
72326	01254	55	10000	00003
72327	01255	51	01353	20000
72330	01256	35	30000	01257
72331	01257	63	00000	30000
72332	01260	41	00023	01254
72333	01261	45	00000	01261
72334	01262	61	00000	01307
72335	01263	11	01343	00023
72336	01264	15	01307	01256
72337	01265	45	00000	01254
72340	01266	61	00000	01307
72341	01267	11	01354	00023
72342	01270	55	10000	00006
72343	01271	61	00000	10000

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72344  01272  41 00023 01270
72345  01273  45 00000 01273
72346  01274  45 00000 01013
72347  01275  45 00000 01030
72350  01276  11 00026 00021
72351  01277  45 00000 01120
72352  01300  45 00000 01214
72353  01301  45 00000 01114
72354  01302  45 00000 01206
72355  01303  11 00027 00021
72356  01304  53 01321 00005
72357  01305  00 01306 00016
72360  01306  63 00000 01322
72361  01307  00 01310 00045
72362  01310  61 00000 01322
72363  01311  45 00000 01103
72364  01312  11 00026 10000
72365  01313  11 00027 10000
72366  01314  00 00000 00000
72367  01315  24 34070 40613
72370  01316  03 01030 40336
72371  01317  15 30123 00720
72372  01320  01 12240 41406
72373  01321  77 77777 77777
72374  01322  00 00000 00037
72375  01323  00 00000 00052
72376  01324  00 00000 00074
72377  01325  00 00000 00070
72400  01326  00 00000 00064
72401  01327  00 00000 00062
72402  01330  00 00000 00066
```

72403	01331	00	00000	00072
72404	01332	00	00300	00110
72405	01333	00	00301	00112
72406	01334	00	00000	00006
72407	01335	00	00000	20000
72410	01336	00	74000	00000
72411	01337	00	00000	00001
72412	01340	00	00000	00004
72413	01341	00	40000	00000
72414	01342	00	00200	00000
72415	01343	00	00000	00013
72416	01344	00	00002	00000
72417	01345	00	00001	00000
72420	01346	00	00100	00000
72421	01347	77	00000	00000
72422	01350	14	00000	00000
72423	01351	00	00000	00002
72424	01352	00	00000	00003
72425	01353	00	00000	00007
72426	01354	00	00000	00005
72427	01355	00	77777	77777
72430	01356	00	00000	00000
72431		11	00000	74000
72432		11	72540	00000
72433		75	31777	72435
72434		11	00001	74001
72435		75	30260	72437
72436		11	72445	00020
72437		75	30073	00020
72440		11	72725	00700
72441		75	31777	72443

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72442		11	74001	00001
72443		11	74000	00000
72444		57	00000	00000
72445	00020	17	00000	00700
72446	00021	71	00704	00711
72447	00022	11	20000	00014
72450	00023	55	10000	00002
72451	00024	11	10000	00015
72452	00025	55	10000	00001
72453	00026	11	10000	00016
72454	00027	11	10000	00017
72455	00030	21	00017	00015
72456	00031	11	00703	00011
72457	00032	75	30010	00250
72460	00033	23	00001	00001
72461	00034	45	10000	00216
72462	00035	11	00714	10000
72463	00036	37	00227	00223
72464	00037	11	00715	10000
72465	00040	37	00227	00223
72466	00041	11	00716	10000
72467	00042	37	00227	00223
72470	00043	11	40000	00010
72471	00044	11	00747	00000
72472	00045	11	00747	40000
72473	00046	57	00300	00000
72474	00047	17	00301	00702
72475	00050	11	00010	40000
72476	00051	15	00046	00053
72477	00052	15	00047	00054
72500	00053	11	30300	10000

72501	00054	31	30301	00000
72502	00055	56	10000	00056
72503	00056	11	10000	00001
72504	00057	11	20000	00002
72505	00060	61	00000	00716
72506	00061	61	00000	00716
72507	00062	11	00001	10000
72510	00063	11	00707	00007
72511	00064	37	00237	00232
72512	00065	37	00237	00230
72513	00066	37	00237	00230
72514	00067	44	00220	00070
72515	00070	11	00002	10000
72516	00071	61	00000	00716
72517	00072	61	00000	00727
72520	00073	61	00000	00727
72521	00074	55	10000	00005
72522	00075	37	00237	00230
72523	00076	61	00000	00712
72524	00077	75	00005	00101
72525	00100	61	00000	00727
72526	00101	15	00001	00131
72527	00102	11	00001	10000
72530	00103	55	10000	00003
72531	00104	51	00731	00003
72532	00105	55	10000	00017
72533	00106	51	00731	00004
72534	00107	11	00732	20000
72535	00110	42	00003	00114
72536	00111	21	00131	00733
72537	00112	11	00124	00136

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72540  00113  45 00000 00130
72541  00114  11 00734 10000
72542  00115  51 00001 20000
72543  00116  47 00127 00117
72544  00117  11 00002 10000
72545  00120  55 10000 00003
72546  00121  51 00731 00005
72547  00122  11 00125 00136
72550  00123  45 00000 00130
72551  00124  45 00000 00153
72552  00125  45 00000 00137
72553  00126  45 00000 00146
72554  00127  11 00126 00136
72555  00130  75 31000 00132
72556  00131  11 30000 01000
72557  00132  21 00131 00735
72560  00133  15 00735 00134
72561  00134  11 31000 00006
72562  00135  21 00134 00736
72563  00136  45 00000 30136
72564  00137  11 00003 00010
72565  00140  15 00703 00011
72566  00141  37 00247 00240
72567  00142  21 00011 00014
72570  00143  11 00005 00010
72571  00144  37 00247 00240
72572  00145  45 00000 00157
72573  00146  11 00003 00010
72574  00147  15 00703 00011
72575  00150  37 00247 00240
72576  00151  21 00011 00017
```

72577	00152	45	00000	00160
72600	00153	15	00703	00011
72601	00154	21	00011	00016
72602	00155	11	00003	00010
72603	00156	37	00247	00240
72604	00157	21	00011	00015
72605	00160	45	20000	00256
72606	00161	11	00006	00010
72607	00162	55	00010	00041
72610	00163	11	00707	00007
72611	00164	37	00247	00241
72612	00165	21	00011	00704
72613	00166	11	00006	00010
72614	00167	55	00010	00003
72615	00170	37	00247	00240
72616	00171	21	00011	00704
72617	00172	37	00247	00240
72620	00173	11	00740	10000
72621	00174	51	00011	20000
72622	00175	43	00013	00206
72623	00176	21	00011	00705
72624	00177	11	00003	20000
72625	00200	43	00004	00213
72626	00201	21	00003	00741
72627	00202	21	00005	00741
72630	00203	11	00134	20000
72631	00204	43	00742	00130
72632	00205	45	00000	00134
72633	00206	16	00703	00011
72634	00207	17	00000	00701
72635	00210	17	00000	00700

72636	00211	17	00000	00702
72637	00212	45	00000	00177
72640	00213	45	10000	00216
72641	00214	75	20002	00053
72642	00215	21	00053	00743
72643	00216	23	10000	10000
72644	00217	56	00000	00056
72645	00220	17	00000	00701
72646	00221	75	00003	72441
72647	00222	17	00000	00700
72650	00223	11	00713	00007
72651	00224	55	10000	00006
72652	00225	61	00000	10000
72653	00226	41	00007	00224
72654	00227	45	00000	30227
72655	00230	61	00000	00712
72656	00231	11	00712	00007
72657	00232	55	10000	00003
72660	00233	51	00744	20000
72661	00234	35	00730	00235
72662	00235	61	00000	30235
72663	00236	41	00007	00232
72664	00237	45	00000	30237
72665	00240	11	00712	00007
72666	00241	11	00737	10000
72667	00242	53	00010	00011
72670	00243	45	00000	00762
72671	00244	21	00011	00704
72672	00245	54	00010	00003
72673	00246	41	00007	00242
72674	00247	45	00000	30247

72675	00250	11	00740	10000
72676	00251	51	00703	20000
72677	00252	72	00705	00706
72700	00253	11	20000	00013
72701	00254	17	00000	00702
72702	00255	45	00000	00034
72703	00256	11	00006	10000
72704	00257	51	00745	20000
72705	00260	43	00746	00262
72706	00261	45	00000	00161
72707	00262	11	00006	00010
72710	00263	55	00010	00041
72711	00264	11	00711	00007
72712	00265	37	00247	00241
72713	00266	21	00011	00704
72714	00267	11	00006	00010
72715	00270	55	00010	00011
72716	00271	11	00711	00007
72717	00272	37	00247	00241
72720	00273	21	00011	00704
72721	00274	11	00711	00007
72722	00275	37	00247	00241
72723	00276	45	00000	00173
72724	00277	00	00000	00000
72725	00700	00	00000	06000
72726	00701	00	00000	04400
72727	00702	00	00000	05000
72730	00703	00	00200	00020
72731	00704	00	00024	00000
72732	00705	00	00000	00040
72733	00706	00	00000	00037

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72734	00707	00	00000	00001
72735	00710	00	00000	00002
72736	00711	00	00000	00003
72737	00712	00	00000	00004
72740	00713	00	00000	00005
72741	00714	45	47150	10411
72742	00715	03	30220	40407
72743	00716	22	04240	15745
72744	00717	00	00000	00037
72745	00720	00	00000	00052
72746	00721	00	00000	00074
72747	00722	00	00000	00070
72750	00723	00	00000	00064
72751	00724	00	00000	00062
72752	00725	00	00000	00066
72753	00726	00	00000	00072
72754	00727	00	00000	00042
72755	00730	61	00000	00717
72756	00731	07	77770	00000
72757	00732	00	17770	00000
72760	00733	00	74000	00000
72761	00734	01	00000	00000
72762	00735	00	01000	00000
72763	00736	00	00001	00000
72764	00737	07	00000	00000
72765	00740	00	00000	77777
72766	00741	00	00010	00000
72767	00742	11	02000	00006
72770	00743	00	00002	00000
72771	00744	00	00000	00007
72772	00745	77	00000	00000

72773	00746	14	00000	00000
72774	00747	45	00000	00047
72775	00750	00	00000	01777
72776	00751	11	73015	72461
72777	00752	45	00000	72431
73000	00753	45	00000	72776
73001	00754	45	00000	72431
73002	00755	45	00000	73020
73003	00756	11	00771	76461
73004	00757	11	00750	00001
73005	00760	16	00772	00200
73006	00761	45	00000	00101
73007	00762	42	00766	00764
73010	00763	35	00767	20000
73011	00764	77	10000	20000
73012	00765	45	00000	00244
73013	00766	06	00000	00000
73014	00767	02	00000	00000
73015	00770	45	00000	00756
73016	00771	45	10000	00216
73017	00772	00	00000	00220
73020		11	00000	74000
73021		11	72152	00000
73022		75	31777	73024
73023		11	00001	74001
73024		75	30357	01013
73025		11	72052	01000

SPUR SUBROUTINE ASSEMBLY

```
76151          15 01601 76153    Y ADDRESS
76152          75 30052 76154      PW FOR
76153          11 30000 00002      EXAMINATION
76154          75 30304 00056     THIS TO
76155          11 76156 00056      ES
76156  00056   15 01753 00121    PW ACQUISITION
76157  00057   11 00347 00372    INITIAL INST. LIMIT
76160  00060   11 01752 00373    INITIAL TEMP. LIMIT
76161  00061   15 01753 00064    SET TREE TEST
76162  00062   31 01761 00000
76163  00063   36 01751 00374    SET TALLY
76164  00064   11 30000 20000
76165  00065   42 00357 00067     WHIFFLETREE
76166  00066   42 00360 00115      TEST
76167  00067   21 00064 01753    STEP
76170  00070   41 00374 00064
76171  00071   41 01761 00120    TEST FOR END
76172  00072   75 31240 00074     STORE
76173  00073   11 00400 74400      MODIFIED ES
76174  00074   75 30200 00076     PART OF
76175  00075   11 77213 01200      CARD ROUTINE
76176  00076   61 00000 01302    CAR. RET.
76177  00077   31 00361 00052     PRINT
76200  00100   61 00000 20000      AVAIL.
76201  00101   34 20000 00006       AND
76202  00102   47 00100 00103        ES
76203  00103   55 00373 10030         FREE
76204  00104   61 00000 01305          SPACE
76205  00105   11 01305 01371            LIMITS
76206  00106   37 01255 01250
76207  00107   37 00107 00110
```

```
76210  00110  23 00372 01751
76211  00111  55 20000 00030
76212  00112  37 00107 00104
76213  00113  75 31777 01746     EXIT
76214  00114  11 74001 00001     RESTORE E.S.
76215  00115  23 00372 00322     ADJUST INST. LIMITS
76216  00116  75 30007 00071      WHIFFLETREE
76217  00117  11 00350 01472        ADDITION
76220  00120  75 30002 00122      CURRENT
76221  00121  11 30000 00362        P W
76222  00122  21 00121 01753     STEP
76223  00123  15 00362 00165     SET SUB. R. EXTRACT.
76224  00124  31 00363 00060
76225  00125  11 20000 00364     NUMBER OF INST.
76226  00126  34 20000 00014
76227  00127  11 20000 00365     NUMBER OF CONST.
76230  00130  34 20000 00014
76231  00131  11 20000 00366     NUMBER OF TEMP.
76232  00132  31 00364 00000      NUMBER
76233  00133  35 00365 00374        INST. AND CONST.
76234  00134  35 00317 00164     SUB. R.
76235  00135  55 00164 00017     TRANSFER
76236  00136  23 00372 00374     NEW INST. LIMIT
76237  00137  42 00343 00157     ALARM
76240  00140  16 20000 00165     SUB. R. LANDING
76241  00141  16 20000 00312     INST. RETURN
76242  00142  36 00346 00367     INST. MODIFICATION
76243  00143  11 00340 10000
76244  00144  52 00362 00363     MODIFIED ENTRANCE
76245  00145  13 00341 20000
76246  00146  36 00374 00370     TEMP. MOD.
```

```
76247  00147  55 00362 10006
76250  00150  51 00336 00362     O P
76251  00151  31 00366 00000      TEST
76252  00152  35 01752 20000       TEMP
76253  00153  42 00373 00155        LIMIT
76254  00154  11 20000 00373     CHANGE LIMIT
76255  00155  11 00373 20000
76256  00156  42 00372 00161
76257  00157  75 31777 76020     ALARM
76260  00160  11 74001 00001
76261  00161  31 00346 00000
76262  00162  35 00374 00365     UPPER LIMIT INST. MOD.
76263  00163  35 00366 00366     UPPER LIMIT TEMP.
76264  00164  30 30000 30000      SUB. R. FOR
76265  00165  11 30000 30000       MODIFICATION
76266  00166  37 00260 00251      MODIFY
76267  00167  45 00000 00312       U ONLY
76270  00170  31 00165 00017      SET INITIAL
76271  00171  15 20000 00233       INST ACQUISITION
76272  00172  41 00364 00233     TALLY INST. MOD.
76273  00173  11 00315 00231
76274  00174  31 00363 00017
76275  00175  35 00363 00363
76276  00176  55 00362 10043
76277  00177  44 00201 00200
76300  00200  11 00316 00231
76301  00201  55 00362 10041
76302  00202  51 00334 20000
76303  00203  55 10000 00003
76304  00204  43 00322 00222     TEST  60 TO 67
76305  00205  16 00344 00231     SET FOR  10,30
```

```
76306  00206  43 00320 00220     TEST FOR
76307  00207  43 01751 00220      10,30
76310  00210  43 00334 00212   TEST FOR  70 TO 77
76311  00211  45 00000 00157
76312  00212  16 00345 00231   SET FOR 74
76313  00213  51 00334 20000
76314  00214  43 00321 00231   TEST FOR 74
76315  00215  16 00332 00231   SET FOR 70, 71, 72, 73
76316  00216  42 00321 00222   TEST FOR 75, 76, 77
76317  00217  45 00000 00157   ALARM
76320  00220  51 00324 20000     TEST FOR
76321  00221  43 00324 00157      17, 37
76322  00222  51 00322 10000
76323  00223  47 00224 00231
76324  00224  43 01752 00230
76325  00225  43 00321 00227
76326  00226  23 00231 01751
76327  00227  23 00231 01752
76330  00230  23 00231 01751
76331  00231  30 00000 00000
76332  00232  45 00000 00071
76333  00233  11 30000 00375   CURRENT INST.
76334  00234  21 00233 00337   STEP
76335  00235  55 00375 10006
76336  00236  51 00336 20000
76337  00237  43 00323 00271   14 SPECIAL
76340  00240  43 00324 00261   V ONLY
76341  00241  43 00327 00261   V ONLY
76342  00242  42 00325 00251   U, V
76343  00243  42 00326 00166   U ONLY
76344  00244  42 00330 00251   U, V
```

```
76345  00245  42 00331 00166     U ONLY
76346  00246  42 00333 00261     V ONLY
76347  00247  42 00335 00251     U, V
76350  00250  45 00000 00261     V ONLY
76351  00251  55 00375 00025
76352  00252  51 00340 10000
76353  00253  42 00346 00256     NO MOD.
76354  00254  42 00365 00265     MOD INST
76355  00255  42 00366 00267     MOD TEMP
76356  00256  37 00256 00257
76357  00257  55 00375 00017
76360  00260  37 00260 00261
76361  00261  11 00375 10000
76362  00262  37 00256 00252
76363  00263  37 00263 00264
76364  00264  45 00000 00312     TO RESTOR
76365  00265  21 00375 00367
76366  00266  45 00000 00256
76367  00267  21 00375 00370
76370  00270  45 00000 00256
76371  00271  11 00375 00371     DUPLICATE
76372  00272  11 00375 10000      SYNTHETIC
76373  00273  51 01757 00375
76374  00274  51 00342 20000
76375  00275  31 20000 00003
76376  00276  35 00375 00375          INSTRUCTION
76377  00277  55 00371 10006
76400  00300  44 00301 00303     ONE, TWO ADDRESS
76401  00301  37 00263 00261
76402  00302  45 00000 00304
76403  00303  37 00263 00251
```

76404	00304	55	00375	20041	REPLACE
76405	00305	11	00342	10000	
76406	00306	53	20000	00371	WITH
76407	00307	11	01757	10000	SYNTHETIC
76410	00310	53	00375	00371	
76411	00311	11	00371	00375	PARTS
76412	00312	11	00375	30000	RETURN INST.
76413	00313	21	00312	01751	STEP
76414	00314	45	00000	00172	
76415	00315	15	00363	01477	
76416	00316	16	00363	01477	
76417	00317	00	17075	30000	
76420	00320	00	00000	00003	
76421	00321	00	00000	00004	
76422	00322	00	00000	00006	
76423	00323	00	00000	00014	
76424	00324	00	00000	00017	
76425	00325	00	00000	00031	
76426	00326	00	00000	00035	
76427	00327	00	00000	00045	
76430	00330	00	00000	00054	
76431	00331	00	00000	00056	
76432	00332	00	00000	01505	
76433	00333	00	00000	00071	
76434	00334	00	00000	00007	
76435	00335	00	00000	00075	
76436	00336	00	00000	00077	
76437	00337	00	00001	00000	
76440	00340	00	00000	77777	
76441	00341	00	00000	00776	
76442	00342	00	00177	70000	

76443	00343	00	00000	00400	LOWE LIMIT INST
76444	00344	00	00000	01632	
76445	00345	00	00000	01531	
76446	00346	00	00000	01000	
76447	00347	00	00000	01500	
76450	00350	44	01473	01474	01472
76451	00351	44	30067	30066	01473
76452	00352	44	30065	30064	01474
76453	00353	44	01476	01477	01475
76454	00354	44	30063	30062	01476
76455	00355	44	30061	30060	01477
76456	00356	44	01472	01475	01500
76457	00357	60	00000	00000	WHIFFLETREE
76460	00360	67	77777	77777	EXTENSION TESTS
76461	00361	30	17301	41142	

SPUR SQUARE ROOT

```
70252  01000  11 01766 01774    CASE ZERO
70253  01001  11 01766 20000    N TO A
70254  01002  46 76020 01003    NEGATIVE
70255  01003  47 01004 01742    ZERO
70256  01004  12 01767 10000     P EVEN
70257  01005  55 10000 00043       OR
70260  01006  44 01007 01011        ODD
70261  01007  21 01767 01751    P   1 TO P
70262  01010  54 01766 00107    N/2 TO N
70263  01011  55 01767 00043    N /2 TO P
70264  01012  11 01767 01775    P  TO R
70265  01013  43 01025 01742    N  EQUAL .9
70266  01014  11 01025 01762    .9   2    TO X
70267  01015  31 01766 00042     COMPUTE
70270  01016  73 01762 01763
70271  01017  54 01762 00107       SQUARE
70272  01020  23 10000 01762
70273  01021  21 01762 01763
70274  01022  44 01015 01023           ROOT
70275  01023  11 20000 01774    N  TO R
70276  01024  45 00000 01742    EXT
70277  01025  37 77777 77777    .9
```

SPUR CUBE ROOT

```
70300  01000  11 01766 01774     CASE ZERO
70301  01001  11 01766 20000     N TO A
70302  01002  47 01003 01742     N ZERO
70303  01003  11 01767 20000      P/3
70304  01004  73 01036 10000       TO Q
70305  01005  47 01006 01013     REM. ZERO
70306  01006  43 01752 01011     REM. 2
70307  01007  21 01767 01751     P   1 TO &
70310  01010  54 01766 00107     N / 2 TO N
70311  01011  21 01767 01751     P   1 TO P
70312  01012  54 01766 00107     N / 2 TO N
70313  01013  11 01767 20000      P  / 3
70314  01014  73 01036 01775       TP P
70315  01015  11 01037 01762     .9 X 2    TO X
70316  01016  11 01766 20000      N
70317  01017  46 01020 01021       NEG.
70320  01020  13 01037 01762     -.9 TO X
70321  01021  43 01762 01742
70322  01022  71 01762 01762     X
70323  01023  54 20000 00045     EXP 35
70324  01024  11 20000 01763
70325  01025  54 01766 20043     N  EXP 70
70326  01026  73 01763 20000       X
70327  01027  36 01762 20000     -X    EXP 35
70330  01030  73 01036 10000       X
70331  01031  21 01762 10000     X  EXP &5
70332  01032  71 10000 01766     N    X
70333  01033  46 01022 01034     NEG.
70334  01034  11 01762 01774     X  EQUAL N
70335  01035  45 00000 01742     EXIT
70336  01036  00 00000 00003
70337  01037  37 77777 77777     .9
```

SPUR nth ROOT SUBROUTINE

70200	01000	11	01761	20000	$n \rightarrow$ A
70201	01001	42	01752	76020	$n < 2 \rightarrow$ ALARM
70202	01002	75	30004	01004	N → S, R
70203	01003	11	01770	01772	
70204	01004	11	01770	20000	N → A
70205	01005	47	01006	01736	N = 0 ? → EXIT
70206	01006	11	01051	01764	.9 → P
70207	01007	46	01010	01013	N NEG. ?
70210	01010	13	01764	01764	-.9 → P
70211	01011	55	01761	10043	n EVEN → ALARM
70212	01012	44	01013	76020	
70213	01013	11	01771	20000	EXP → A
70214	01014	73	01761	01775	EXP/N → 1775, REM. → A
70215	01015	11	10000	01765	EXP/N → P
70216	01016	47	01017	01022	REM. = 0 ?
70217	01017	21	01765	01751	EXP/N + 1 → P
70220	01020	75	30002	01024	S = N → C
70221	01021	11	01772	01770	
70222	01022	11	01770	20000	N → A
70223	01023	43	01764	01742	N = ±.9 → EXIT
70224	01024	11	01761	20000	$n \rightarrow$ A
70225	01025	36	01752	01052	$n - 2 = J \rightarrow 1052$
70226	01026	11	01764	01766	$X_{i-1} \rightarrow$ B
70227	01027	11	01765	01767	
70230	01030	37	01030	01031	
70231	01031	37	01741	01633	N/X_{i-1}^{n-1}
70232	01032	41	01052	01026	
70233	01033	37	01030	01026	$X_{i-1} \rightarrow$ B
70234	01034	37	01741	01655	$N/X_{i-1}^{n-1} - X_{i-1}$
70235	01035	73	01761	20000	$/n = \Delta X$
70236	01036	37	01741	01712	NORMALIZE Δ X
70237	01037	47	01040	01047	$\Delta X = 0$? → EXIT

70240	01040	11	01775	01052	ΔX EXP. $\rightarrow$ 1052
70241	01041	37	01030	01026	$X_{i-1} \rightarrow B$
70242	01042	37	01741	01656	$X_{i-1} + \Delta X = X_i$
70243	01043	11	01774	01764	$X_i \rightarrow P$
70244	01044	11	01775	01765	
70245	01045	23	01771	01052	$(X_i \text{ EXP}) - (\Delta X \text{ EXP}) \rightarrow A$
70246	01046	42	01754	01020	$A > 35 \rightarrow$ EXIT
70247	01047	75	30002	01742	EXIT
70250	01050	11	01764	01774	$X_i \rightarrow R$
70251	01051	37	77777	77777	.9

THE RAMO-WOOLDRIDGE CORPORATION

LOS ANGELES 45, CALIFORNIA

DATE: January 9, 1956

SUBJECT: Computing Center Organization

FROM: W. F. Bauer

The following delineates the areas of interest, cognizance, and responsibility of the five groups comprising the organization of the Digital Computing Center.

SYSTEMS AND TRAINING

1. Develop, maintain and improve a comprehensive computation system for the 1103 and 1103A including component parts such as compiler, algebraic coding scheme, service routines, and the routines necessary for effecting an automatic system, implementing, insofar as is possible, the suggestions for such programs and routines made by all other groups.

2. Develop such administrative procedures concomitant to the computation system to ensure the proper flow of information to and from the personnel of the Operations Group which operates the various equipments, and cooperate with that group in effecting the plan.

3. Keep subroutine and service routine library records, disseminate appropriate programming and system operation information to Computing Center personnel and other interested parties, and participate in cooperative programming efforts and in the exchange of program information between 1103 or 1103A users.

4. Aid in the general recruiting program and assume major responsibility in the initial instruction and training of personnel in programming techniques.

5. Recruit and train computer operators, operate the 1103 (or 1103A) computer, and develop operating techniques necessary to insure the highest standards of computer use.

6. Carry out specific projects in programming and computer studies as may be assigned.

OPERATIONS

1. Aid the Systems Group in developing methods and procedures for operation of the 1103 (or 1103A) computation system, and appropriately execute such procedures.

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2. Schedule 1103 (or 1103A) computer time and develop and initiate methods and procedures as necessary to generate and maintain adequate records concerning problem assignments, records necessary for budget and fiscal requirements, and records of computer operating data.

3. Operate all auxiliary and off-line equipment, including hand computer equipment, recruit and train operators of such equipment, and design procedures as are necessary in the operation of such equipment.

4. Determine the need and specifications for any equipment to be modified, purchased or especially built, and transmit information as needed to programming groups on the operation and characteristics of such equipment.

5. Perform computer programming as necessary, especially on those problems involving special equipment such as analog-digital converters used in simulation and data reduction activities.

PROGRAMMING

1. Make contacts as necessary with customers and problem originators in the programming and running of assigned problems.

2. Assume major responsibility for the central GMRD programming effort as assigned, such as aerodynamics, structures, and air frame and trajectory analysis.

3. Cooperate with and advise the Numerical Analysis and Systems Groups on the development of routines necessary for production computation.

4. Cooperate with and advise the Operations Group in the development of a computation system and its subsequent adoption.

5. Assume major responsibility for the general recruiting program and the evaluation of prospective programmers.

NUMERICAL ANALYSIS

1. Consult with customers or problem originators on problems requiring special attention in regards formulation for numerical handling, advise on the formulation and machine plan of all problems in the Computing Center, and assume major responsibility for certain problems as assigned.

2. Conduct basic and applied research in numerical analysis and machine techniques and publish the results whenever appropriate.

3. Ascertain the need for, determine specifications, and develop techniques of standard numerical operations (e.g. matrix inversion, differential equation solving) as are needed and, when appropriate, perform the computer programming necessary.

4. Aid in the general recruiting program, and assume major responsibility in the recruitment of numerical analysts in cooperation with the Programming Group.

5. Provide technical support and coordination to the activities of consultants to the Computing Center in numerical analysis.

MATHEMATICAL ANALYSIS

1. Consult with customers or problem originators on problems, performing such mathematical research and analysis as is assigned or necessary; advise the Computing Center on the formulation of problems when appropriate; and consult with the Numerical Analysis Group to determine the combination of machine and analytical techniques likely to give most fruitful results.

2. Conduct basic research in Applied Mathematics as is appropriate and publish such results.

3. Aid in the general recruiting program, and assume major responsibility in the recruitment of applied mathematicians in cooperation with the Programming Group.

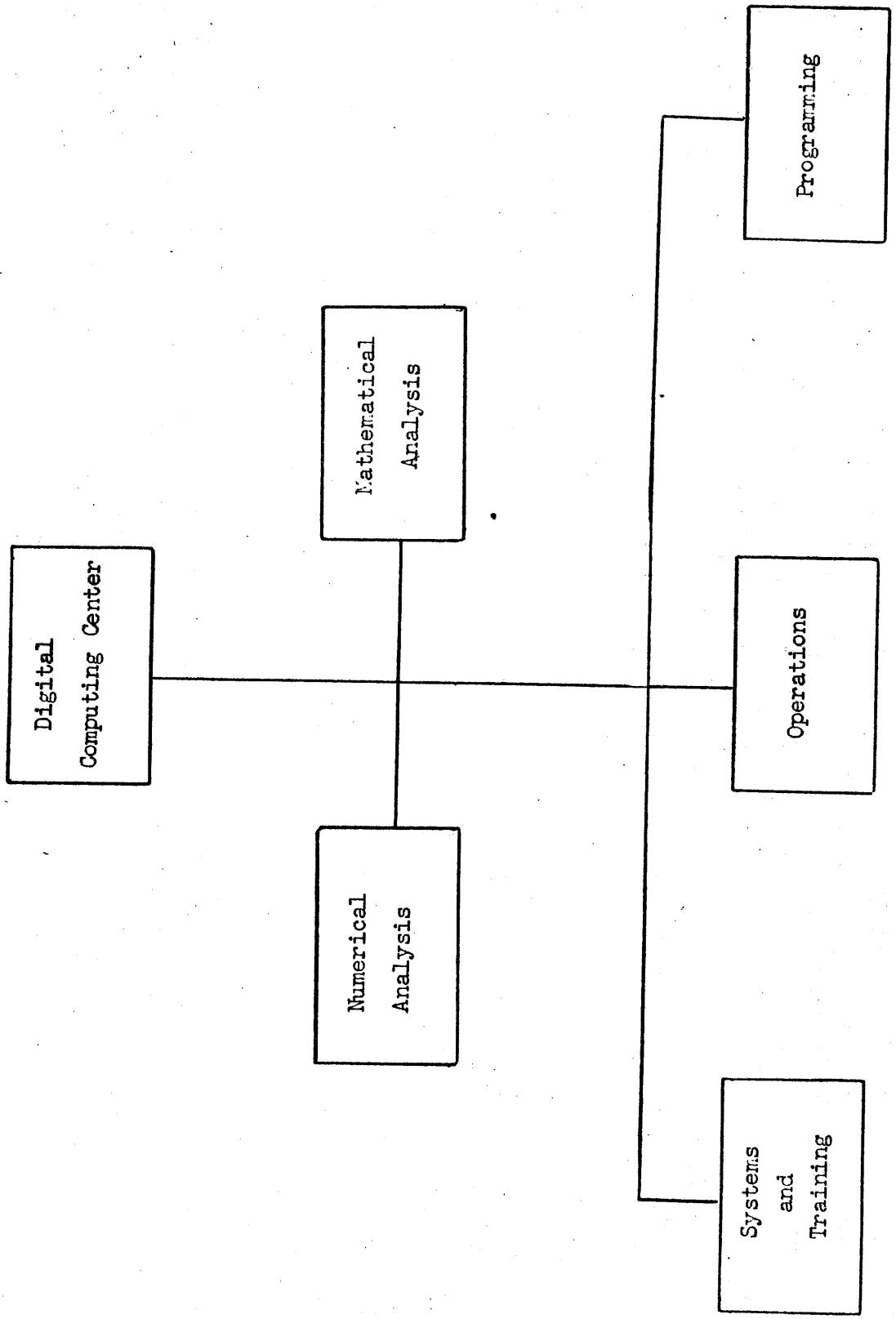
4. Provide technical support and coordination to the activities of consultants to the Computing Center in applied mathematics.

5. Provide and maintain sources of information in applied mathematics in the form of appropriate seminars, lectures, courses, and the Computing Center Library.

Walter F. Bauer

Walter F. Bauer

:njs


Digital
Computing Center
Mathematical
Analysis
Numerical
Analysis
Programming
Operations
Systems
and
Training

MATHEMATICAL SERVICES BRANCH

At the Air Force Armament Center the bulk of the machine computations are performed by two Directorates, the Directorate of Ballistics and the Directorate of Technical Support.

Within the Directorate of Technical Support the Mathematical Services Branch is responsible for the reduction of data on each test project to insure that data are suitable for analysis and/or inclusion in the final report. This Branch is divided into three Sections; Test Data, Computation and Equipment Maintenance.

The Test Data Section establishes mathematical and assessment procedures for processing test data; receives, stores, edits, and reviews raw and processed data; assists other agencies in programming problems; spot lchecks processed data, accomplishes assessment on selected portions of test data; prepares data for submission to project and analysis personnel.

The Computation Section accomplishes computation on the electronic digital computer; assists mathematicians in working out computation and reduction techniques and in selecting instrumentation methods compatible with computing and analyzing equipment; operates analog-to-digital converts, plotters, electronic analyzers, recorders, and computer output devices, develops techniques and procedures applicable thereto.

The Equipment Maintenance Section maintains data reduction and computing equipment of the Center; provides service assistance in the electronic computer and associated equipment; accomplishes minor modification of existing equipment as required by Project Mathematicians.

Each of these Sections are divided into operating groups with defined responsibilities in specialized fields as indicated on the organization chart.

Within the Directorate of Ballistics the Ballistics Computations Officer performs necessary data programming and computations utilizing existing facilities to greatest extent possible; provides consultant services to develop new data reduction and computation techniques.

A third organization, the Analysis Division, also initiates computing requirements at the Air Force Armament Center. Within this Division the Test Analysis Branch recommends priorities for all the Center's computing facilities and associated functions; applies numerical analysis techniques and performs coding and computations of analysis problems on the Center's computers as required. The Research Branch originates improved and/or new computing techniques and procedures where existing ones are inadequate or non-existent, except in the ballistics area; investigates, on a continuing basis, computing methods and techniques employed elsewhere, for possible use at the Center.

In addition the Applied Mathematics Division of the Directorate of Statistical Services, Air Proving Ground Command, assists in programming and operating Air Force Armament Center projects on the computers available in that Command.

UNPACKED FLOATING POINT CARD READ

```
7 400   00742   56 00000 30000     EXIT
7 401   00743   75 31777 72403     STORE
7 402   00744   11 00001 74001       ES
72403   00745   75 30352 00747     ROUTINE
72404   00746   11 72400 00742      TO ES
72405   00747   11 00742 20000     SET
72406   00750   36 01264 72432      REPEAT
72407   00751   35 01305 20000     SET
72410   00752   16 20000 00770      EXIT
72411   00753   55 00742 20025     TEST FOR
72412   00754   44 00757 00756      ES
72413   00755   00 00000 00114       ADDRESSES
72414   00756   32 00776 00000     ADDRESS MODIFICATION
72415   00757   55 20000 00017
72416   00760   37 00760 00761
72417   00761   16 20000 00763     SET ACQUISITION
72420   00762   11 00777 01024     ERASE INSTRUCTION
72421   00763   71 01264 30000     ACQUIRE CONTROL WORD
72422   00764   55 20000 00006
72423   00765   37 00760 00754     X
72424   00766   55 20000 00017
72425   00767   37 01001 01004     TP SIBRPITOME
72426   00770   75 31777 30000     RESTORE E S
72427   00771   11 74001 00001      AND EXIT
72430   00772   75 31777 72432     RESTORE E S
72431   00773   11 74001 00001      AND
72432   00774   30 00000 0000         REPEAT
72433   00775   02 00000 00104
72434   00776   74 00000 00000
72435   00777   11 00000 00000
72436   01000   30 00000 0000*    REPEAT
72437   01001   45 00000 30000     EXIT
```

THE RAMO-WOOLDRIDGE CORPORATION
LOS ANGELES 45, CALIFORNIA

UTILITY ROUTINE LIBRARY

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FRI-1	10-03-55	SIMPLIFIED FERRANTI INPUT FOR BOOTSTRAP
HTO-0	07-25-55	DECIMAL OUTPUT ROUTINE FOR FLEXOWRITER AND PUNCH
INT-1	10-10-55	INTERPOLATION WITH UNEQUAL INCREMENTS IN ARGUMENT
LOG-1	11-22-55	FIXED POINT NATURAL LOGARITHM
LOG-2	08-10-55	FLOATING POINT NATURAL LOGARITHM ROUTINE

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MDP-0	12-09-55	THE FLEXOWRITER MEMORY DUMP, REVISED
MDP-1	12-09-55	THE BIOCTAL MEMORY DUMP, REVISED
MDP-2	12-09-55	THE OCTAL CARD DUMP
MDP-3	12-09-55	CHANGED WORD POST MORTEM
MDP-4	05-01-56	OCTAL CARD DUMP
MII-0	05-01-56	MANUAL INSPECTION AND INSERTION
MTI-0	11-30-55	LINEAR MATRIX EQUATION SOLVER
MTI-1	07-26-56	LINEAR MATRIX EQUATION SOLVER, FLOATING POINT
MTI-2	08-03-56	LINEAR MATRIX EQUATION SOLVER, COMPLEX
NRT-0	12-01-55	NTH ROOT ROUTINE
NUI-3	05-01-56	NUMERICAL INTEGRATION BY THE GILL METHOD
NUI-4	05-10-56	FLOATING POINT GILL METHOD
NUI-5	06-20-56	GILL METHOD, COMPLEX
POL-0	09-04-56	ALGEBRAIC EQUATION SOLVER
RAN-0	05-20-56	NORMALLY DISTRIBUTED PSEUDO RANDOM NUMBERS
RPH-0	05-23-56	COLUMN HEADING ROUTINE
SAM-0	08-09-55	AUTOMATIC SAMPLER
SIN-0	05-01-56	CENTRAL EXCHANGE SINE-COSINE ROUTINE
SIN-1	05-01-56	POLYNOMIAL MULTIPLY SINE-COSINE ROUTINE
SIN-2	05-01-56	SMALL ANGLE SINE-COSINE ROUTINE
SIN-3	08-10-55	FLOATING POINT SINE-COSINE ROUTINE
SIN-4	05-15-56	FLOATING POINT SINE-COSINE
SNI-1	06-15-56	ARCSINE-ARCOSINE ROUTINE
SNI-2	08-01-56	ARCSINE-ARCOSINE, FLOATING POINT
SQR-0	05-01-56	SQUARE ROOT ROUTINE
STT-0	12-09-55	STORAGE TO MAGNETIC TAPE TRANSFER
TNI-0	05-01-56	ARCTANGENT ROUTINE
TNI-1	06-15-56	FLOATING POINT ARCTANGENT ROUTINE
TST-0	12-09-55	MAGNETIC TAPE TO STORAGE TRANSFER
URT-1	WRITE UP NOT AVAILABLE	
URT-3	WRITE UP NOT AVAILABLE	

CUMULATIVE ERRATA 08-15-56

BULLETINS #12 AND #14

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

RAMO-WOOLDRIDGE PROGRAMMING AND OPERATING CONVENTIONS

1. Drum addresses 55359 to 56383 (76000b to 77777b) have been reserved for the drum image of electrostatic storage. These 1024 cells will be used by those service routines which operate in electrostatic storage and which must restore electrostatic storage after performing their functions. This part of the drum should not be used by the programmer to store part of his production program (Note: Drum addresses start at 40000 in decimal notation).

2. Drum cells 52287 to 55358 (70000b to 75777b) are reserved for the storage of service routines and are not, in general, available for general program use.

3. Drum cells 48191 to 52286 (60000b to 67777b) will be used for the assembly data, assembly program, and subroutines. These cells are available for general program use, since the information will be stored in these cells only during program assembly. If more space is required for subroutines, cells 57777b and lower may be used.

4. Electrostatic storage cells 13 through 22 (15b - 26b) have been set aside for a ten-word constant pool as follows:

13	Zero	00015	00 00000 00000
14	Six Bit Extractor	00016	00 00000 00077
15	Advance u	00017	00 00001 00000
16	Advance v	00020	00 00000 00001
17	Advance u and v	00021	00 00001 00001
18	Decimal 72	00022	00 00000 00110
19	Alternator	00023	52 52525 25252
20	Operation Code Extractor	00024	77 00000 00000
21	"n" Extractor	00025	00 07777 00000
22	(not yet assigned)	00026	

5. Cells 23 through 32 (27b through 40b) have been set aside for temporary storage. These temporary cells should be used in the strictest sense of the word and the programmer should not assume information will remain in these cells unchanged in passage from one portion of a program to another.

6. There will be three methods of starting the computer depending upon the amount of information stored on the drum and magnetic tape as follows:

   a. If the Ferranti read-in program is stored on the drum in its normal place along with the other utility routines, a tape can be read in by transferring control to cell 40001.

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b. If the service routines are not on the drum, an MT start is performed which reads the service routines onto the drum from magnetic tape Unit = 0. During this transfer, check sums are completed and checked against sums previously obtained upon storage of the routines on tape.

c. In the event the service library data has been removed from the magnetic tape Unit = 0 and the drum due to engineering maintenance or another reason, a bootstrap procedure will be used to read the service routine library and Ferranti read-in routine into appropriate positions in the computer from either paper tape or binary cards.

7. Certain jump instructions will be read into cells 40001 through 40040 along with the service library data. The jump instruction will cause control to revert to the routines as indicated in the list of 40000 group entrances.

The jump word in 40000 is placed there during read-in of the program tape prepared by the assembly routine. The remaining jump words will be assigned as necessary. The usage of these cells to transfer control to the appropriate service routines will result in the following advantages: the cells are easily remembered; the PAK is easily set to addresses in the indicated range by means of the MD start; and the cells serve as "symbolic entrances" since the position of the service routines on the drum can be changed without changing the entrance address, and the programmer need not concern himself with the knowledge of the new location.

8. In programming production problems it is desirable that conditional stop orders be included so that the computer operator can halt the progress of a production run when it becomes necessary. Such stops should be strategically placed in short loops and at a point where the contents of A and Q are not relevant. It will be necessary, therefore, that the programmer supply the computer operator with the following data:

a. How to set up the stop order(s). That is, for example, which MS selecting switches must be set to "stop".

b. What are the areas of ES and the drum used by the program.

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

PROGRAMMING REMINDERS

The following list of Programming Reminders has been compiled using the experience of the members of the programming staff. The list has been divided into two groups: general, and those reminders pertaining to the One Pass Assembly Routine (RAWOOP, CMP-0).

General Reminders

1. An index junp changes the contents of the accumulator.

2. Use (n-1) with an index junp, assuming the index jump is performed after the operation.

3. Clear the accumulator before using an MA instruction.

4. A magnetic tape command changes the contents of the Q-register.

5. The order of the j and n in a repeat instruction is as follows:

   RP j n w

6. The B register occupies A_{70}, A_{69} .....A_{35} and is different from AL. Not only can one perform such operations as TP B A but the fault circuitry will not prevent one from jumping to B, as it will for the A register. The operation SF B k will result in the scale factoring af A + B. (This is applicable only to the Ramo-Wooldridge 1103.)

7. When the computer is halted in the middle of a repeat instruction sequence, the PAK register contains the complement of j(n-r).

8. When using an RP instruction followed by a TJ or EJ instruction, the rightmost fifteen bits of the Q-register contain j(n-r) upon jumping out of the sequence. Since j is present n-r must be obtained by an extraction rather than with a TV instruction.

9. It is interesting to note that much can be said concerning error growth for unrounded multiplication and division. The following rules hold:

   Multiplication (axb)

   the truncated product (contents of B register) is too small if $axb > 0$

   the truncated product is too large if $axb < 0$

   the absolute value of the product is always too small

Division (a/b)

the actual quotient is too small if $b > 0$

too large if $b < 0$

Hence, one can predict, for example, that $\sum_i a_i/b_i$ will be too small if $b_i > 0$. This bias precludes the possibility of employing the usual formulas for probable error which assume a normal distribution of error about a mean zero.

Reminders for the One Pass Assembly Routine

1. If it is desirable to refer to the constant and temporary storage pools with symbolic addresses, directory cards should be included for them.

2. Rawoop converts decimal numbers to binary numbers occupying 35 bits plus a sign bit.

3. When converting drum addresses, 40000 in decimal is equivalent to 40000 in octal.

4. When specifying the beginning of a region, one must use the first symbolic address of a block. For example, D 03M00 00500 must be used and not D 03M15 00515.

5. Since SNAP addresses are limited to 9 bits the A, Q and B registers cannot be addressed directly.

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

The Utility Routine Library Handling Package for Paper Tape Input

Normal Operation

During normal operation, the Service Routine Library is stored on the drum. In order to use one of the routines, control is transferred to one of the low-numbered drum addresses in the 40000b channel (see the list of "Service Routine Starting Addresses").

Details concerning the operation of these routines and their locations can be found in the write-ups.

MT Start

If, at any time, the library stored on MD is destroyed by a program, or because the drum interlace has been changed, or for some other reason, the entire library may be loaded onto MD from magnetic tape. Selecting MT Start and starting effects loading of the service routine library from MT zero. PAK is set to the FRI-0 starting address upon completion of the transfer. Selecting MT Start, setting $A_R = 1$, and starting effects loading of the service routine library and the assembly program and subroutines from MT zero. PAK is set to the CMP-0 starting address upon completion of the transfer.

Bootstrap

Since the Ferranti reader requires a programmed read in, it is necessary to "bootstrap" into the machine when no input routine is stored in memory. The procedure devised to load an input program involves the use of one binary card (since this method requires the fewest number of instructions to be loaded manually). It is necessary to key in manually only four words which perform the read in of one binary card (24 words) and transfer control to these 24 words.

This binary card contains a simplified Ferranti Input Routine (FRI-0) which then begins to read in the service routine library paper tape. This tape contains at its beginning the regular FRI-0 input routine and instructions transferring it to its proper location on MD. When FRI-0 has been loaded on MD control is transferred to it and FRI-0 reads in the remainder of the tape.

Following FRI-0 on the tape are the library, a Magnetic Tape to MD transfer routine (URT-1), and an MD to Magnetic Tape transfer routine (URT-3). When the complete paper tape has been read in the computer halts with the library loaded on MD. PAK is set to 40000 by an MD Start, the machine is started and URT-3 transfers the library and URT-1 to magnetic tape unit zero. The computer then halts with PAK set to 40001, the FRI-0 starting address.

Detailed Descriptions of Routines

Detailed descriptions, operating instructions, and codes for the routine mentioned above are included in the notebook.

Operating Instructions for the Bootstrap Procedure (Loads MD and MT zero with Service Routine Library)

1. Put the binary card deck in reader making sure that card reader is set for two fields and that all three switches on the reproducer are away from the card hoppers. Also be sure that there are cards in the punch hopper as the reader will not operate without them.

2. Put the library paper tape in the Ferranti Reader.

3. Position MT zero at the dead space immediately preceeding the first block. (Maintenance people will perform this function if requested).

4. Key in the following program:

00104	17 00000 00104	pick card
00105	17 00000 00105	read and pick card
00106	75 30030 00000	read one binary card
00107	76 10000 00000	then jump to 00000

5. START at 00104. The computer reads in one card containing the simplified Ferranti routine, then switches control to this routine which reads in FRI-0 and the necessary orders to transfer it to MD. After FRI-0 has been placed on MD, control is transferred to it and it reads in the library tape and the MT to MD and MT transfer routines. The computer then halts with the MS instruction 56 00000 40001.

6. Select MD Start

7. Set low order octal digit of Q to the address of the MT unit desired.

   To load tape zero, omit this step of the procedure.

8. START. The MD to MT routine loads the MT to MD routine, 40001b thru 40040b, 70000b thru 75777b, and 60000 thru 67777 onto MT zero. The computer then halts with the MS instruction 56 00000 40001, setting PAK to the FRI-0 starting address.

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Pool of Flexowriter Codes

Specifications

Identification Tag:	FLX-0
Type:	Constant Pool
Storage:	17 cells, addresses 75757b thru 75777b
Note:	This pool of certain flexowriter codes has been established in order to prevent duplication of storage in the Service Routine Library. See the listing for details.

Approved by: W. F. Bauer June, 1956

```
D          FLX00 55343
FLX00              37 B      F 0          75757  00 00000 00000
FLX01              52 B      L 1          75757  00 00000 00037
FLX02              74 B      E 2          75760  00 00000 00052
FLX03              70 B      X 3          75761  00 00000 00074
FLX04              64 B      0 4          75762  00 00000 00070
FLX05              62 B      W 5          75763  00 00000 00064
FLX06              66 B      R 6          75764  00 00000 00062
FLX07              72 B      1 7          75765  00 00000 00066
FLX08              60 B      T 8          75766  00 00000 00072
FLX09              33 B      E 9          75767  00 00000 00060
FLX10              45 B      R CAR RETURN 75770  00 00000 00033
FLX11              04 B        SPACE      75771  00 00000 00045
FLX12              57 B      C SHIFT DOWN 75772  00 00000 00004
FLX13              47 B      0 SHIFT UP   75773  00 00000 00057
FLX14              51 B      D TAB        75774  00 00000 00047
FLX15              42 B      E PERIOD     75775  00 00000 00051
FLX16              56 B      S MINUS      75776  00 00000 00042
START                                     75777  00 00000 00056
```

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CUMULATIVE ERRATA

CVF-0 11/14/55

Page 5, line 12 from the bottom should read "n = (50000b)" and not "n + 1 = (50000b)".

DET-2 7/25/56

Page 4, Line 00R10 should read "SP A0000 00016 00776 31 20000 00020"

EGN-0 5/1/56

Page 8, line 14 should start "or the ERA paper tape reader)....."

Page 16, line 7 should start "if $n \leq 38$,.....

EXT-3 8/10/55

Page 1, drum assignment should read "63766 b through 64044 b."

HTO-0 7/25/55

Page 1, drum assignment should read "62504 b through 63037 b".

MDP-3 12/9/55

Page 2, line 12, reference to MDP-2 should read MDP-4.

Page 2, line 14, should start "each card contains six words".

NRT-0 12/1/55

Page 2, line 5 should read "$2 \leq n \leq 2^{12}$"

NUI-3 5/1/56

NUI-4 5/10/56

NUI-5 6/20/56

In each of these Gill Method routines it should be noted under "Operating instructions" that the cells reserved for the q_1 must be set to zero by the programmer initially and whenever a discontinuity occurs.

It has been pointed out that the error analysis in Gill's paper is not applicable to these routines.

NUI-5 6/20/56

Page 1 "type" should read "subroutine, available on cards for assembly".

"Assembly Routine Spec" line should be replaced by "Regions used: GIL, GIN, GIM, GCN"

SIN-4 5/15/56

Page 1, "Storage" should read "65 words total program storage. 5 words temporary storage pool used, addresses 27 b through 33b".

THE RAMO-WOOLDRIDGE CORPORATION
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Utility Routine Transfer Drum to Magentic Tape

Specifications

Identification Tag:	URT-3
Type:	Service routine (part of library loading package)
Storage:	110 instructions, addresses 00045b thru 00222b
	8 constants in program, addresses 00223b thru 00232b
	All of ES is used for temporary storage but not included with the program
	118 words total program storage, addresses 00045b thru 00232b
	The temporary and constant storage pools are not used by this routine
Entrance:	40036b
Machine Time:	100 seconds approximately
Mode of Operation:	Fixed point

Coded and Checked by:	R. Beach	August, 1955
Approved by:	W. F. Bauer	August, 1955

Description

Upon being entered the routine first bootstraps itself and URT-1 into ES, then sets up all references to magnetic tape to correspond to the unit selected when URT-3 is activated. URT-1 is transferred to ES beginning at cell 1700b.

The contents of cells 40001b thru 40040b and 70000b thru 75777b are then summed and the sum placed in 01774b and 01775b. The contents of cells 01700b thru 01775b are then summed and the sum placed in 01776b and 01777b. The information in cells 01700b, 70000b thru 75777b, and 40001b thru 40040b are then transferred to MT in that order.

The contents of cells 60002b thru 67777b are summed and the sum placed in 60000b and 60001b.

STT-0 is entered to dump the information in cells 60000b thru 67777b (the subroutine library consisting of RAWOOP and the subroutines).

URT-3 computes the sum of all information placed on MT, rewinds MT to its original position and reads back the data from MT, summing as it reads.

If the sum is correct, a BM instruction is given to return MT to its original position and computation halts with PAK set to 40001b, the FRI-0 starting address.

Operating Instructions

1. Select MD Start.

2. Set the number of the MT to be loaded in the low order octal digit of Q.

3. Start.

   URT-3 transfers the complete library to MT and halts with the MS instruction 56 00000 40001 after a successful transfer.

Alarm Conditions

If the sum of data read back from MT is not correct the alarm routine is entered; the tag word URT-3 and the address 00070 are printed on the flexowriter. The sum of the data on MT appears in A.

Restarting at this time initiates another transfer to data.

Warning

1. It is advisable to position MT at the first block before loading so that the MT can be repositioned, manually if necessary.

2. After a successful transfer the machine halts but MT is still rewinding to its original position. If a master clear is executed and the machine started a reference to the rewinding MT (before the rewinding is complete) will cause trouble. If no master clear has been executed the machine will wait for the reversing to be completed.

THE RAMO-WOOLDRIDGE CORPORATION
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Utility Routine Transfer-Magnetic Tape to Drum

Specifications

Identification Tag:	URT-1
Type:	Service routine (part of Library Loading Package)
Storage:	57 instructions, addresses 00000b thru 00070b 1 constant in program, address 00073b (remaining constants stored with instructions) The remainder of ES is used as temporary storage The constant and temporary storage pools are not used by this routine
Entrance:	MT Start
Machine Time:	Approximately 15 seconds for successful transfer of the service routine library only, or approximately 35 seconds for transfer if CMP-0 and the subroutine library are included.

Coded and Checked By:	R. Beach	April, 1955
Approved by:	W. F. Bauer	August, 1955

Description

This routine is located in the first two blocks of the magnetic tape unit used for the library (normally MT#0) and is specifically designed to transfer the library from magnetic tape to magnetic drum.

It operates in three different modes, the mode of operation having been selected when it was activated. Mode No. 1 loads addresses 40001b thru 40040b and 70000b thru 75777b only. Mode No. 2 loads these addresses and addresses 60000b thru 67777b. Mode No. 3 advances past the library and reads in the first block of the ERA maintenance routine loader, then transfers control to that loader.

This routine does not save the contents of ES since it is assumed that it will be used only when a complete reloading of the computer memory is necessary. An MT Start reads in the first 32 words of the routine and starts operation. The routine first reads in an additional 32 words from MT (remainder of the routine itself) and then checks its sum, which is stored at the end of the second block. In doing this, it also checks the sum of the service routine library which is stored in the second block.

After a successful sum check the routine reads in the 96 blocks needed to fill 70000b thru 75777b. Twenty-four blocks are read in at one time and transferred to MD, then read back into ES and summed. When all 96 blocks have been transferred the routine reads in one more block and transfers this into 40001 thru 40041, reads it back into ES, sums, and adds the sum to the sum of the 96 blocks previously transferred. This computed sum is then checked against the correct sum.

If Mode No. 1 has been selected a rewind instruction is given and the computer halts with the MS instruction 56 00000 40001, setting PAK to the FRI-0 starting address.

If Mode No. 2 has been selected, TST-0 is activated to read in RAWOOP and the subroutine library. A rewind instruction is given and the computer then halts with the MS instruction 56 00000 40010, setting PAK to the CMP-0 starting address.

Operating Instructions

I. To transfer the service routine library only

1. Select MT Start
2. Change PCR (if necessary) to select the proper MT unit
3. Start. The routine loads 40001b thru 40041b and 70000b thru 75777b and halts with the MS instruction 56 00000 40001, setting PAK to the FRI-0 starting address. Successful transfer takes about 15 seconds.

II. To transfer the service routine library, CMP-0, and the subroutine library

1. Select MT Start
2. Change PCR (if necessary) to select the proper MT unit.

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3. Make A = 1

4. Start. The routine loads 40001b thru 40040b, 70000b thru 75777b, and 60000b thru 67777b and halts with the MS instruction 56 00000 40010 setting PAK to the starting address of CMP-0. Successful transfer takes about 35 seconds.

III. To load ERA Maintenance Routines

1. Select MT Start.

2. Change PCR (if necessary) to select the proper MT unit.

3. Make A $\geq$ 2

4. Start. The routine advances the MT unit and loads the 229th block into ES placing the first word in cell zero. The number in the accumulator is reduced by 2 and left in A for the ERA loader to use in selecting its mode of operation. Control is then transferred to cell zero.

Alarm Conditions

1. If the machine halts on a final stop almost immediately after an MT start the transfer routine is not in ES correctly.

   Select MT start and start for another transfer. If the second transfer is not successful revert to the bootstrap procedure to load the library.

2. If the flexowriter prints an "e" and the machine halts on a final stop the sum of the library transferred to the drum is not correct.

   Select MT start and start for another transfer. (Wait for rewinding to be completed before executing start).

3. When operating in Mode No. 2 TST-0 is activated after address 40001b thru 40040b and 70000b thru 75777b have been loaded successfully. If the sum test fails while loading addresses 60000b thru 67777b, the alarm routine prints the tag word TST-0 and the address 75777b. Starting causes rewind and another MT transfer to addresses 60000b thru 67777b.

Warning

After a transfer the computer halts but MT is still rewinding to its original position. If a Master Clear is executed and the machine started, a reference to the rewinding MT (before rewinding is complete) will cause trouble. If no Master Clear has been executed the machine will wait for the rewinding to be completed.

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

THE RAMO-WOOLDRIDGE ONE-PASS ASSEMBLY ROUTINE

Specifications

Identification Tag:	CMP-0	
Type:	Service Routine	
Entrances:	40000b and 40010b	
Coded by:	Jules Mersel	
Code Revised by:	Thomas Tack	October 1955
Approved by:	Walter F. Bauer	October 1955

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Description

The Ramo-Wooldridge one-pass assembly program (RAWOOP) is designed to translate an 1103 program originally coded in symbolic, regional, octal, and decimal form into its final octal form.

The program will accept instructions with symbolic addresses and numerical data in binary or decimal form. It will cause subroutines to be appropriately assembled into the program. The result of assembling a program will be output in a form which facilitates program check out and rapid read in of the translated data.

Input-Output

Punched cards are used as input for RAWOOP. The punched card contains one 1103 word with remarks or contains an instruction to the assembly program with remarks. RAWOOP's output is via both punched cards and punched paper tape. The output card contains an exact duplicate of the corresponding input card plus an octal translation of the input data. The programmer can obtain a side by side listing of his untranslated program, remarks, and translated program by listing the output deck on associated equipment such as the IBM 407.

The punched paper tape is a seventh-level bioctal tape complete with insert and check addresses, and is used to read the translated program into the 1103 by either the ERA photo-electric reader or by the Ferranti tape reader with an appropriate read in program. A leader and trailer is automatically included on each tape prepared.

Input and Output Cards

The input and output cards are standard 80-column, 12-row cards. The allocation of the information with respect to the card columns is as follows:

1-5	symbolic address of the untranslated word
7-10	1103 operation characters or pseudo-instruction symbols of the untranslated word
12-16	u address of the untranslated word
18-22	v address of the untranslated word
24-26	decimal scaling information for the untranslated word
28-30	binary scaling information for the untranslated word
32-43	alpha-numeric remarks

It is noted that symbolic coding for SNAP (Interpretive floating point package) deviates from these conventions (see pg. 6). In addition to the above columns, the output cards contain the translated information in columns 47-67.

On the input cards, zeros need not be punched.

FIGURE 1

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PAGE_____ OF_____

PROBLEM_____

Line	ADDRESS	OP	U	V	± D	± B	COMMENTS
1	D		1C	512			THIS IS NOT
2	D		99Z	630			
3	D		12T	49 0100			A PROGRAM.
4	D		73L	1832			
5	D		T	2			
6	1C	RP	3 19	1C 2			IT IS A LIST
7	1C 1	TN	12T 5	Q			
8	1C 2	SP	99Z13	9			OF EXAMPLES
9	1C 3	MJ	3	99Z 1			
10	1C 4	LA	12T 4	2 18			OF THE TYPES
11	1C 5	ZJ	99Z	99Z 02			
12	1C 6	-	123456	789 01	4	180	OF WORDS
13	1C 7		3123		- 6	22	
14	1C 8		1 6793		8	- 10	ACCEPTABLE
15	1C 9	TPQ		A			
16	1C10	21	12T28	12T 12	B R R		TO CMP-0.
17	1C11	RJ	73L 1	73L 2			
18	1C12	SJ	99Z23	99Z 30			
19	1C13	1	0246		3	F	
20	1C14		7777		B		
21	73L	SUB	5101 8	23 4			
22	START		01C00				
23	DIC00	72	03421	01C 29	B B R		
24	DIC01	17	D1C29	0342 1	B R B		
25	DIC02	27	1RC29	DBC 28	B R R		
26	DIC03	ADSU	K9P00	K9P 01			
27	DIC04	MPDV	K9P00	K9P 01	B		
28	DIC05	PMLD	K9P00	K9P 01		S	
29	DIC06	STF1	K9P00	K9P 01	B S		
30	DIC07	FLRT	K9P00	K9P 01	B	S	
31	DIC08	RDPD	0000	0000 10			

CODED BY_____ CHECKED BY_____

FORM 64 SOCAL STAT.

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SYMBOLIC (← FOR DATA)

LOCATION	OPN.	U	V	± D	± B
00000	00 0	00000	00000	0 0 0	000
11111	11 1	11111	11111	1 1 1	111
22222	22 2	22222	22222	2 2 2	222
33333	33 3	33333	33333	3 3 3	333
44444	44 4	44444	44444	4 4 4	444
55555	55 5	55555	55555	5 5 5	555
66666	66 6	66666	66666	6 6 6	666
77777	77 7	77777	77777	7 7 7	777
88888	88 8	88888	88888	8 8 8	888
99999	99 9	99999	99999	9 9 9	999

REMARKS

0000000000000
1111111111111
2222222222222
3333333333333
4444444444444
5555555555555
6666666666666
7777777777777
8888888888888
9999999999999

ABSOLUTE

LOCATION	OPN	U	V
00000	00	00000	00000
11111	11	11111	11111
22222	22	22222	22222
33333	33	33333	33333
44444	44	44444	44444
55555	55	55555	55555
66666	66	66666	66666
77777	77	77777	77777
88888	88	88888	88888
99999	99	99999	99999

THE RAMO-WOOLDRIDGE ONE PASS ASSEMBLY PROGRAM

Speed of Assembly

Due to the 1103's ability to read and punch cards while simultaneously punching paper tape, RAWOOP takes only a few seconds more than the total card reading time to execute its entire translation. Errors do not necessitate complete re-assembly and consequently the routine is exceedingly economical in its use of machine time (see below).

Symbolic Addresses

A five character form, in keeping with 1103 machine form, is used for symbolic addresses. The first three characters designate the region of the address while the last two characters are the sequence number of the address within its region.

For example, DRJ00 is the zeroth address in region DRJ and 01C19 is the nineteenth address in region 01C (01C00 is the zeroth address in region 01C). In keeping with the one-pass nature of RAWOOP, the sequence numbers are consecutive decimal numbers. The absolute address assigned to 01C19 is nineteen greater than the address assigned to 01C00. Thus, the address structure has a regional character.

As indicated above, the first three characters of the relative address or region are alpha-numeric.

The absolute address for region 000 (all zeros) has already been chosen in RAWOOP to be zero. Consequently, 00029 would have 00035 as its octal translation; absolute machine addresses up to 99 will be correctly translated. Furthermore, the regions A00, B00, and Q00 are best avoided, as in some cases reference to them will be interpreted as addressing the A, B, or Q registers respectively.

The assembly program recognizes the alphabetic letter "O" as different from the numeric zero but in order to avoid confusion the programmer will probably not want to use symbolic addresses involving the letter "O".

A, B, and Q Addresses

The accumulator, the B register (accumulator bits $A_{70} - A_{35}$), and the Q register must be addressed by putting an A, B, or Q, respectively, in the leftmost column of either the u or v fields. The remaining four columns of the field may have no punches or zero punches. The octal translations of A, B, or Q are 20000, 30000, and 10000 respectively.

Addressing Involving j, k, and n

The command structure of the 1103 is such that the u and v addresses at times contain numbers rather than machine addresses (as in the case in the SPuk, RPjn, w and MJjv commands). The representation of j, n type instructions uses j as the first character and n as the last four characters with the quantities j and n written as decimal numbers. Thus the j, n number 30199

is translated to 30307b. No distinction is made between j, n addresses and j addresses. If the programmer desires to use the last four characters of a j, type address to store a number (this cannot be used to store a relative address) he may do so accounting for the fact that these four digits will be treated as the n portion of a j, n type address.

In the 1103 the k address structure is used to represent left circular shifts from 0 to 127 places. However, since the internal hardware occasionally makes it desirable to have the first octal bit of a k address be a number other than zero, k addresses will be treated in exactly the same manner as j, n addresses; for example, 20017 becomes 20021b.

Octal-Symbolic Words

In order to allow the programmer to mix octal and symbolic addresses in the same instruction three special types of words ("BBR","BRB", and BRR") have been included in RAWOOP. The first letter of the triad refers to the operation, the second, to the u address and the third, to the v address. R means symbolic (regional) and B means octal (binary). Thus, a BBR word has its operation and u address octal and its v address regional. The flag BBR goes into the D card field (columns 24-26). These flags cannot be attached to SNAP commands. Examples can be found on lines 23-25 of figure 1.

Void Addresses

Certain of the 1103 commands such as FS--, RJj,n-- have ignored addresses associated with them. All such addresses are treated by RAWOOP as if they were relative addresses and are available for the storage of pre-setting addresses. An all-zero address, of course, is translated into all zeros.

Directory Cards

In a one-pass assembly program, it is necessary that at the beginning of the program sufficient information is supplied to enable all symbolic addresses to be assigned absolute addresses. RAWOOP does this by means of directory cards. A directory card has a D punched in column 1, the base word of the region (e.g. 01C00) in the u address columns, and the absolute decimal address of the base word in the v address columns. For examples, see figure 1. RAWOOP can handle up to 73 directory cards in any one assembly. The programmer is cautioned not to follow his directory cards with program cards destined for a region D00. Such an ordering would prevent RAWOOP from differentiating between the two types of cards.

For purposes of assigning decimal addresses to the drum, the convention was adopted that octal address 40,000 on the drum has the decimal address 40,000. Thus the drum addresses range decimally from 40,000 - 56,383.

Symbolic Addresses of Program Data

With the exception of the D cards and the START card, all the input cards have a relative address punched in columns 1-5. This address is the address of the word to the right and, in conjunction with the decimal address of the corresponding directory card, completely determines the memory location into which this card will be read by the bioctal tape punched by RAWOOP.

Commands

The 1103 alphabetic representation of the commands is used. These two letter combinations, such as RA for the "replace add" or "21 command", are entered into columns 9 and 10. All the standard 1103 commands are recognized by RAWOOP and this recognition implies knowing whether the addresses associated with the command are of the u, v, the jn, v, or of the u, k types.

In addition to the standard 1103 commands, the special commands IP, PM, and MM are recognized. The PM and MM commands and the availability of the B register for addressing are modifications on the Ramo-Wooldridge 1103. The PM command is a "polynomial multiply" command for polynomial evaluation whose octal equivalent is 24; the MM command is the "modified multiply-add" (faster in operation than MA) whose octal equivalent is 25. None of these modifications are used in the operation of RAWOOP; the program will operate on any 1103 with reproducer and high-speed punch.

The IP commands are treated as if the command structure were IPuv. However, for use in SNAP, a pseudo command is available. This has the form ABCDuv, where AB and CD are alphabetic SNAP commands, while u and v are symbolic addresses restricted in their assignment to the lower half of electrostatic storage. This form is translated by RAWOOP into 14A'u'C'v' where A' and C' are the octal representations of the SNAP commands AB and CD respectively, while u' and v' are 9 bit numbers. A' and u' are packed into the u address of the translated command and occupy the left 6 bits and right 9 bits respectively. C' and v' are similarly placed in the v address. On the input card AB occupies columns 7 and 8, while CD appears in columns 9 and 10.

SNAP provides for a B-box whose contents can be added to the address of a SNAP command before its execution. To cause RAWOOP to translate SNAP commands so that this signal will be given, a "B" is placed in column 25 of the D field to modify the u address, or in column 29 of the B field to modify the v address of the SNAP command. Upon finding a "B" in column 25 and/or 29, RAWOOP adds two (2) to the corresponding SNAP operation.

If the programmer places the letter "S" in column 26 of the D field and/or column 30 of the B field of a SNAP pseudo command, RAWOOP adds one (1) to the corresponding SNAP operation. On execution of this command, the contents of the F register will be stored in the address associated with this command.

For example, if symbolic address K9P00 has its octal address equal to 00500, the translation of lines 26-31, of figure 1, are respectively:

```
14   04500   10501
14   16500   20501
14   24500   31501
14   37500   40501
14   46500   51501
14   70000   74010
```

It is sometimes desirable to place a relative address in a word that has zeros for its command code. To allow for this, the command 00 (zeros) is recognized and translated into 00. The u and v addresses must be symbolic addresses. As usual, however, an address of five zeros is translated into five zeros.

Decimal Numbers

Decimal numbers are presented to RAWOOP as normalized numbers times a power of ten. The programmer also states the binary scaling factor to be applied to the resulting rounded binary number. For example, -739.1 is presented as -7.391×10^2.

All decimal numbers are normalized so that their absolute value lies between 1 and 9.99999 99999.

The sign of the number is in column 9, the integral part in column 10, and the fractional part in columns 12-16 and 18-22. The power of 10 allowed is from -10 to +10. This exponent goes into columns 24-26. The desired binary scale factor goes into columns 28-30. For examples, in line 13, figure 1, the number to be translated is 3.123×10^{-6} with a scale factor of 2^{22}.

In all cases a minus sign represents a negative number and a zero or no punch a positive number.

Floating decimal numbers are presented to RAWOOP in the same manner as decimal numbers. However, instead of a binary scale factor being placed in columns 28-30, an F is punched in column 28. The converted floating point decimal number is in the form used by SNAP. That is, the left most bit is a sign bit, the next eight bits represent the exponent (increased by 128) and the twenty-seven bits on the right comprise the mantissa. In this form a negative number appears as the complement of the corresponding positive number.

Octal Constants

Octal constants can be inserted into the program using RAWOOP. The octal constant is entered into columns 9-10, 12-16, and 18-22. A "B" is punched into column 24 to signify that the number is in octal (binary) form. This feature implies that programs coded in the usual machine language will be correctly assembled.

PX 71900-10-(72)

Start Card

The signal to RAWOOP that all the cards have been received is a card with START punched in columns 1-5, and a relative address punched in columns 12-16.

The signal causes RAWOOP to insert into the translated program (in locations 00000b and 40000b) a manual jump to the octal translation of the relative address. For this reason, it is not possible to program anything in cells 00000b and 40000b.

After the resulting punched paper tape is read into the 1103, a magnetic drum start will start the problem at the relative address indicated in the u columns of the untranslated word.

Subroutines

RAWOOP is designed to translate subroutines coded in octal relative to 01000b (or 02000b) and stored on the drum, and include them into the main program. This is accomplished by one pseudo command, the "SUB" command.

Columns 1-5 of the SUB command contain the relative address at which the subroutine is to be stored. Columns 7, 8, and 9 contain the letters SUB.

Columns 12-16 contain the drum address of the cell in which the first word of the subroutine is stored for use by RAWOOP (this address is a "decimal drum address").

Columns 18, 19, and 20 contain the number of words (in decimal) in the subroutine. Columns 21 and 22 contain the number of constants (in decimal) which are placed at the end of the subroutine and are not to be modified during translation. In practice the information in these columns is simply copied by the programmer from a subroutine specification given on the title page of the subroutine write-up. Columns 25, 26, 28, 29, and 30 contain the relative address at which the subroutine is to be executed if this differs from the storage address. If these columns are blank or zero the storage address will be used as the execution address. The subroutine will be translated relative to the execution address but loaded (via the bioctal output tape) at the storage address.

The programmer is cautioned not to place a SUB card immediately after the directory cards.

The programmer has the options of including in the output cards the translated subroutine cards. With jump switch No. 3 off, the punching of these cards is suppressed. On the other hand, with this switch on, prior to starting the assembly, these cards are provided.

Subroutine Compiling and Constant Pools

There are two versions of RAWOOP (only four words differ). The non Ramo-Wooldridge version of RAWOOP assumes that subroutines stored on the drum are coded relative to address 01000b. The Ramo-Wooldridge version of RAWOOP assumes that subroutines are coded relative to address 02000b.

The Ramo-Wooldridge version of RAWOOP punches out on the bioctal tape a constant pool which is used in Ramo-Wooldridge subroutines. The pool is ten words long and starts in memory location 00015b. The sum of this pool is included in the memory sum recorded on the output tape. These constants are punched by RAWOOP before D cards are read and, of course, can be written over after they enter the high-speed storage. If constant pool cards are also desired they may be obtained by putting MJ 1 on before beginning the assembly.

Memory Sums

RAWOOP calculates the memory sum of all translated words including the 00000b and 40000b jump instructions. This sum is the double precision sum of the split extension of the translated words. The sum is both printed on the listing and read by the output paper tape into addresses 75202b and 75203b of the drum. The high order value of the sum is in 75202b. This placing of the sum is consistent with the Ramo-Wooldridge Ferranti read in routine. RAWOOP checks its own memory sum at the beginning of every assembly. Upon a memory sum disagreement, the routine prints "CMP-0".

Ordering of Input Cards

RAWOOP places the following requirements on the ordering of the input cards:

1. All directory cards must come first. The directory cards however, can have any order within themselves.

2. The START card must come last.

The cards actually giving the words of the program, subject to the restrictions already made, follow the directory cards. In the interest of minimizing the number of insert and check addresses on the output bioctal tape the cards should be in order within their regions. However, a correct output tape will be produced regardless of the order of the incoming program cards.

Suppression of Punched Paper Tape

If for any reason an input paper tape is not desired, the high-speed punching can be suppressed by turning on the j = 2 manually selective jump.

Storage Used by RAWOOP

RAWOOP uses all of high speed storage, cells 40000b and 40010b and stores itself in 60000b through 62117b. If subroutines are compiled, it also uses 43000b through 47777b.

Operating Instructions

The following points are important in the operation of RAWOOP:

1. The reproducer must be set for three fields.

2. The input cards must be placed face down with at least four blank cards following the START card at the back of the deck.

3. Both the typewriter and the high-speed punch must be turned on.

4. When RAWOOP is first read into the 1103, an MD start will store RAWOOP on the drum and start RAWOOP. All subsequent starts are made from address 40010b. When a run is completed, it stops with a manually selective stop to 40010. Pressing the START button causes another program to be assembled. The program checks its own memory sum at the beginning of an assembly and prints out "CMP-0" when the check sum fails.

5. All cards should be cleared from the read and write channels of the reproducer at the end of the program.

6. All reproducer switches must be on normal setting (away from the card hoppers on the Ramo-Wooldridge 1103).

7. All MS and MJ switches should be turned off except as noted above.

Error Detection

If more than 73 directory cards are entered the flexowriter prints "too many d cards" and the computer halts. It is not possible to continue the assembly after this error has occurred.

All other errors, including a D card occurring in the main deck will not stop the machine. For each card with an error on it, "ERROR" will be printed on the Flexowriter. The contents of the erroneous card will be ignored and will not effect the memory sum. The corresponding output cards will have "error" punched on them in the place ordinarily used for the translated information. If the error appears with respect to the START card, addresses 00000 and 40000 will be loaded with the word 45 00000 00000b by the paper tape.

The detected errors can be corrected by a second assembly of only the new corrected input cards, their associated D cards, and the START card. This will give a secondary input tape with its own memory sum.

Programming Reminders

1. If it is desirable to refer to the constant and temporary storage pools with symbolic addresses, directory cards should be included for them.

2. RAWOOP converts decimal numbers to binary numbers occupying 35 bits plus a sign. Decimal numbers not in the correct range will be translated incorrectly or can cause an error card to be punched.

3. When converting drum addresses, 40000 in decimal is equivalent to 40000 in octal.

4. When specifying the beginning of a region, one must use the first symbolic address of a block. For example, D 03M00 00500 must be used, and not D 03M15 00515.

5. To assemble a number of programs consecutively, it is necessary to have two cards between programs.

6. Directory cards must not be followed immediately by

    a. SUB cards
    b. program cards directed to region D00.

7. Attention is called to the use of A00, B00 and Q00 as regions. If these regions are addressed, reference may be made to the A, B, or Q registers.

8. Since the last two words of the translated program are start addresses inserted in 00000 and 40000, it is impossible to program for these cells using RAWOOP.

9. Correcting or replacing words on an assembled program tape will in most cases invalidate the sum checks at the end of the tape. The programmer has the following options for correcting or altering a program:

    a. re-assemble
    b. add the corrected words with proper insert and check addresses after the sum check
    c. re-assemble the incorrect cards only and enter into the machine the old and new assemblies in that order.

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Definite Integral Evaluation Routine

Specifications

Identification Tag:	DIE-0
Type:	Subroutine
Assembly Routine Spec:	SUB 49810 05804
Storage:	54 instructions, addresses 00P00 thru 00P07 00S00 thru 00S26 00N00 thru 00N18 4 constants in program, addresses 01C00 thru 01C03 58 words total program storage, addresses 00P00 thru 00P07 00S00 thru 00S26 00N00 thru 00N18 01C00 thru 01C03 10 words temporary storage pool used, addresses 00027b (00T00) thru 00040b (00T09) The constant pool is used by this routine
Drum Assignment:	Addresses 63122b thru 63213b
Program Entrance:	Address 00P02
Program Exit:	Address 00P01
Mode of Operation:	Fixed point

Coded by:	F. Meek	June 7, 1955
Code Checked by:	R. Bigelow	June 10, 1955
Machine Checked by:	F. Meek	July 7, 1955
Approved by:	W. Bauer	July 26, 1955

Description

Assuming that $y = f(x)$ is a tabulated function with equal increments in the argument $(x_0, x_1, x_2, \ldots, x_n)$, this routine will approximate the definite integral

$$\frac{1}{(x_n - x_0)} \int_{x_0}^{x_n} y\,dx$$

using either Simpson's rule or a modification of Simpson's rule.

The function values may be stored in ascending order of the argument in any block of consecutive storage cells.

At the time of entry into the subroutine the programmer must supply the value of n (that is, the number of intervals, one less than the number of points) and the address of the cell containing the first function value $y_0 = f(x_0)$.

The routine gives as a result an approximation to

$$\frac{1}{(x_n - x_0)} \int_{x_0}^{x_n} y\,dx$$

and the programmer must then multiply this result by $(x_n - x_0)$ to obtain the approximation to the integral itself.

Notation

$$I = \int_{x_0}^{x_n} f(x)\,dx, \quad J = \frac{1}{(x_n - x_0)} I.$$

I^* and J^* are approximations to I and J, respectively.

$\varepsilon = I^* - I$.

Range of y_i, J^*, and n

The only restriction on the y_i's is that they must be single precision fixed point numbers. The number of intervals n must be greater than one but can be arbitrarily large. The result J^* will be given scaled by the same amount that the y_i's were scaled.

In order to obtain the maximum significance for J^* the y_i's should be scaled as far to the left as possible.

Programming Instructions

Before entering the routine the function values y_i must be stored in ascending order of the arguments in consecutive storage cells.

1. Place $n \cdot 2^{0}$ in A.

2. Place the address of $y_0 = f(x_0)$ in Q_v

3. Enter the routine with the instruction RJ 00K01 00K02 (assuming 00K00 is the region that was assigned to the routine during assembly)

At the time of exit from the routine the result J* is left in A, scaled by the same amount that the y_i's were scaled. The numbers y_i have been left in their original state.

Mathematical Analysis

Let the equal increment of x be denoted by

$$h = x_i - x_{i-1} = \frac{x_n - x_0}{n} > 0, \quad i = 1, 2, \ldots, n.$$

Suppose I is to be approximated by a quadrature formula of the form

$$I^* = h \sum_{i=0}^{n} c_i f(x_i) = \frac{x_n - x_0}{n} \sum_{i=0}^{n} c_i y_i$$

where the c_i are the appropriate coefficients, e.g., for the trapezoidal rule $c_0 = c_n = 1/2$ and $c_i = 1$ otherwise. Let

$$J^* = 1/n \sum_{i=0}^{n} c_i y_i.$$

Then

$$I^* = (x_n - x_0) J^*.$$

Notice that J* does not involve x, and therefore J* can be computed without regard to the scaling of x. For this reason J* rather than I* is obtained by the subroutine.

If n is even Simpson's rule is used throughout the interval (x_0, x_n). If n is odd Simpson's rule is used over the interval (x_0, x_{n-3}) and Newton's three-eighths rule is used over the interval (x_{n-3}, x_n),

therefore

$$J^* = 1/3n \, (y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + \ldots + 4y_{n-1} + y_n) \text{ for n even, and}$$

$$J^* = 1/3n \, (y_0 + 4y_1 + 2y_2 + \ldots + 4y_{n-4} + y_{n-3}) +$$

$$+ 3/8n \, (y_{n-3} + 3y_{n-2} + 3y_{n-1} + y_n) \text{ for n odd.}$$

Error Analysis

Let α be some value in the closed interval (x_0, x_n) and let β and γ be values in the closed intervals (x_0, x_{n-3}) and (x_{n-3}, x_n) respectively.

If $\frac{d^4y}{dx^4}$ is continuous throughout the interval (x_0, x_n) and if n is even

$$\varepsilon = \frac{y^4(\alpha)\ (x_n - x_0)^5}{180n^4}, \text{ where } y^4(\alpha) = \left.\frac{d^4y}{dx^4}\right]_{x=\alpha}$$

If $\frac{d^4y}{dx^4}$ is continuous throughout the invertal (x_0, x_{n-3}) and exists throughout the interval (x_{n-3}, x_n) and if n is odd

$$\varepsilon = 1/n^5 \left[\frac{n-3}{180}\ y^4(\beta) + \frac{3}{80}\ y^4(\gamma)\right]\left[x_n - x_0\right]^5.$$

For the derivation of these quadrature formulas and their error terms, see Milne's Numerical Calculus, pp. 120 thru 124.

Machine Time

The time required for this subroutine is (2.25 + .62n) ms, $n \neq 3$. When n = 3 the time required is 2.73 ms.

Machine Checking

Two preliminary test cases were run:

1. n = 99, $y_i = -(2^{35}-1)$ for all i. The result obtained was -2^{35} (it should have been $-(2^{35}-1)$.
2. n = 98, $y_i = (2^{35}-1)$ for all i. The correct result, $(2^{35}-1)$, was obtained.

In addition, the following computations were performed:

1. SIN-0 was used to produce a table of sines and cosines for the arguments $y = \pi X/2 = (\pi/2)\cdot n\cdot 2^{-4}$, n = 0, 1, 2, . . . , 99.
2. Let $S = \int_0^b \cos y dy = \sin b$ and $C = \int_0^b \sin y dy = 1-\cos b$. DIE-0 was used to compute S* and C* for $b = (\pi/2)\cdot n\cdot 2^{-4}$, n = 2, 3, 4, . . . 9, n = 10,15,20,25 n = 30,40,50, . . . 90, and n = 99

3. For each b (or n) $\varepsilon_s = S^* - \sin b$ and $\varepsilon_c = C^* - 1 + \cos b$ were computed. The following tables resulted:

n	$\varepsilon_s \cdot 10^6$	$\varepsilon_c \cdot 10^6$
2	.101	.010
3	.338	.050
4	.197	.039
5	.422	.125
6	.287	.087
7	.490	.215
8	.365	.151
9	.540	.316
10	.429	.229
15	.560	.650
20	.477	.713
25	.200	1.056
30	.101	1.022
40	-.365	.881
50	-.506	.415
60	-.198	.039
70	.286	.087
80	.516	.516
90	.286	.945
99	-.338	.981

It was to be expected that, in general, the errors would be greater for n odd. The overall behavier of ε_s and ε_c is easily seen to be consistent with the fact that ε_s and ε_c represent the errors in integrating the cosine and the sine respectively. For example, ε_s is small for n = 30 because it is the error obtained in

$$\int_0^{\frac{15}{16}\pi} \cos y\,dy = \int_0^{\frac{1}{16}\pi} + \int_{\frac{1}{16}\pi}^{\frac{\pi}{2}} + \int_{\frac{\pi}{2}}^{\frac{15}{16}\pi}$$

$$= \int_0^{\frac{1}{16}\pi} + \int_{\frac{1}{16}\pi}^{\frac{\pi}{2}} - \int_{\frac{1}{16}\pi}^{\frac{\pi}{2}} = \int_0^{\frac{1}{16}\pi}$$

since $\int_{\frac{\pi}{2}}^{\frac{15\pi}{16}} = -\int_{\frac{1}{16}\pi}^{\frac{\pi}{2}}$

In fact, ε_s for n = 30 (b = (15/16)π) is exactly equal to ε_s for n = 2 (b = (1/16)π).

Evidently, all the errors ε_s and ε_c are less than their corresponding maximum estimates as computed by the formulas above under Error estimate. In particular, for n = 10 and 15, the following maximum error estimates were hand computed:

n	Max ε_s 10^6	Max ε_c 10^6
10	.508	.421
15	.740	.903

```
D                00C00 00013
D                00T00 00023
D                01C00 01078
D                00P00 01024
D                00S00 01032
D                00N00 01059
D                D1C00 49864
D                D0P00 49810
D                D0S00 49818
D                D0N00 49845
D0P00    MS  00000 00P00
D0P01    MJ  00000 00000
D0P02    TP  A0000 00T01
D0P03    TP  Q0000 00T02
D0P04    DV  01C00 00T03
D0P05    ZJ  00N00 00P06
D0P06    TV  00S22 00S19
D0P07    TP  00T01 00T03
D0S00    MP  01C01 00T01
D0S01    TP  A0000 00T04
D0S02    TP  00C03 00T05
D0S03    TP  01C02 00T06
D0S04    TP  00C03 00T07
D0S05    TP  00T03 A0000
D0S06    DV  01C00 00T08
D0S07    RS  00T08 00C03
D0S08    TV  00T02 00S11
D0S09    SP  00C00 00000
D0S10    RP  30003 00S12
D0S11    MA  00T05 00000
D0S12    TP  A0000 00T09
D0S13    LA  A0000 00036
D0S14    TP  A0000 00T00
D0S15    IJ  00T08 00S23
D0S16    SP  00T09 00036
D0S17    SA  00T00 00036
D0S18    DV  00T04 00T04
D0S19    MJ  00000 00000
D0S20    TP  00T04 A0000
D0S21    MJ  00000 00P01
D0S22    00  00000 00S20
D0S23    RA  00S11 01C00
D0S24    SP  00T09 00036
D0S25    SA  00T00 00036
D0S26    MJ  00000 00S10
D0N00    TV  00N18 00S19
```

```
D                00015  00 00000 00000
 I     O         00027  00 00000 00000
  R     R        02066  00 00000 00000
   E     Y       02000  00 00000 00000
    C            02010  00 00000 00000
     T           02043  00 00000 00000
DRUM             63210  00 00000 00000
  STORAGE        63122  00 00000 00000
    DIREC/       63132  00 00000 00000
      TORY       63165  00 00000 00000
NO ALRM EXIT     63122  56 00000 02000
NORMAL EXIT      63123  45 00000 00000
ENTRY  STORE     63124  11 20000 00030
N AND ADRS       63125  11 10000 00031
OF YO            63126  73 02066 00032
IS N EVEN        63127  47 02043 02006
YES EXIT TO      63130  16 02036 02033
S20    N/BAR     63131  11 00030 00032
EQUALS N         63132  71 02067 00030
STORE 3N         63133  11 20000 00033
  STORE 1        63134  11 00020 00034
       4         63135  11 02070 00035
   AND  1        63136  11 00020 00036
INDEX IS ONE     63137  11 00032 20000
HALF N/BAR       63140  73 02066 00037
MINUS ONE        63141  23 00037 00020
PRESTORE V       63142  16 00031 02023
CLEAR A          63143  31 00015 00000
FORM             63144  75 30003 02024
      SUM        63145  72 00034 00000
STORE            63146  11 20000 00040
  PARTIAL        63147  54 20000 00044
       SUMS      63150  11 20000 00027
IS INDEX NEG     63151  41 00037 02037
YES    STORE     63152  31 00040 00044
INTEGRAL TO      63153  32 00027 00044
X N/BAR          63154  73 00033 00033
STORE INTE/      63155  45 00000 00000
GRAL IN A        63156  11 00033 20000
GO TO EXIT       63157  45 00000 02001
DUMMY/SEE P6     63160  00 00000 02034
MDFY V BY 2      63161  21 02023 02066
RESTORE PAR/     63162  31 00040 00044
TIAL SUMS        63163  32 00027 00044
GO TO S10        63164  45 00000 02022
N IS ODD EX/     63165  16 02065 02033
```

```
D0N01   TP  00T01  A0000
D0N02   ST  01C01  00T03
D0N03   ZJ  00S00  00N04
D0N04   TP  A0000  00T04
D0N05   LA  00T01  00003
D0N06   TP  01C01  00T06
D0N07   TP  01C03  00T07
D0N08   TP  01C03  00T08
D0N09   TP  01C01  00T09
D0N10   RA  00T02  00T03
D0N11   TV  00T02  00N14
D0N12   SP  00C00  00000
D0N13   RP  30004  00N15
D0N14   MA  00T06  00000
D0N15   DV  00T01  00T06
D0N16   RA  00T04  00T06
D0N17   MJ  00000  00P01
D0N18   00  00000  00N05
D1C00   00  00000  00002
D1C01   00  00000  00003
D1C02   00  00000  00004
D1C03   00  00000  00009
START
```

```
IT TO N5          63166  11 00030 20000
N/BAR IS N/3      63167  36 02067 00032
IS N 3            63170  47 02010 02047
YES CLEAR T4      63171  11 20000 00033
  STORE 8N        63172  54 00030 00003
  STORE 3         63173  11 02067 00035
        9         63174  11 02071 00036
        9         63175  11 02071 00037
    AND 3         63176  11 02067 00040
STORE ADRS        63177  21 00031 00032
OF YN/BAR         63200  16 00031 02061
  CLEAR A         63201  31 00015 00000
FORM              63202  75 30004 02062
        SUM       63203  72 00035 00000
STORE INTE/       63204  73 00030 00035
GRAL IN A         63205  21 00033 00035
GO TO EXIT        63206  45 00000 02001
DUMMY/SEE NO      63207  00 00000 02050
CONSTANTS 2       63210  00 00000 00002
          3       63211  00 00000 00003
          4       63212  00 00000 00004
      AND 9       63213  00 00000 00011
```

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Interpretive Floating Point Package

Specifications

Identification Tag: SNAP

Type: Service Routine (with entrance from program available)

Storage: Cells (00000-00012)
(00724-01023)
(70000b-71750b)

The constant pool is used by this routine.

Service Entrance: Address 40012b

Program Entrance: See Description

Coded by: R. Beach
D. Gantner
M. Perry
M. Speer
R. Summers

Approved by: W. Bauer October 10, 1955

Description

SNAP is an interpretive floating point package for the ERA 1103. It contains a single address floating binary point arithmetic section, floating decimal data input and output on cards, fixed-to-floating and floating-to-fixed conversion, square root, load and store operations. Additional features include an address modifier, or "B-box", and optional replacement of the result of an operation in the address of the operand. Experience has shown that representative programs using SNAP operate at about 1,000 programmed operations per second. The speed is obtained by fast floating point operations and the fact that many operations are performed at machine speed.

The package is entered by execution of an Interpret (IP) instruction. The u and v portions of this instruction each contain a complete SNAP command. Of these fifteen bits, four contain the operation part, one the B-box option, one the replace option, and the remaining nine the address part. Accordingly, only the lower half (512 cells) of electrostatic may be addressed directly. However, use of the B-box makes any electrostatic or magnetic drum cell indirectly addressable.

A packed number representation is used and results are normalized after each execution. Each floating point number occupies one 36 bit cell. One bit contains the sign, eight the characteristic and twenty-seven the mantissa. Hence the range of the numbers is approximately $\pm 10^{38}$ and approximately eight significant decimal digits are contained in the mantissa. The representation is such that all 1103 logical commands may be validly applied. Therefore, floating point number comparisons may be made at regular machine speed and no need exists for inclusion of comparison commands in the SNAP repertoire.

SNAP occupies approximately 900 cells on the magnetic drum and 300 cells in electrostatic. When a card is to be punched or read, appropriate coding is brought in automatically from the drum. These are the only occasions on which drum references are made.

SNAP commands may be written with alphabetic operations and symbolic addresses, and then assembled by RAWOOP. Floating point numbers may also be included in the program and will be converted and assembled by RAWOOP.

PX 71900-10-(108)

Storage

SNAP uses cells (00000 - 00012), (00724 - 01023) and (70000b - 71750b). In addition, it makes use of the Ramo-Wooldridge constant pool (00013 - 00022). When executing SNAP commands, cell 00000 must contain the word (45 00001 VVVVV).

The following assignments are of interest to the programmer:

00002 F

00003 C

00004 B-box

00005 P_0
00006 P_1
00007 P_2
00008 P_3 } output hopper
00009 P_4
00010 P_5
00011 P_6

Instruction Structure

An instruction occupies a 36 bit cell and contains two SNAP commands, as schematically shown below.

IP	Left Command	Right Command
35-30	29-15	14-0

The left and right SNAP commands are identical in form and have the format shown below.

Operation	B	S	Address
29-26 14-11	25 10	24 9	23-15 8-0

Replace option (result replaced if bit is one)

B-box option (address modified if bit is one)

Number Representation

Floating binary point numbers are each packed into a single 36 bit cell with assignments as follows:

S	Char.	Mantissa
35	34-27	26-0

"Sign" (zero when positive)

The characteristic has a bias of 128 (200b). The binary point lies between bits 26 and 27. To negate a number, the full 36 bits are complemented.

This representation allows use of the Transmit Magnitude and Transmit Negative instructions as well as all comparison jumps. In addition, fixed point decimal output routines give useful conversions when supplied with 27 as a scale factor.

SNAP Commands

The list of commands follows. Parentheses indicate "contents of". F and C are specific electrostatic cells reserved for the package. α is the address part of a SNAP command and may be any address in the lower half of electrostatic (00000-00511). Double length extensions of the results are stored in A, the machine accumulator. The time column below gives average execution times in milliseconds. The operations are further clarified on succeeding pages.

CODE	OPERATION	TIME	RESULT
NO 00	No operation	.43	(F) ⟶ A,F
AD 04	Add	2.18	(F) + (α) ⟶ A,F
SU 10	Subtract	2.21	(F) - (α) ⟶ A,F
MP 14	Multiply	1.94	(F) x (α) ⟶ A,F
DV 20	Divide	2.20	(F) ÷ (α) ⟶ A,F
PM 24	Poly. Mpy.	3.45	[(F) x (C)] + (α) ⟶ A,F
LD 30	Load	1.06	(α) ⟶ A,F
ST 34	Store	.98	(F) ⟶ α,A,F
FI 40	Fix	1.39	(F) floating ⟶ [A,F] fixed at scale α
FL 44	Float	1.87	(F) fixed at scale α ⟵ [A,F] floating
RT 50	Square Root	3.25	$\sqrt{(F)}$ ⟶ A,F
RD 70	Read Data	500	Floating decimal numbers (four per card), are read, converted, and stored.
PD 74	Punch Data	583	Floating binary numbers are converted and punched as floating decimal numbers (six per card).

NO (00)

The No Operation command is included to complete the right half of a partial instruction. To gain speed, it short-circuits the normal interpretive loop, disabling the replace feature. For this reason the address part (3 octal digits) is available for storage of dummy addresses. When used as a left command, execution time is extended. The B-box option must not be exercised.

AD (04), SU (10), MP (14), DV (20), PM (24).

Results are normalized after each execution. Alarms are provided for "division by zero", and "exponent overflow". When the result is less than 2^{-129}, it is made exactly zero.

LD (30), ST (34)

The Load and Store commands perform functions normally left to standard machine instructions. However, their inclusion in the repertoire extends the use of the B-box, permitting address modification of more complete loops.

Note especially that the reserved cells F, C, B-box, and P_1, are simply electrostatic cells. They may be operated on by machine instructions, as well as SNAP commands. Since the use of machine instructions invariably saves execution time (by a factor of ten to twenty), such use is recommended when storage is not extremely critical or the B-box is not being used.

FI (40), FL (44)

When Fixing or Floating, the scale α is in the standard 1103 notation; i.e. when α is zero, the point is at the extreme right and when α is 35, the point lies between bits a_{35} and a_{34}. The scale α may not be negative but there is no restriction on the upper limit, other than that imposed by overflow. An alarm is provided for this condition.

Since α is not an address, the B-box and store options lose their usual meaning. SNAP does not handle them in the normal manner and they should therefore not be programmed.

RT 50

The square root is accurate to one in the last place. Note that since the argument is in F, the address part may be used (in connection with the replace option) to store the result. An alarm is provided for negative arguments.

RD 70

Upon execution of the Read Data command, floating decimal numbers, each with an associated address (four per card), are read, converted to floating binary numbers, and stored at address α (or α plus B-box) plus the associated address. If it is desired to read in less than four numbers per card, then the associated address field of the decimal number to be ignored must be left blank.

Each floating decimal number consists of a ten digit signed mantissa and a two digit signed exponent. Upon conversion, the mantissa is truncated to 27 bits. The decimal point is at the left of the mantissa field and the leading digit must be non-zero. An alarm is provided if the absolute value of the exponent is greater than 37.

A single RD command initiates the reading of any number of cards. Reading is terminated either by the detection of a blank card, or after loading a card which contains a 12 punch in either column 79 or 80. A blank card or a 12 punch in column 80 returns control to the command following the RD command. A 12 punch in column 79 halts the computer with PAK = 71336 after the card has been loaded. Starting will then return control to the command following the RD command. Reading is accomplished at the rate of 480 numbers per minute.

The following card column assignments are made:

(1-4)(22-23)(41-42)(60-61)	Not used
(5-9)(24-28)(43-47)(62-66)	Associated address
(10-19)(29-38)(48-57)(67-76)	Mantissa (decimal point at left)
(20-21)(39-40)(58-59)(77-78)	Exponent of 10
(79-80)	12 punch will terminate read.

If the exponent or the mantissa is negative, an eleven punch is included over its rightmost digit.

PD (74)

Output is in floating decimal, eight significant digits with sign and a signed exponent whose range is $\pm$ 38. Results may be punched in any of six punch positions, up to six numbers per card. In addition, a four digit identification number may be punched. Punching may occur at rates up to 100 cards per minute.

Dependent on the value of α, execution of the command (PD α) stores the number for future punching or punches a card. Specifically, when $0 \leq \alpha \leq 6$, (F) is stored in cell P_α for future punching in card field α. When α is 10, 20, 30, or 50, contents of the output hopper are converted to decimal and punched, after which the output hopper is set to zero. Only the four least significant octal digits of the U-address part of P_0 are converted to a decimal integer and punched in the identification field. If (P_i) is zero, its field in the output card will be blank. All SNAP output cards have a 12 punch in column 75 and also have a 12 punch in column 78, 79, or 80 when α is 50, 30, or 20 respectively. The SNAP output board is wired to give single spacing before printing except when 78, 79, or 80 contain 12 punches. In these cases, page ejection, triple spacing, or double spacing occur respectively, before printing.

Because of the characteristics of the Bull Reproducer, a blank card is pushed through the punch side on the first read cycle following a punch cycle. SNAP keeps track of these sequences and positions an extra card when required. Since a card cycle of one half second is wasted each time this occurs, interspersed reading and punching should be avoided when convenient. The blank cards may be removed from the output deck by a single sort, selecting 12 punches in column 75, since only legitimate output cards contain this punch. Upon completion of a program using the PD command, the Bull should be cleared manually to punch and feed the final card.

The output hopper (cells 00005-00011) need not be loaded by a PD command, but may be loaded by any appropriate 1103 or SNAP command. It is also possible to use the hopper as temporary storage. Note, however, that if fixed point numbers remain in the hopper when punching is initated, the punch routine may fail.

The following card column assignments are made:

(1)	Sign of mantissa
(2-9)	Mantissa (point at left)
(10)	Sign of exponent
(11-12)	Exponent
(13) (14-21) (22) (23-24) (25) (26-33) (34) (35-36) (37) (38-45) (46) (47-48) (49) (50-57) (58) (59-60) (61) (62-69) (70) (71-72) (77-80)	Identification

Replace Option

When a bit is present in the replace position of a SNAP command, the result of the execution is stored (replaced) at the effective address of the operation. This is in addition to the normal storage of the result in A and F.

B-box Option

The B-box, or address modifier, is contained in cell 00004. When a SNAP command has a bit present in its B-box position, the U-portion of cell 00004 is added to the address part (a) of the command to form the effective address for this execution. The operation part and the V-portion of the B-box must be zero (either positive or negative), and the effective address must not exceed 77777b. Use of this option does not alter the actual address which remains constant.

The B-box is loaded by standard 1103 Transmit instructions and may be incremented or decremented by the Replace instructions.

If the effective address exceeds77777b, a portion of SNAP will be destroyed. Note that, although the nine bit address part of a SNAP command compels the actual address to be less than 512, the effective address using the B-box may be as large as 77777b. Note also that it is possible to decrement an actual address by loading the B-box with a negative number.

Symbolic Coding

Although it is possible to code for SNAP in octal, it is much easier to code symbolically for assembly on RAWOOP. The advantages of using alphabetic operations and symbolic addresses are magnified by the peculiar command structure of SNAP instructions. Regular machine instructions may be interspersed arbitrarily with SNAP instructions.

At the end of this section is a facsimile of a standard RAWOOP coding sheet. It contains some sample floating point numbers and SNAP instructions (not a program), and their assembled equivalents (in the Comments column). There are two alphabetic operations, two symbolic addresses, and two optional B-box and store columns in each instruction. The left hand items in each pair are combined

to form the left SNAP command, the right hand items to form the right command. The numbers in rows (1), (2), and (3) are respectively .125 -4096, and 1.125.

	ADDRESS	OP	U	V	±	D	±	B	COMMENTS
	D		99Z00	256					
(1)		1	25		-	01	F		17 64000 00000
(2)		-4	096			3	F		56 23777 77777
(3)		1	125				F		20 14400 00000
(4)	LDSU	99Z02	99Z04			B		B S	14 32402 13404
(5)	ADFI	99Z03	21			BS			14 07403 40025
(6)	RDLD	99Z00	99Z05						14 70400 30405
(7)	ADNO	99Z07				S			14 05407 00000

Consult the RAWOOP write-up for more complete details on symbolic coding.

Alarms

An alarm routine is self-contained in SNAP. When an alarm condition is reached, the flexowriter types out a word having the form

TT P-XXXXX

where TT is the alarm type, P is an L or an R (left or right command), and XXXXX is the location of the instruction which caused the alarm. Upon completion of the typing, a Manual Stop zero occurs. If the computer is now started, F and A are set to zero and execution of the next command is initiated. See below for the exception when reading data.

The following types of alarm may occur:

1. EO Exponent Overflow - The absolute value of the result is greater than $(1 - 2^{-27})2^{126}$.
2. RT Square Root of a negative number
3. DV Division by zero
4. FI Fixing causes the number to overflow the F register
5. RD Absolute value of input number is equal to or greater than 10^{38}. Starting the computer after alarm causes normal reading except that a zero replaces the erroneous number.

Operating Instructions (Activation of SNAP)

1. Insure that SNAP is intact on the magnetic drum. (This can be accomplished by a transfer of the Service Routine Library from magnetic tape).
2. Load the problem program - Program should include the R-W constant pool.

3. Set PAK to 40012b and start - This causes SNAP to be read into its electrostatic locations, sets the B-box, F, C, and output hopper to zero, supplies an appropriate jump in cell zero, positions cards on each side of the reproducer, and gives control to cell 40000 which normally initiates execution of the problem program.

Programmed Activation of SNAP

It is occasionally desirable to activate SNAP from the program. This may be accomplished by execution of one of the two commands given below.

It is assumed that cell 40000b contains (MJ 00000 VVVVV) which RAWOOP supplies.

1. For initial activation (37 40000 40012) - execution of this instruction has the same effect as (3) in Operating Instructions above except that control is given to cell (n + 1) when the instruction is in cell n.

2. For reactivation (a) (37 40000 71050) - same as (1) above except that card positioning is omitted.

   (b) (37 40000 71047) - same as (2,a) above except that one blank is fed on the punch side to insure that a RD has not cleared the punch station.

Subroutines

Many of the common subroutines have been coded using the SNAP number representation for argument and result. Others are in process. Their use is extremely simple.

It is, however, possible to employ any fixed point subroutine in a floating point program by the expedient of the Fix and Float commands contained in SNAP. Note that conversion is rapid and that scaling is easily supplied in the address part of the command.

Design Criteria

The philosophy which leads to this package states that, in order of importance, the following three items are virtues:

(1) Simplicity - To produce faster coding with fewer errors.

(2) Execution speed - To conserve machine time.

(3) Minimum storage usage - Both in the problem program and in the package, to conserve high speed storage.

With these in mind, a single address system was chosen. While logical operations are generally best served by multiple addresses, use of a single address is indicated for arithmetic operations. Since the four basic arithmetic operations may occur in a great variety of sequences, a multiple address system must either waste many of the addresses or contain contain a very large number of arithmetic command types. Wasting addresses wastes storage in the main program; inclusion of a large number of command types expends storage in the package. Thus (3) is satisfied by the single address. With only one kind of each of the arithmetic operations, jumping and sorting in the arithmetic section is minimized.

Furthermore, use of only one operand saves the unpacking of multiple packed numbers. So the requirements of (2) are met. Finally, the consideration of (1), ultimate simplicity is achieved with a system which always operates on the same register with but a single operand.

SNAP Sampler Trace

Description

This routine monitors the course of a SNAP program by punching out the results of those SNAP commands which are specified in a list prepared by the programmer. A parameter word will indicate the location of this list.

This list has the following specifications:

a. The list is made up of sublists of four words each. These sublists have the form:

00	FA	LA
00	Np	Ns
00	00000	00000
00	00000	00000

FA is the address where the trace is to start and LA the address at which it is to stop. Np is the number of times FA is to be passed before starting the trace, while Ns is the number of times the section FA to LA is to be traced. The last two words are used by the trace to store the blocked instructions.

b. This list must not be placed in cells 15b thru 107b, but may be put on the drum. In any case, a parameter word 00 Lo Lf will specify its location. Lo is the address of the first word of the list and Lf is the address of the last word. This parameter word must be loaded into cell 71777b Restoring the library from magnetic tape loads an all zero word into cell 71777b. If this word is not changed, a complete trace of all SNAP commands is automatically performed

c. Any number of sublists may be used. A particular address must appear only once in the list since blocking a blocked instruction is not possible.

d. The storage addresses FA and LA must be the addresses in which the instructions to be blocked are actually stored at the time the blocking routine is activated.

The operation of the trace is as follows:

a. When a blocked FA is reached in the program, N_p and N_s are examined. If $N_p = 0$, $N_s \neq 0$ then tracing is initiated and a start indicator placed in the word containing N_p and N_s. On the other hand, if $N_p = 0$ and $N_s \neq 0$ does not occur, then no action is taken.

b. At each SNAP execution, after a trace start, the F register is transferred to the next available position in the trace output hopper (last seven cells in ES). When this hopper contains the results of six SNAP commands (three IP instructions) then the SNAP output routine is used to punch a card containing the information in the trace hopper. The identification field of the output card contains the address of the instruction which produced the numbers in fields one and two. This address is in octal and will be 1725 if the instruction was an FA. The SNAP output command operation is in no way altered during tracing.

c. To empty the trace hopper at any time, start at 72125b. One card will be punched and the machine will stop on MS 0 with PAK = 77777b. SNAP must be in ES to exercise this option.

d. In the event the trace hopper is emptied when it contains no information, a card will be punched containing the address 7777 in the identification field, while the rest of the card will be blank.

e. When a blocked LA is reached in the program and if a start indicator was set up in the word containing the associated N_p and N_s then tracing is stopped and the trace hopper emptied. Otherwise, no action is taken.

f. The execution of the instruction at FA will be traced, but that at LA will not.

g. The seven cells of ES, 1771b - 1777b, cannot be used by the programmer if the trace is to be employed. Normal SNAP operation will not destroy the contents of these cells.

Programming Instructions

1. Load cell 71777b with the parameter word 00 Lo Lf where Lo and Lf are the locations of the first and last words of the list.
2. Load the list in form described above.
3. Start at 72000b. The routine will block the proper instructions as per the list supplied, modify SNAP in order to perform the trace, and then stop with PAK set at 40012b.
4. In the event no parameter word is loaded (and no list is supplied) a start at 72000b will initiate the blocking routine to modify SNAP on MD so that all SNAP commands will be traced. A stop will follow with PAK set at 40012b.

Warnings and Restrictions

1. The list can not occupy cells 15b - 107b.
2. Cells 1771b - 1777b must be reserved for the trace hopper and cannot be used by the programmer.
3. SNAP must be in ES at the time each FA and LA is reached in the program.
4. The instructions in FA and LA must not be read into or out of by the program.
5. Only SNAP commands are traced.
6. The trace can only be used with SNAP and not with the complex version.
7. Activating the trace modifies the copy of SNAP on MD and destroys the complex arithmetic portion of SNAP. To start another program using SNAP or its complex version, it is necessary to restore the library from magnetic tape.

8. An abnormality exists for the following type of a list:

00	FA_1	LA_1
00	N_{p1}	N_{s1}
00	00000	00000
00	00000	00000
00	FA_2	LA_2
00	N_{p2}	N_{s2}
00	00000	00000
00	00000	00000

Assume that N_{p1}, N_{s1}, N_{p2}, N_{s2} are such that tracing in both sublists is concurrent. Further, suppose that FA_1, FA_2, LA_2, LA_1 are executed in the order given. Hence, the trace will be initiated at FA_1 and once again at FA_2. When LA_2 is reached, the trace will stop since it was started at FA_2.

The instructions from LA_2 to LA_1 will not be traced and the trace will be stopped once again when LA_1 is reached. At this time the hopper will be punched. Other unusual combinations can be analyzed in a similar fashion.

THE RAMO-WOOLDRIDGE CORPORATION
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Interpretive Floating Point Package - Complex

Identification:	SNIP
Type:	Service Routine (with entrance from program available)
Storage:	Cells
	634 thru 1023
	70000b thru 71662b This includes SNAP
	The constant pool is used by this routine.
Service Entrance:	Address 40013b
Program Entrance:	See description

Coded by:	C. Koos	
	M. Perry	January, 1956
Code Checked by:	C. Koos	January, 1956
Machine Checked by:	C. Koos	January, 1956
Approved by:	W. F. Bauer	April, 1956

Description

SNIP is the complex arithmetic version of SNAP, a floating point interpretive package. An understanding of the use of SNAP is presupposed.

The activation of this routine changes SNAP into SNIP on the magnetic drum. The original version of SNAP can be obtained again only by a transfer of the Service Routine Library from magnetic tape.

SNIP performs its operations in either real or complex arithmetic depending on a mode which is selected by the programmer, and may be changed at any time.

In the complex mode

1. The complex numbers to be operated on must be in rectangular form, with the real and imaginary parts of the number stored in consecutive cells (For example, the complex number x + iy would be stored in the machine with x in cell α and y in cell $\alpha + 1$).

2. The floating Complex Accumulator requires two cells: Cell 00002, F, is used for the real part; Cell 00003, C, is used for the imaginary part, that is, the two cells 00002 and 00003 constitute the Complex Floating Accumulator, F_c.

3. The Polynomial Multiply command of SNAP is changed so that its execution will result in computing the absolute value of the number stored in F_c.

4. The Fix, Float, Read, Punch and No Operation commands operate exactly as in SNAP, while the remaining commands are changed only in the sense that they now use both cells 00002 and 00003 for the floating accumulator and cells α and $\alpha + 1$ for the argument as explained above.

5. The machine accumulator A contains the real part of the result after the execution of any one of these operations.

6. The Replace and B-box options may be used in all cases that are permitted by SNAP, with two consecutive cells being operated on as described. Keep in mind that the B-box must be indexed by two when used in referencing a list of complex numbers.

7. It is not permissible to load F_c with TP instructions; a Load command must be executed for this purpose.

In the real mode

1. All SNAP commands except Polynomial Multiply operate as in SNAP itself.

2. The execution of the Polynomial Multiply command will give the absolute value of (F_c) just as it does in the complex mode.

SNIP commands

The Complex Accumulator, F_c, is defined as two specific electrostatic cells which contain the complex number x + iy: cell 00002, F, contains x and cell 00003, C, contains y. Both x and y are stored as SNAP numbers; that is, each has its own binary exponent. The notation α_c represents the address of a complex number x + iy, where x is stored at α and y at $\alpha + 1$, that is, $(\alpha) = x$, $(\alpha + 1) = y$.

The following definitions apply when in the complex mode:

Code	Result
AD 04	$(F_c) + (\alpha_c) \rightarrow F_c$; $(F) \rightarrow A$
SU 10	$(F_c) - (\alpha_c) \rightarrow F_c$; $(F) \rightarrow A$
MP 14	$(F_c) \times (\alpha_c) \rightarrow F_c$; $(F) \rightarrow A$
DV 20	$(F_c) \quad (\alpha_c) \rightarrow F_c$; $(F) \rightarrow A$
PM 24	$\lvert(F_c)\rvert \longrightarrow F_c$; $(F) \rightarrow A$
LD 30	$(\alpha_c) \longrightarrow F_c$; $(F) \rightarrow A$
ST 34	$(F_c) \longrightarrow \alpha_c$; $(F) \rightarrow A$
RT 50	$\sqrt{(F_c)} \longrightarrow F_c$; $(F) \rightarrow A$

The NO (no operation), FI (fix), FL (float), RD (read data) and PD (punch data) instructions of SNAP are unaltered. The PM (polynomial multiply) instruction of SNAP is replaced by the absolute value instruction whether operating in the real or complex arithmetic mode if SNIP has been activated.

Manual Activation of SNIP

1. Insure that both this routine and SNAP are intact on the magnetic drum. (This can be accomplished by a transfer of the Service Routine Library from magnetic tape).

2. Load the problem program - The program should include the Ramo-Wooldridge constant pool, and a jump to start in 40000b, as supplied by RAWOOP.

3. Set PAK to 40013 and start--this changes SNAP into SNIP and causes it to be read into its electrostatic locations, sets the B-box, F, C, and output hopper to zero, supplies an appropriate jump in cells zero and one, positions cards on both sides of the reproducer, and gives control to cell 40000b which normally initiates execution of the problem program. At this time the routine is in the real arithmetic mode.

Programmed Activation of SNIP

Depending on the card positioning desired any one of three different return jump instructions may be used to activate SNIP from the program. Each assumes that there is a manual jump instruction in cell 40000b (such as that supplied by RAWOOP), and in each case control is returned to the instruction immediately following the return jump.

a. Execution of 37 40000 40013b positions cards on both sides of the reproducer.

b. Execution of 37 40000 71644b feeds one card on the punch side of the reproducer.

c. Execution of 37 40000 71646b omits all card positioning.

Otherwise the effect of programmed activation is the same as that described in step 3 under manual activation.

Switching Modes

Activation of SNIP by any one of the methods described above leaves it in the real arithmetic mode. At any time after SNIP has been activated the mode may be switched as follows:

To switch from the real mode to the complex mode execute the return jump

37 01541 01713b

To switch from the complex mode to the real mode execute the return jump

37 01541 01715b

In either case the desired mode change is accomplished, cell 00003, C, is set to zero, and control is returned to the cell immediately following the return jump. The real mode should ordinarily be used wherever possible because it is considerably faster than the complex mode.

Alarms

The SNAP alarm routine is used, with the possibility of the same type of alarm occurring (EW, RT, DV, FI, RD). It is not advisable to continue the problem after an alarm, since either the real or imaginary part of a number may have caused the alarm.

"A DV alarm will occur if the real and the imaginary parts of the denominator are both less than about $2 \cdot 2^{-65}$ in absolute value.

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

The Ferranti Input Routine (revised)

Specifications

Identification Tag:	FRI-0
Type:	Service routine (with subroutine entrance)
Special Storage:	The constant and temporary storage pools are not used by this routine
Service Entrance:	Address 40001b
Program Entrance:	Address 40001b
Program Exit:	Address 40020b
Alarm Exit:	The alarm exit is used by this routine

Coded by:	R. Beach	May 18, 1955
Code Checked by:	R. Summers	May 19, 1955
Machine Checked by:	R. Beach	August 4, 1955
Revised by:	C. Koos	December 1, 1955
Approved by:	W. Bauer	December 9, 1955

Description

I. General

This routine is designed to read, by means of the Ferranti reader, seven-level bioctal tape prepared as described below. The routine reads in paper tape at the full speed of the Ferranti with only short hesitation when a check or insert address is encountered.

If desired, the tape may contain a check sum to be tested for agreement with the computed sum of the data read-in. The routine will read data into any ES or MD cell although the reading of information into certain drum cells (as described in detail below) will result in abnormal operation.

The routine stores the contents of ES on MD at addresses 76000b through 77777b and then transfers itself to ES. It sums itself (in ES) and checks the sum against the correct sum (stored on MD).

The Ferranti reader is started in the free running mode and the routine proceeds to read tape and process the information contained on the tape in the same manner as does the ERA photoelectric reader (for exceptions, see II. 3 and 4).

Each word to be transferred to memory is summed as it is read in from tape. Words which are to be read into ES are first stored in the MD image of ES (76000b thru 77777b).

During operation all words are read into ES from the tape and a block transfer to MD is made when (1) ES has been filled with data (that is, when 924 words have been read in); (2) an insert address appears on the tape; or (3) the "end of tape" seven-level combination has been read in (see II. 4).

The reader is stopped before making the transfer and is started again after the transfer has been completed in the first two cases; in the last case, the reader is stopped, ES is restored from the MD image and control is transferred to the exit.

The reader is also halted when a check address appears on the tape. If no check sum test (see II. 3) is to be made after a successful check address test the reader is started immediately; if the check sum test is specified the reader is started after the test is made and the sum determined to be correct.

The routine does not prevent read in to addresses 76000b thru 77777b nor to those calls used by the routine for its own operations.

II. Requirements for Tape Preparation

1. The first word on a tape must be an insert address.

2. Check addresses should be used, although FRI-0 will operate without them. A check address immediately following an insert address must be the same as the insert address.

3. For a check sum test the following four words must appear on the tape at the point where the sum is to be tested:

   a. Insert address 75202b

   b. High order 36 bits of check sum

   c. Low order 36 bits of check sum

   d. Check address 75204b

Operating Instructions (to be followed when the routine is used as a service routine)

1. Set PAK to 40001b and start.

2. Computation will halt with the MS instruction 56 00000 40001b at the completion of the read in.

Programming Instructions (to be followed when the routine is used as a subroutine)

1. Enter the routine with the RJ instruction 37 40020 40001b

2. Control is returned to the cell immediately following the RJ instruction as soon as an "end of block" punch is reached on the tape.

Alarm Conditions

1. No "end of tape" punch. This condition is indicated bby the tape running completely out of the Ferranti reader. When such a condition occurs the operator should.

   a. Master clear

   b. Set PAK to 00074b and start

   c. When computation halts (when a service entry was used) with the MS instruction 56 00000 40001b the machine will be returned to its original state and the data read from the tape will be properly stored.

      If a program entry was used control will be transferred to the proper cell in the main program.

2. FRI-0 not transferred to ES correctly. If ALR-1 prints "FRI-0 xxxxx and (A) and (Q), the sum of the program transferred to ES has failed to check. Starting at this point transfers FRI-0 to ES again.

   A second failure indicates that FRI-0 is not on the drum correctly and should be restored.

3. Check address failure. If ALR-1 prints "ALAR C" and (A) and (Q), a check address has failed. In the alarm print (A_R) is the address of the next

cell to be loaded and (Q) is the check address that was read in from paper tape.

Starting at this time will cause the machine to ignore the failure and operation will continue normally.

4. Check sum failure. If ALR-1 prints "ALAR M" and (A) and (Q), the check sum on the tape has failed to agree with the computed sum. The computed sum is in A at the time the alarm print occurs.

Starting at this point will cause the routine to ignore the failure and to begin to read in the tape again.

If at any time (ES) need to be restored from its image, starting at 40040b will transfer the image to ES and transfer control to the FRI-0 exit.

5. And "end of tape" (or "end of block") punch must be present on the tape to halt read in. This consists of seventh level punches in two consecutive frames on the tape at the point where the read in is to be stopped. This seventh level combination acts as a signal to FRI-0 to restore (ES) and stop the Ferranti reader. It is compatible with the ERA photoelectric reader in that it is an illegal combination which halts the ERA reader.

Note: If there is a sixth level punch in the second of two consecutive frames having seventh level punches the stop is bypassed. The check sum is cleared and the reading continues. This will still be an illegal combination which will halt an ERA photo-electric reader.

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Arcsine-Arcosine Routine
Specifications

Identification Tag:	SNI-1
Type:	Subroutine
Assembly Routine Spec:	SUB 50410 08014
Storage:	80 words total program storage
	7 words temporary storage pool used, addresses 00027b thru 00035b
	The constant pool is used by this routine
Entrance and Exit:	RJ 00K01 00K03 for the arcsine
	RJ 00K01 00K02 for the arcosine
Alarm:	The alarm exit is used to print "Alarm" if the absolute value of the argument exceeds one.
Drum Assignment:	Addresses 64252b thru 64371b
Machine Time:	6.0 ms average, 6.6 ms maximum time
Mode of Operation:	Fixed point

Coded by:	A. Franck (ERA)	May 14, 1955
Translated by:	D. Gantner	August 16, 1955
Machine Checked by:	T. Tack	August 25, 1955
Approved by:	W. Bauer	September 12, 1955

Description

This subroutine computes F(x) = arcsin x or F(x) = arcos x (depending on which of two entrances is used) by use of a polynomial approximation. (See Rand Sheet No. 39).

The routine was originally coded by Dr. A. Franck of ERA and has been adopted for use at The Ramo-Wooldridge Corporation.

Notation

x = sine or cosine of an angle F(x).

F(x) = the computed angle in radians whose sine or cosine is x.

The ranges of the results are the principal values, defined as follows:

$$-\pi/2 \leq \text{arcsine } x \leq \pi/2$$

$$0 \leq \text{arcosine } x \leq \pi$$

Programming Instructions

1. Place the argument scaled by 2^{33} (i.e. $x \cdot 2^{33}$) in A.

2. Enter the routine with an RJ instruction. If the routine was assigned to region 00K00 for assembly use the instruction

```
RJ  00K01  00K03  for the arcsine, or
RJ  00K01  00K02  for the arcosine.
```

3. At the time of exit from the routine the result $F(x) \cdot 2^{33}$ is left in A.

Alarm Conditions

If the |x| is greater than one an alarm exit will occur. The word "alarm" and the address of the cell in the main program containing the RJ instruction which was used to enter SNI-1 will be printed on the flexowriter.

Pushing the start button after the alarm halt will transfer control to the exit of SNI-1.

```
D           DSC00 50410
D           ASC00 01024
DSC00   37 75701 75702 B
DSC01   MJ 00000 00000
DSC02   MJ 00000 ASC57
DSC03   MJ 00000 ASC60
DSC04   TP 00013 00024
DSC05   TM A0000 00025
DSC06   TJ ASC66 ASC00
DSC07   TJ ASC67 ASC09
DSC08   MJ 00000 ASC00
DSC09   TP A0000 Q0000
DSC10   ZJ ASC11 ASC52
DSC11   SJ ASC12 ASC13
DSC12   TP 00016 00024
DSC13   TM A0000 A0000
DSC14   EJ ASC68 ASC55
DSC15   MP 00025 ASC69
DSC16   LA A0000 00037
DSC17   AT ASC70 00026
DSC18   MP 00025 00026
DSC19   LA A0000 00037
DSC20   AT ASC71 00026
DSC21   MP 00025 00026
DSC22   LA A0000 00039
DSC23   AT ASC72 00026
DSC24   MP 00025 00026
DSC25   LA A0000 00038
DSC26   AT ASC73 00026
DSC27   MP 00025 00026
DSC28   LA A0000 00038
DSC29   AT ASC74 00026
DSC30   MP 00025 00026
DSC31   LA A0000 00038
DSC32   AT ASC75 00026
DSC33   MP 00025 00026
DSC34   LA A0000 00036
DSC35   AT ASC76 00026
DSC36   TN 00025 A0000
DSC37   SA ASC68 00002
DSC38   TP ASC78 00027
DSC39   EJ ASC78 ASC47
DSC40   TP A0000 00028
DSC41   SP 00028 00034
DSC42   DV 00027 00029
DSC43   LA 00027 00071
DSC44   RS Q0000 00027
```

```
ALARM EXIT
ROUTINE EXIT
ARCCOS ENTRY
ARCSIN ENTRY
```

```
64252   00 00000 00000
02000   00 00000 00000
64252   37 75701 75702
64253   45 00000 00000
64254   45 00000 02071
64255   45 00000 02074
64256   11 00015 00030
64257   12 20000 00031
64260   42 02102 02000
64261   42 02103 02011
64262   45 00000 02000
64263   11 20000 10000
64264   47 02013 02064
64265   46 02014 02015
64266   11 00020 00030
64267   12 20000 20000
64270   43 02104 02067
64271   71 00031 02105
64272   54 20000 00045
64273   35 02106 00032
64274   71 00031 00032
64275   54 20000 00045
64276   35 02107 00032
64277   71 00031 00032
64300   54 20000 00047
64301   35 02110 00032
64302   71 00031 00032
64303   54 20000 00046
64304   35 02111 00032
64305   71 00031 00032
64306   54 20000 00046
64307   35 02112 00032
64310   71 00031 00032
64311   54 20000 00046
64312   35 02113 00032
64313   71 00031 00032
64314   54 20000 00044
64315   35 02114 00032
64316   13 00031 20000
64317   32 02104 00002
64320   11 02116 00033
64321   43 02116 02057
64322   11 20000 00034
64323   31 00034 00042
64324   73 00033 00035
64325   54 00033 00107
64326   23 10000 00033
```

```
DSC45   RA 00027 00029
DSC46   QJ ASC41 ASC47
DSC47   MP A0000 00026
DSC48   LA A0000 00037
DSC49   ST ASC77 Q0000
DSC50   IJ 00024 ASC52
DSC51   TN Q0000 Q0000
DSC52   RS Q0000 00023
DSC53   DV ASC79 A0000
DSC54   MJ 00000 ASC01
DSC55   TN ASC77 Q0000
DSC56   MJ 00000 ASC50
DSC57   TP ASC77 00023
DSC58   TV ASC65 ASC54
DSC59   MJ 00000 ASC04
DSC60   TP 00013 00023
DSC61   TV ASC64 ASC54
DSC62   MJ 00000 ASC04
DSC63   TN A0000 A0000
DSC64   MJ 00000 ASC01
DSC65   00 00000 ASC63
DSC66   67 77777 77777 B
DSC67   10 00000 00001 B
DSC68   10 00000 00000 B
DSC69   53 24135 20070 B
DSC70   33 24414 25535 B
DSC71   56 40071 51545 B
DSC72   37 50417 41233 B
DSC73   46 23706 66522 B
DSC74   26 61651 66073 B
DSC75   44 42003 30653 B
DSC76   31 10375 51633 B
DSC77   31 10375 52421 B
DSC78   37 77777 77777 B
DSC79   00 00000 00002 B
START
```

```
64327   21 00033 00035
64330   44 02051 02057
64331   71 20000 00032
64332   54 20000 00045
64333   36 02115 10000
64334   41 00030 02064
64335   13 10000 10000
64336   23 10000 00027
64337   73 02117 20000
64340   45 00000 02001
64341   13 02115 10000
64342   45 00000 02062
64343   11 02115 00027
64344   16 02101 02066
64345   45 00000 02004
64346   11 00015 00027
64347   16 02100 02066
64350   45 00000 02004
64351   13 20000 20000
64352   45 00000 02001
64353   00 00000 02077
64354   67 77777 77777
64355   10 00000 00001
64356   10 00000 00000
64357   53 24135 20070
64360   33 24414 25535
64361   56 40071 51545
64362   37 50417 41233
64363   46 23706 66522
64364   26 61651 66073
64365   44 42003 30653
64366   31 10375 51633
64367   31 10375 52421
64370   37 77777 77777
64371   00 00000 00002
```

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THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Floating Point Arcsine-Arccosine Routine

Specifications

Identification Tag:	SNI-2
Type:	Subroutine
Assembly Routine Spec:	SUB 50349 06112
Storage:	61 words total program storage. 3 words temporary storage pool used, addresses 00027b thru 00031b The constant pool is used by this routine.
Entrance and Exit:	RJ 00K01 00K02 for the arcsine RJ 00K01 00K03 for the arccosine
Alarm Exit:	The alarm exit is used to print "alarm" if the absolute value of the argument exceeds one.
Drum Assignment:	Address 64155b thru 64251b
Machine Time:	7.17 ms average, 8.74 ms maximum
Mode of Operation:	Floating point

Coded by:	M. Perry	August 25, 1955
Code Checked by:	R. Bigelow	August 28, 1955
Machine Checked by:	M. Perry	September 7, 1955
Approved by:	W. Bauer	September 12, 1955

Description

When supplied with an argument X in SNAP form, this routine will compute the arcsine or the arcosine of X (depending on which of two entrances was used) using a Rand Polynomial Approximation producing the answer in SNAP form.

Programming Instructions

The SNAP floating point routine must be in E.S. when this subroutine is entered.

1. Place the argument X in the accumulator. X must be in SNAP form.

2. Return Jump to the subroutine. Assuming that the subroutine was assigned to region 00K00 for assembly, use the instruction RJ 00K01 00K02 for arcsine, or RJ 00K01 00K03 for arcosine.

3. At the time of exit from the subroutine, the double length extension of arcsine X, or arcosine X, in SNAP form will be in the accumulator.

The ranges of the results are the principal values, defined as follows:

$$-\pi/2 \leq \text{arcsine } X \leq \pi/2$$
$$0 \geq \text{arcosine } X \leq \pi/$$

Error Analysis

The error in the result produced by this subroutine is less than 2^{-26}.

Mathematical Analysis

1. The Rand Polynomial Number 39 is evaluated using the absolute value of X as the argument. Designate the result as P(X).

2. The square root of 1 minus the absolute value of X is found using the square root subroutine within SNAP. Designate this result as R(X).

3. If X is positive, let Y = P(X)R(X)

   If X is negative, let Y = π-P(X)R(X)

4. Arcsine X = $(\pi/2)$-Y

   Arcosine X = Y

5. This procedure places arcsine X in the first or fourth quadrant, and arcosine X in the first or second quadrant.

Alarm Conditions

An alarm print will occur if the argument is outside the range $-1 \leq X \leq 1$. The flexowriter will print "alarm" and the address of the cell in the main program containing the RJ instruction which was used to enter SNI-2.

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```
D          00K00 00906
D          00T00 00722
D          00C00 00754
D          SRT00 00927
D          00P00 00877
D          0AS00 50349
D          1AS00 01024
D          2AS00 50398
D          3AS00 01073
0AS00  37  75701 75702 B
0AS01  MJ
0AS02  RP  20002 1AS04
0AS03  TP  00018 00023
0AS04  TP  A0000 00024
0AS05  TM  A0000 A0000
0AS06  TP  B0000 00025
0AS07  ST  3AS08 Q0000
0AS08  TJ  00K14 1AS12
0AS09  QT  00K03 00025
0AS10  SP  Q0000 00008
0AS11  TV  B0000 1AS12
0AS12  LA  00025 00000
0AS13  ST  3AS09 Q0000
0AS14  SF  Q0000 00T04
0AS15  SJ  1AS17 1AS16
0AS16  ZJ  1AS00 1AS32
0AS17  LA  A0000 00027
0AS18  TN  B0000 00T03
0AS19  LA  00T04 00027
0AS20  TP  1AS01 00C00
0AS21  RJ  00C00 SRT00
0AS22  TP  00P02 00C00
0AS23  SP  00T04 00000
0AS24  SS  SRT26 C0008
0AS25  TV  B0000 1AS31
0AS26  SN  3AS00 00036
0AS27  RP  20007 1AS29
0AS28  PM  3AS01 00025
0AS29  MP  B0000 00T03
0AS30  LA  A0000 00010
0AS31  SP  B0000 00000
0AS32  TP  B0000 00025
0AS33  TP  00024 Q0000
```

```
SNAP CONS
SNAP TEMP
SNAP EXIT
SNAP SQ ROOT
SNAP CONS
ARCSN RTN 49
REL 2000  49
ARCSN CNS 11
REL 2000  11
ALARM EXIT
NORMAL EXIT


COS ENTRY
X
X ABS
CLEAR 25
X-50
X ZERO
M




M FIXED    33
X LESS 1









1/X FLOATED
SF IN TO4


FIND ROOT
REPAIR SNAP









A/7
EVAL RAND.
POLY       29
           56
           66


           31
X
```

```
01612  00 00000 00000
01322  00 00000 00000
01362  00 00000 00000
01637  00 00000 00000
01555  00 00000 00000
64155  00 00000 00000
02000  00 00000 00000
64236  00 00000 00000
02061  00 00000 00000
64155  37 75701 75702
64156  45 00000 00000
64157  75 20002 02004
64160  11 00022 00027
64161  11 20000 00030
64162  12 20000 20000
64163  11 30000 00031
64164  36 02071 10000
64165  42 01630 02014
64166  51 01615 00031
64167  31 10000 00010
64170  16 30000 02014
64171  54 00031 00000
64172  36 02072 10000
64173  74 10000 01326
64174  46 02021 02020
64175  47 02000 02040
64176  54 20000 00033
64177  13 30000 01325
64200  54 01326 00033
64201  11 02001 01362
64202  37 01362 01637
64203  11 01557 01362
64204  31 01326 00000
64205  34 01671 00010
64206  16 30000 02037
64207  33 02061 00044
64210  75 20007 02035
64211  24 02062 00031
64212  71 30000 01325
64213  54 20000 00012
64214  31 30000 00000
64215  11 30000 00031
64216  11 00030 10000
```

```
0AS34   QJ 1AS35 1AS37          X NEG          64217  44 02043 02045
0AS35   SP 3AS11 00001          PI             64220  31 02074 00001
0AS36   ST 00025 00025                         64221  36 00031 00031
0AS37   IJ 00023 1AS40                         64222  41 00027 02050
0AS38   SP 3AS11 00000                         64223  31 02074 00000
0AS39   ST 00025 00025                         64224  36 00031 00031
0AS40   SF 00025 00023                         64225  74 00031 00027
0AS41   ZJ 1AS42 1AS01                         64226  47 02052 02001
0AS42   LA A0000 00027                         64227  54 20000 00033
0AS43   TP B0000 00025          M FINAL        64230  11 30000 00031
0AS44   SP 00023 00027                         64231  31 00027 00033
0AS45   AT 3AS10 Q0000          E FINAL        64232  35 02073 10000
0AS46   CC 00025 Q0000          PACK           64233  27 00031 10000
0AS47   TP A0000 A0000          EXTEND         64234  11 20000 20000
0AS48   MJ 00000 1AS01          OUT            64235  45 00000 02001
2AS00   01 26249 11000 -03  42  A/7            64236  05 12750 53762
2AS01   06 67009 01000 -03  40  A/6            64237  06 65103 05327
2AS02   -1 70881 25600 -02  38  A/5            64240  73 50016 32330
2AS03   03 08918 81000 -02  36  A/4            64241  01 76420 76052
2AS04   -5 01743 04600 -02  34  A/3            64242  77 14476 15552
2AS05   08 89789 87400 -02  32  A/2            64243  00 26616 51661
2AS06   -2 14598 80160 -01  30  A/1            64244  77 62210 01542
2AS07   01 57079 63050      28  A 0            64245  00 31103 75516
2AS08   06 20000 00000 B        50             64246  06 20000 00000
2AS09   10 00000 00000 B        1          33  64247  10 00000 00000
2AS10   07 40000 00000 B        60             64250  07 40000 00000
2AS11   01 57079 63268      31   PI OVER 2     64251  03 11037 55242
START                                          00000  45 00000 00000
```

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THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Floating Point Arctangent Routine

Specifications

Identification Tag:	TNI-1
Type:	Subroutine
Assembly Routine Spec:	SUB 50137 05114
Storage:	51 words total program storage. 3 words temporary storage pool used, addresses 00027b thru 00031b The constant pool is used.
Entrance and Exit:	RJ 00K01 00K02
Drum Assignment:	Address 63631b thru 63713b
Machine Time:	4.27 ms average, 5.8 ms maximum
Mode of Operation:	Floating point

Coded by:	M. Perry	July, 1955
Code Checked by:	R. Bigelow	July, 1955
Machine Checked by:	M. Perry	August, 1955
Approved by:	W. Bauer	August, 1955

Description

When supplied with an argument X in SNAP form, this routine will evaluate Arctan X (in radians) using a Rand Polynomial Approximation producing an answer in SNAP form.

Programming Instructions

1. Place the double length extension of X in the accumulator.

   X must be in SNAP form.

2. Return Jump to the subroutine. Assuming that the subroutine was assigned to region 00K00 for assembly, use the instruction RJ 00K01 00K02.

3. At the time of exit from the subroutine, the double length extension of Arctan X will be in the accumulator in SNAP form. The range of the result will be the principal value, defined as follows:

$$-\pi/2 \leq \text{Arctan } X \leq \pi/2$$

Error Analysis

The error in the result produced by the routine is less than 2^{-25}.

Mathematical Analysis

1. If $x \geq 1$, the identity Arctan X = $(\pi/2)$ - Arctan (1/X) is used.

2. Rand Polynomial Number 13 is evaluated using X (or 1/X) as the argument.

Range of Variable

No alarm conditions exist. Any number which can be expressed in SNAP form can be entered and the result will have the accuracy stated above.

```
D          00T00 50137
D          01T00 01024
D          02T00 50174
D          03T00 01061
00T00   00 00000 00000
00T01   MJ 00000 00000
00T02   TP 00013 00025
00T03   TP 03T00 01T35
00T04   SJ 01T05 01T06
00T05   TP 03T01 01T35
00T06   TM A0000 Q0000
00T07   QT 03T02 00023
00T08   SS Q0000 00000
00T09   SA 03T03 00008
00T10   TM B0000 00024
00T11   SJ 01T12 01T15
00T12   SN 00015 00039
00T13   DV 00023 00023
00T14   TP 03T04 00025
00T15   SP 03T05 00000
00T16   SS 00024 00000
00T17   SJ 01T20 01T18
00T18   TV A0000 01T19
00T19   LA 00023 00000
00T20   TP B0000 00023
00T21   MP B0000 Q0000
00T22   LA A0000 00001
00T23   TP B0000 00024
00T24   SN 03T06 00035
00T25   RP 20007 01T27
00T26   PM 03T07 00024
00T27   PM 00025 00023
00T28   TP B0000 A0000
00T29   ZJ 01T30 01T01
00T30   SF A0000 00024
00T31   TP A0000 00023
00T32   SP 00024 00000
00T33   SA 00014 00035
00T34   SA 00023 00027
00T35   TP B0000 A0000
00T36   MJ 00000 01T01
```

```
ARCTN RTN 37      63631  00 00000 00000
TO BE ALTERD      02000  00 00000 00000
ARCTN CNS 14      63676  00 00000 00000
TO BE ALTERD      02045  00 00000 00000
ALARM EXIT        63631  00 00000 00000
NORMAL EXIT       63632  45 00000 00000
NORMAL ENTRY      63633  11 00015 00031
                  63634  11 02045 02043
                  63635  46 02005 02006
NEG ARG           63636  11 02046 02043
                  63637  12 20000 10000
M                 63640  51 02047 00027
                  63641  34 10000 00000
MINUS E           63642  32 02050 00010
E ABS             63643  12 30000 00030
                  63644  46 02014 02017
1                 63645  33 00017 00047
1 OVER M  28      63646  73 00027 00027
PI OVER 2         63647  11 02051 00031
                  63650  31 02052 00000
                  63651  34 00030 00000
                  63652  46 02024 02022
42/E ABS          63653  16 20000 02023
                  63654  54 00027 00000
ARG OF POLY       63655  11 30000 00027
                  63656  71 30000 10000
                  63657  54 20000 00001
ARG SQUARED       63660  11 30000 00030
C/15              63661  33 02053 00043
                  63662  75 20007 02033
POLY              63663  24 02054 00030
  EVALUATION      63664  24 00031 00027
                  63665  11 30000 20000
                  63666  47 02036 02001
SCALE             63667  74 20000 00030
M FINAL           63670  11 20000 00027
                  63671  31 00030 00000
E/128 FINAL       63672  32 00016 00043
PACK              63673  32 00027 00033
EXTEND            63674  11 30000 20000
OUT               63675  45 00000 02001
```

```
02T00   TP B0000 A0000                POS CONDITN    63676  11 30000 20000
02T01   TN B0000 A0000                NEG CONDITN    63677  13 30000 20000
02T02   00 07777 77777 B              MASK           63700  00 07777 77777
02T03   20 00000 00000 B              128            63701  20 00000 00000
02T04   01 57079 63268            27  PI OVER 2      63702  00 14441 76652
02T05   00 00000 00052 B              42             63703  00 00000 00052
02T06   04 05405 80000 -03        36  C/15           63704  00 20465 76350
02T07   02 18612 28800 -02        34  C/13           63705  00 26305 45073
02T08   -5 59098 86100 -02        33  C/11           63706  77 43277 43606
02T09   09 64200 44100 -02        32  C/9            63707  00 30535 75750
02T10   -1 39085 33510 -01        31  C/7            63710  77 56144 71644
02T11   01 99465 35990 -01        30  C/5            63711  00 14610 05133
02T12   -3 33298 56050 -01        29  C/3            63712  77 65253 17101
02T13   09 99999 33290 -01        28  C/1            63713  00 17777 77515
START
```

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

CHANGED WORD POST-MORTEM ROUTINE (revised)

Specifications

Identification Tag:	MDP-3
Type:	Service Toutine (with subroutine entrance)
Special Storage:	The constant pool and temporary storage pool are not used by this routine.
Service Entrance:	Address 40037b
Program Entrance:	40037b
Program Exit:	40020b
Alarm Exit:	The alarm exit is not used by this routine.
Machine Time:	(14.1 + .5n) seconds where n=number of cards punched.

Coded by:	R. Beach	October 26, 1955
Code Checked by:	R. Beach	October 26, 1955
Machine Checked by:	R. Beach	October 26, 1955
Revised by:	C. Koos	December 1, 1955
Approved by:	W. F. Bauer	December 9, 1955

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Description

This routine compares ES with the MD image of ES and prints out those words of ES which are not the same as their correspondent in the image. ES is not altered by the routine, and the MD image is up-dated to be identical with ES when exit is made from the routine.

The routine stores ES at addresses 66000b to 67777b and reads portions of this image and the regular image (76000b - 77777b) into ES and compares words.

If the corresponding words are the same, they are replaced by zero, unless the new value is zero. In the latter case the word is replaced by 45 40037 40020b. The changed words and zeros are then read into ES. ES is then dumped on the line printer. (Note: Until the line printer is in use, this dump will be made onto cards by employing MDP-4). ES and the 76000b image are then restored from the 66000b image.

Each card contains six words. If any one word is zero, it should be ignored as it is not a changed word. A word which has been changed to zero has been given the arbitrary tag 45 40037 40020b and will be punched as such. Also, a word that was changed to this tag will be identified in the same manner. The programmer must therefore distinguish between these two cases.

Operating Instructions

1. When routine is used as a service routine set PAK to 40037b. Routine will find changed words, print them out, and stop on 56 00000 40037b.

2. When routine is used as a subroutine enter routine with 37 40020 40037b. Operation of routine is the same except that routine exits to address y+1 if y is the address of the RJ instruction used to enter the routine.

3. Most service routines use all or parts of ES and their activation will destroy the old 76000b image. Hence, if a changed word comparison is desired, the execution of MDP-3 must precede the use of other post-mortem routines.

Alarm Conditions

There are no alarm conditions in this routine. However, if the routine hangs up during punching, or if the machine is halted during punching, a start at 40040b will clear the punch, restore ES, and up-date the 76000b image.

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Nth Root Routine

Specifications

Identification Tag:	NRT-0
Type:	Subroutine
Assembly Routine Spec:	SUB 51316 03701
Storage:	36 instructions, addresses 10F00 thru 10F35 1 constant in program, address 10F36 37 words total program storage, addresses 10F00 thru 10F36 4 words temporary storage pool used, addresses 00027b thru 00033b The constant pool is used by this routine.
Program Entrance:	Address 10F02
Program Exit:	Address 10F01
Alarm Exit:	The alarm exit is used by this routine.
Drum Assignment:	Address 66064b thru 66130b
Machine Time:	Average execution time $2(n-2) + 5$ milliseconds for $n \leq 50$
Mode of Operation:	Fixed point

Coded by:	W. Frank	November 25, 1955
Code Checked by:	W. Frank	November 28, 1955
Machine Checked by:	W. Frank	November 30, 1955
Approved by:	W. F. Bauer	December 1, 1955

Description

This subroutine extracts the nth root of any number M, scaled at 2^{35}, and such that

$$\left|M \cdot 2^{35}\right| \leq 2^{35} - 1.$$

n must be an integer in the range

$$2 \leq n < 2^{12}$$

The routine must be entered with $M \cdot 2^{35}$ in A and $n \cdot 2^{0}$ in Q. The result will be left in A, scaled at 2^{35}, at the conclusion of the routine.

Programming Instructions

1. Place $M \cdot 2^{35}$ in A_R. (A_L) is ignored by this routine.
2. Place $n \cdot 2^{0}$ in Q.
3. Enter the subroutine with RJ 00F01 00F02, where 00F00 is the location of the first word of NRT-0.
4. The subroutine returns control to the cell following the RJ instruction with $(\sqrt[n]{M}) \cdot 2^{35}$ in A.

Alarm Conditions

The subroutine enters the alarm routine ALR-1 if n is negative or M is negative for n even. In either case, the word "alarm" is printed on the flexowriter, followed by the octal address of the RJ instruction used to enter NRT-0.

Execution Time

The time taken to find the nth root of a number is inversely proportional to the magnitude of the number and directly proportional to the size of n. An average estimate, for $n \leq 50$, is approximately 3(n-2) + 5 milliseconds.

Mathematical Method

An iterative procedure, employing the Newton-Raphson method*, is used to solve the equation

$$x^n = M$$

The process is of second order and is defined by

$$x_{i+1} = x_i + \frac{1}{n}\left[\frac{|M|}{(x_i)^{n-1}} - x_i\right]$$

where $x_0 \cdot 2^{35} = 2^{35} - 1$

The iteration is terminated when

$$\frac{|M|}{(x_i)^{n-1}} - x_i \geq 0$$

A secondary test is made to insure

$$|M| < (x_i)^{n-1}$$

This test is necessary, even though the process is monotonic; for, it is possible that truncation of the result of multiplication and division can violate this property. In that event, x_{i-1} is taken as the solution. A special case is M = 0, where the solution is x = 0 for all p.

Accuracy

The error in the result of this routine was found to be less than 10^{-10}; that is, for an input argument, which is correct to 35 bits, one can expect an answer which may be incorrect at most in the right octal digit.

*Scarborough, J.B., Numerical Mathematical Analysis, second edition, The John Hopkins Press, Baltimore, Md., 1950, p. 192.

```
D                00F00  01024
D                10F00  51316
D                0CP00  00013
10F00    37      75701  75702  B        ALARM
10F01    MJ      00000  0               EXIT
10F02    ZJ      00F03  00F01           ARG ZERO
10F03    TP      A0000  0CP11
10F04    TP      Q0000  0CP10
10F05    QT      00016  A0000           N EVEN OR
10F06    ZJ      00F09  00F07             OD
10F07    TP      0CP11  A0000
10F08    SJ      00F00  00F09           ALARM
10F09    TM      0CP11  0CP14
10F10    TP      00F36  0CP12           SET X0 VALUE
10F11    54      0CP10  20017  BRB
10F12    SJ      00F00  00F13           N NEGATIVE
10F13    TU      A0000  00F17
10F14    RS      00F17  00015
10F15    RS      00F17  00015
10F16    SP      0CP12  00035           SET UP B
10F17    RP      00000  00F19
10F18    MP      B0000  0CP12           XITH TO N-1
10F19    TP      B0000  0CP13
10F20    TP      0CP14  A0000
10F21    TJ      0CP13  00F23
10F22    MJ      00000  00F30
10F23    LA      A0000  00035
10F24    DV      0CP13  A0000
10F25    ST      0CP12  A0000
10F26    SJ      00F27  00F30           CONVERGENCE
10F27    DV      0CP10  A0000
10F28    AT      0CP12  0CP12           XITH PLUS 1
10F29    MJ      00000  00F16
10F30    TP      0CP11  A0000
10F31    SJ      00F32  00F34
10F32    TN      0CP12  A0000
10F33    MJ      00000  00F01
10F34    TP      0CP12  A0000
10F35    MJ      00000  00F01
10F36    37      77777  77777  B

     2000    00  00000  00000
66064        00  00000  00000
       15    00  00000  00000
66064    37  75701  75702
66065    45  00000  00000
66066    47  02003  02001
66067    11  20000  00030
66070    11  10000  00027
66071    51  00020  20000
66072    47  02011  02007
66073    11  00030  20000
66074    46  02000  02011
66075    12  00030  00033
66076    11  02044  00031
66077    54  00027  20017
66100    46  02000  02015
66101    15  20000  02021
66102    23  02021  00017
66103    23  02021  00017
66104    31  00031  00043
66105    75  00000  02023
66106    71  30000  00031
66107    11  30000  00032
66110    11  00033  20000
66111    42  00032  02027
66112    45  00000  02036
66113    54  20000  00043
66114    73  00032  20000
66115    36  00031  20000
66116    46  02033  02036
66117    73  00027  20000
66120    35  00031  00031
66121    45  00000  02020
66122    11  00030  20000
66123    46  02040  02042
66124    13  00031  20000
66125    45  00000  02001
66126    11  00031  20000
66127    45  00000  02001
66130    37  77777  77777
```

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THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Gill Method Subroutine

Specifications

Identification Tag:	NUI-3
Type:	Subroutine
Assembly Storage Spec:	SUB 49880 07414
Storage:	59 instructions, addresses OGM00 thru OGM40 1GM00 thru 1GM17 15 constants in program, addresses OGC00 thru OGC14 74 words total program storage, addresses OGM00 thru OGM40 1GM00 thru 1GM17 OGC00 thru OGC14 10 words temporary storage pool used, addresses 00027b (OGT00) thru 00040b (OGT09)
Drum Assignment:	Addresses 63230b thru 63341b
Program Entrances:	Addresses OGM02, OGM03, and OGM04
Program Exit:	Address OGM01
Machine Time:	(10.3 n + 1.9) ms per point average, where n equals the number of equations in the system
Mode of Operation:	Fixed point
Coded by:	J. Carlson R. Douthitt M. Elmore R. Summers
Code Checked by:	M. Elmore — June 8, 1955
Machine Checked by:	M. Elmore — July 7, 1955
Approved by:	W. Bauer — July 22, 1955

Description

The Gill Method Subroutine integrates a system of first order, differential equations using a step-by-step process. Using the values of the variables at a point and the coding for computing the derivative of each of the dependent variables at that point, the Gill Method Subroutine produces the coordinates for the next point of the solution each time it is entered.

A special entrance sets up the subroutine for a particular system of equations, thus allowing the subroutine to solve concurrently several different systems in the same program.

The independent variable is incremented within the subroutine itself.

Notation

The system of equations to be solved is

$$\frac{dy_i}{dx} = f_i\,(x, y_1, y_2, \ldots, y_n),\ (i = 1, 2, \ldots, n).$$

q_i are intermediate values of the calculation (zero initially)

Δx is the increment of the independent variable x

h is the binary scaling power of x (i.e. $x \cdot 2^h$ is in the computer)

h-1 is the binary scaling power of Δx

m_i is the binary scaling power of y_i

f is the common difference between the scaling power of y_i and the scaling power of $\frac{dy_i}{dx}$ for each i.

$m_i - f$ is the binary scaling power of $\frac{dy_i}{dx}$

$L = 73 + f - h$

Programming and Operating Instructions

Assign the Gill Method Subroutine to some arbitrary region, say OGMOO.

In order to solve a given system, the following array of variables, derivatives, intermediate values, and parameters should be assigned a region, say OGNOO.

OGN00		L	
OGN01	00 OGN05 OGN06		
OGN02		n-1	
OGN03		Δx	scaled 2^{h-1}
OGN04		x	scaled 2^{h}
OGN05		$\frac{dy_1}{dx}$	scaled m_1 - f
OGN06		y_1	scaled m_1
OGN07		q_1	initially zero
OGN08		$\frac{dy_2}{dx}$	scaled m_2 - f
OGN09		y_2	scaled m_2
OGN10		q_2	initially zero

The q_i must be set to zero initially by the programmer.

In addition, the coding for computing $\frac{dy_i}{dx}$ for all i, (i = 1, 2, . . . , n) should be assigned a region, say ODE00. This coding will use the values in region OGN00 to compute all $\frac{dy_i}{dx}$ as specified by the equations in the system and should place the results in the appropriate places in region OGN00. It should then exit to the Gill Method Subroutine with an MJ 00000 OGM04 (see below).

Assuming the Gill Method Subroutine is in region OGM00, the three entrances are OGM02, OGM03, and OGM04. The exit is OGM01.

The first entrance, OGM02, is used for setting up the Gill Method Subroutine only for the particular system to be solved. It is entered by an RJ command followed by a parameter word which specifies the location of the variables, and the location of the coding for calculating the derivatives:

RJ OGM01 OGM02
00 OGN00 ODE00

The second entrance, OGM03, is the entrance for producing a point of the solution. It is entered by an RJ command: RJ OGM01 OGM03. Entering using this command results in four passes through both the Gill Method Subroutine and the coding for computing the derivatives, and leaves in region OGN00 the new values of the variables, the derivatives at those values, and x advanced by Δx, ready for the next step.

The third entrance, OGM04, is the entrance from the coding for calculating the derivatives and is used on each of the four passes necessary for computing one point. As noted above, it is entered by an MJ command in the ODE00 region:

Mathematical Analysis

Theory. "A Process for the Step-by-Step Integration of Differential Equations in an Automatic Digital Computing Machine" by S. Gill, published in Cambridge Philosophical Society Proceedings, Vol. 47, Part I, January 1951, should be consulted for a detailed analysis of the process on which the subroutine is based.

Suppose we know the point $(X, Y_1, Y_2, \ldots, Y_n)$ on the curve defined by the system of equations

$$\frac{dy_1}{dx} = f_1 (x, y_1, y_2, \ldots, y_n)$$

$$\frac{dy_2}{dx} = f_2 (x, y_1, y_2, \ldots, y_n)$$

$$\vdots$$

$$\frac{dy_n}{dx} = f_n (x, y_1, y_2, \ldots, y_n)$$

The Gill Method is a process by which we can find the next point on the curve: i.e. the value of $y_1, y_2, \ldots, y_n$ for $x = X + h$.

The process can be better understood if the case where n=1 is first considered.

We have the point (X,Y) on the curve $\frac{dy}{dx} = f(x,y)$, and we want to find y at $X + h$; i.e. we want $k = \delta y$ such that $\left[\frac{dy}{dx}\right]_{X+h,\ Y+k} = f(X + h, Y + k)$.

We derive k by making four approximations and averaging them in a particular way.

First approximate the curve by a straight line through (X,Y) with the slope $\left[\frac{dy}{dx}\right]_{X,Y} = f(X,Y)$, and find a first approximation to k:

$$k_o = h \cdot f(X,Y)$$

Then we travel a fraction m of the way along this line to the point $(X + mh, Y + mk_o)$ and find $f(X + mh, Y + mk_o)$.

This gives us a new straight line through $(X + mh, Y + mk_o)$ with slope $f(X + mh, Y + mk_o)$, and we find

$$k_1 = h\, f(X + mh, Y + mk_o)$$

We now use k_o and k_1 to find a third point at which f is calculated: $(X + nh, Y + [n-r]k_o + rk_1)$.

$$k_2 = h\, f(X + nh, Y + [n-r]\, k_o + rk_1)$$

Similarly,

$$k_3 = h \cdot f\ (X + ph,\ Y + \left[p-s-t\right]\ k_o + sk_1 + tk_2$$

The weighted average of k_o, k_1, k_2, and k_3 is the desired $k = \delta y$:

$$\delta y = y\ (X + h) - y\ (X) = c_o k_o + c_1 k_1 + c_2 k_2 + c_3 k_3$$

where $c_o + c_1 + c_2 + c_3 = 1$.

For a system of equations, the same four steps given above are made for each equation and

$$\delta y_i = c_o k_{io} + c_1 k_{i1} + c_2 k_{i2} + c_3 k_{i3} \text{ where } c_o + c_1 + c_2 + c_3 = 1.$$

The above process is, for certain values of m, n, p, s, t, c_o, c_1, c_2, and c_3, the Runge-Kutta process. The Gill process was derived, with application to machine use in mind, by minimizing the number of storage cells required. For the Gill Method the above constants are

$m = 1/2$,	$r = 1 - \sqrt{1/2}$,	$c_o = 1/6$
$n = 1/2$,	$s = \ - \sqrt{1/2}$,	$c_1 = (1/3)\ (1 - \sqrt{1/2})$
$p = 1$,	$t = 1 + \sqrt{1/2}$,	$c_2 = (1/3)\ (1 + \sqrt{1/2})$
		$c_3 = 1/6$

The Gill process further systematizes the calculation so as to increase the accuracy and simplify the coding.

<u>The Subroutine</u> As used in the Gill Method Subroutine, the process is as follows:

1st pass:

Advance x by $(1/2)h$

$$k_{io} = h \cdot f_i\ (x,\ y_{10},\ y_{20},\ \ldots,\ y_{no})$$

$$r_{i1} = (1/2)k_{io} - q_{io}$$

$$q_{i1} = q_{io} + 3r_{i1} - (1/2)k_{io}$$

$$y_{i1} = y_{io} + r_{i1}$$

Calculate $f_i\ (x, y_{11}, y_{21}, \ldots, y_{ni})$ in programmer's own coding.

2nd pass:

$$k_{i1} = h\ f_i\ (x, y_{11}, y_{21}, \ldots, y_{n1})$$

$$r_{i2} = (1 - \sqrt{1/2})\ (k_{i1} - q_{i1})$$

$$q_{i2} = q_{i1} + 3r_{i2} - (1 - \sqrt{1/2})\ k_{i1}$$

$$y_{i2} = y_{i1} + r_{i2}$$

Calculate $f_i\ (x, y_{12}, y_{22}, \ldots, y_{n2})$ in programmer's own coding.

3rd pass:

Advance x by (1/2)h

$k_{i2} = h \cdot f_1 (x, y_{12}, y_{22}, \ldots, y_{n2})$

$r_{i3} = (1 + \sqrt{1/2})(k_{i2} - q_{i2})$

$q_{i3} = q_{i2} + 3r_{i3} - (1 + \sqrt{1/2})\, k_{i2}$

$y_{i3} = y_{i2} + r_{i3}$

Calculate $f_i (x, y_{13}, y_{23}, \ldots, y_{n3})$ in programmer's own coding.

4th pass:

$k_{i3} = h \cdot f_i (x, y_{13}, y_{23}, \ldots y_{n3})$

$r_{i4} = (1/6)(k_{i3} - 2q_{i3})$

$q_{i4} = q_{i3} - 3r_{i4} - (1/2)k_{i3}$

$y_{i4} = y_{i3} + r_{i4}$

Calculate $f_i(x, y_{14}, y_{24}, \ldots, y_{n4})$ in programmer's own coding.

Machine Checking

A driver routine solved two systems of equations both separately and concurrently, using the Gill Method Subroutine. The two systems solved are given below to indicate accuracy and to serve as examples.

1. Equations

$$\left.\begin{aligned}\frac{dy_1}{dx} &= y_2\\ \frac{dy_2}{dx} &= -y_1\end{aligned}\right\}$$ equivalent to the second order equation,

$$\frac{d^2y}{dx^2} + y = 0.$$

$\Delta x = .0872664626 = \pi/36 = 5^\circ$

Initial Conditions

At $x=0$, $y_1 = 0$ and $y_2 = 1$.

Solution

$y_1 = \sin x$

Accuracy

In a spot check of the results, the greatest absolute error observed was 1.5×10^{-6}. (For $x = 3.1415925696$, $y_1 = .0000015425$. However, $\sin x = .000000084$).

2. Equations

$$\left.\begin{aligned}\frac{dy_1}{dx} &= y_2\\ \frac{dy_2}{dx} &= y_3\\ \frac{dy_3}{dx} &= \frac{y_3 + 4x^2}{x}\end{aligned}\right\}$$ Equivalent to the third order equation

$$x\frac{d^3y}{dx^3} - \frac{d^2y}{dx^2} = 4x^2$$

$\Delta x = .1$

Initial Conditions

At $x = .1$, $y_1 = .000025$, $y_2 = .001$, $y_3 = .03$

Solution

$$y_1 = \frac{x^4}{3} - \frac{x^3}{60} + \frac{x}{6000} - \frac{1}{120{,}000}$$

Accuracy

In a spot check of the results, the greatest relative error observed was 3.4×10^{-6}. (For $x = .1999999975$, $y_1 = .00042499858$. However, the solution is actually .00042500002).

D		GM	[illegible]		[illegible]	00	00000	03000
D		1GM	[illegible]		02051	00	00000	00000
D		2GM	[illegible]		63230	00	00000	00000
D		3GM	49921		63231	00	00000	00000
D		0GC	1083		02073	00	00000	00000
D		1GC	49939		63323	00	00000	00000
D		0GT	23		00027	00	00000	00000
2GM00	00	00000	00000		63230	00	00000	00000
2GM01	MJ				63231	45	00000	00000
2GM02	MJ		1GM00	TO SET UP	63232	45	00000	02051
2GM03	MJ		0GM36	ENTER	63233	45	00000	02044
2GM04	TP	0GM00	00000	RE ENTER	63234	11	02000	10000
2GM05	QJ	0GM06	0GM40	WHAT	63235	44	02006	02050
2GM06	QJ	0GM38	0GM07	PASS	63236	44	02046	02007
2GM07	TP	00000	0GM00	STORE CTR	63237	11	10000	02000
2GM08	RA	0GM10	0GC01	UP PASS	63240	21	02012	02074
2GM09	RP	30003	0GM11	STORE	63241	75	30003	02013
2GM10	TP		0GT05	PASS CONS	63242	11	00000	00034
2GM11	TU		0GM15	RESET	63243	15	00000	02017
2GM12	TV		0GM39	ADDRESSES	63244	16	00000	02037
2GM13	TP		0GT06	RESET N 1	63245	11	00000	00037
2GM14	RP	30004	0GM36		63246	75	30003	02020
2GM15	TP		0GT00		63247	11	00000	00027
2GM16	MP		0GT01	CALC K	63250	71	00000	00027
2GM17	LA	A		SHIFT L	63251	54	20000	00000
2GM18	TP	A	0GT03	STORE K	63252	11	20000	00032
2GM19	MP	0GT05	0GT05	AK	63253	71	00034	00032
2GM20	MA	0GT06	0GT02	AK BQ	63254	72	00035	00031
2GM21	LA	A	38		63255	54	20000	00046
2GM22	TP	A	0GT04	STORE R	63256	11	20000	00033
2GM23	AT	A	A	2R	63257	35	20000	20000
2GM24	AT	0GT04	A	2P	63260	35	00033	20000
2GM25	LA	A	34		63261	54	20000	00042
2GM26	MA	0GT07	0GT03	3R CK	63262	72	00036	00032
2GM27	LA	A	36	ADD OLD Q	63263	54	20000	00046
2GM28	AT	0GT02	0GT02	EQUALS Q	63264	35	00031	00031
2GM29	RA	0GT01	0GT44	NEW Y	63265	21	00030	00033
2GM30	RP	30002	0GM32	STORE	63266	75	30002	02040
2GM31	TP	0GT01		Y AND Q	63267	11	00030	00000
2GM32	RA	0GM15	0GC01	ADVANCE	63270	21	02017	02074
2GM33	RA	0GM31	0GC02	ADDRESSES	63271	21	02037	02075
2GM34	IJ	0GT08	0GM14	CYCLE N	63272	41	00037	02016
2GM35	MJ				63273	45	00000	00000
2GM36	TU	0GC00	0GM10		63274	15	02073	02012
2GM37	TP	0GM21	Q		63275	11	02025	10000
2GM38	RA				63276	21	00000	00000
2GM39	MJ		0GM07		63277	45	00000	02007

PX 71900-10-(91)

```
2GM40   QJ 0GM01 0GM07
3GM00   SP 0GM01 00015
3GM01   TU A     1GM02
3GM02   TP       0GT00
3GM03   TV 0GT00 0GM35
3GM04   TU 0GT00 1GM05
3GM05   TV       0GM17
3GM06   RA 0GT00    15
3GM07   RP 10003 1GM09
3GM08   TU 0GT00 0GM11
3GM09   RA 0GM13    15
3GM10   AT    15 A
3GM11   TU A     0GM16
3GM12   TU A     0GM38
3GM13   LQ A        21
3GM14   TV Q     0GM38
3GM15   RA 0GM38    15
3GM16   RA 0GM01    16
3GM17   MJ       0GM01
1GC00       GC
1GC01           3       B
1GC02                 3 B
1GC03    5                - 1  34  A1 SCALE 34
1GC04   -1                     34  B1       34
1GC05   -5                - 1  34  C1       34
1GC06   02 92893 21881    - 1  34  A2 SCALE 34
1GC07   -2 92893 21881    - 1  34  B2       34
1GC08   -2 92893 21881   -01  34  C2 SCALE 34
1GC09    1 70710 67812        34  A3       34
1GC10   -1 70710 67812        34  B3       34
1GC11   -1 70710 67812        34  C3       34
1GC12    1 66666 66667    - 1  34  A4       34
1GC13   -3 33333 33333    - 1  34  B4       34
1GC14   -5                - 1  34  C4       34
```

```
63300   44 02001 02007
63301   31 02001 00017
63302   15 20000 02053
63303   11 00000 00027
63304   16 00027 02043
63305   15 00027 02056
63306   16 00000 02021
63307   21 00027 00017
63310   75 10003 02062
63311   15 00027 02013
63312   21 02015 00017
63313   35 00017 20000
63314   15 20000 02020
63315   15 20000 02046
63316   55 20000 00025
63317   16 10000 02046
63320   21 02046 00017
63321   21 02001 00020
63322   45 00000 02001
63323   00 02073 00000
63324   00 00003 00000
63325   00 00000 00003
63326   10 00000 00000
63327   57 77777 77777
63330   67 77777 77777
63331   04 53730 31460
63332   73 24047 46317
63333   73 24047 46317
63334   33 24047 46320
63335   44 53730 31457
63336   44 53730 31457
63337   02 52525 25253
63340   72 52525 25252
63341   67 77777 77777
```

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

Floating Point Gill Method

Identification Tag:	NUI-4
Type:	Subroutine
Assembly Routine Spec:	SUB 51921 08914
Storage:	89 words total program storage 9 words temporary pool used, addresses 27 b thru 37 b The constant pool is used.
Entrance and Exit:	RJ GIL01 GIL02 set up RJ GIL01 GIL03 to get next point MJ 0 GIL04 From derivative calculation
Machine Time:	Approximately (9.7 + 84.6n) m.s. per time interval, where n equals the number of equations in the system.

Coded by:	J. Carlson	May, 1956
Approved by:	W. F. Bauer	May 10, 1956

Description

The Gill Method Subroutine integrates a system of first order, differential equations using a step-by-step process. Using the values of the variables at a point and the coding for computing the derivative of each of the dependent variables at that point, the Gill Method Subroutine produces the coordinates for the next point of the solution each time it is entered.

A special entrance sets up the subroutine for a particular system of equations, thus allowing the subroutine to solve concurrently several different systems in the same program.

The independent variable is incremented within the subroutine itself.

Notation

The system of equations to be solved is

$$\frac{dy_i}{dx} = f_i\,(x, y_1, y_2, \ldots, y_n),\ (i = 1, 2, \ldots, n).$$

n is the number of equations in the system.

q_i are intermediate values of the calculation (zero initially)

x is the increment of the independent variable x

Programming and Operating Instructions

SNAP must be in E.S.

Assign the Gill Method Subroutine to some arbitrary region, say GIL00. This region need not be located in the low numbered half of E.S.

In order to solve a given system, the following array of variables, derivatives, intermediate values, and parameters should be assigned a region, say DEQ00. Although the programmer will undoubtedly desire to have this region located in the low numbered half of E.S., it is not necessary for the operation of this subroutine.

DEQ00	n	Fixed point form scaled 2^0.
DEQ01	Δx	Floating point form
DEQ02	x	"
DEQ03	$\frac{dy_1}{dx}$	"
DEQ04	y_1	"
DEQ05	q_1	"

(The q_i must be set to zero initially by the programmer.)

DEQ06 $\frac{dy_2}{dx}$

DEQ07 y_2

DEQ08 q_2

In addition, the coding for computing $\frac{dy_i}{dx}$ for all i, (i = 1, 2, . . ., n) should be assigned a region, say DFQ00. This coding will use the values in region DEQ00 to compute all $\frac{dy_i}{dx}$ as specified by the equations in the system and should place the results in the appropriate places in region DEQ00. It should then exit to the Gill Method Subroutine with an MJ 00000 GIL04 (see below).

Assuming the Gill Method Subroutine is in region GIL00, the three entrances are GIL02, GIL03, and GIL04. The exit is GIL01.

The first entrance, GIL02, is used for setting up the Gill Method Subroutine only for the particular system to be solved. It is entered by an RJ command followed by a parameter word which specifies the location of the variables, and the location of the coding for calculating the derivatives:

```
RJ  GIL01  GIL02
00  DEQ00  DFQ00
```

The second entrance, GIL03, is the entrance for producing a point of the solution. It is entered by an RJ command: RJ GIL01 GIL03. Entering using this command results in four passes through both the Gill Method Subroutine and the coding for computing the derivatives, and leaves in region DEQ00 the new values of the variables, the derivatives at those values, and x advanced by Δx, ready for the next step.

The third entrance, GIL04, is the entrance from the coding for calculating the derivatives and is used on each of the four passes necessary for computing one point. As noted above, it is entered by an MJ command in the DFQ00 region:

```
MJ  00000  GIL04
```

Mathematical Analysis

Theory. "A Process for the Step-by-Step Integration of Differential Equations in an Automatic Digital Computing Machine" by S. Gill, published in Cambridge Philosophical Society Proceedings, Vol. 47, Part I, January 1951, should be consulted for a detailed analysis of the process on which the subroutine is based.

Suppose we know the point $(X, Y_1, Y_2, \ldots, Y_n)$ on the curve defined by the system of equations

$$\frac{dy_1}{dx} = f_1(x, y_1, y_2, \ldots, y_n)$$

$$\frac{dy_2}{dx} = f_2 (x, y_1, y_2, \ldots, y_n)$$

$$\vdots$$

$$\frac{dy_n}{dx} = f_n (x, y_1, y_2, \ldots, y_n)$$

The Gill Method is a process by which we can find the next point on the curve: i.e. the value of $y_1, y_2, \ldots, y_n$ for $x = X + h$.

The process can be better understood if the case where $n = 1$ is first considered.

We have the point (X,Y) on the curve $\frac{dy}{dx} = f(x,y)$, and we want to find y at $X + h$; i.e. we want $k = \delta y$ such that $\left[\frac{dy}{dx}\right]_{X+h,\, Y+k} = f(X + h, Y + k)$.

We derive k by making four approximations and averaging them in a particular way.

First approximate the curve by a straight line through (X,Y) with the slope $\left[\frac{dy}{dx}\right]_{X,Y} = f(X,Y)$, and find a first approximation to k:

$$k_o = h \cdot f(X,Y)$$

Then we travel a fraction m of the way along this line to the point $(X+mh, Y+mk_o)$ and find $f(X + mh, Y + mk_o)$.

This gives us a new straight line through $(X + mh, Y + mk_o)$ with slope $f(X + mh, Y + mk_o)$, and we find

$$k_1 = h\, f(X + mh, Y + mk_o)$$

We now use k_o and k_1 to find a third point at which f is calculated: $(X + nh, Y + [n-r]\, k_o + rk_1)$.

$$k_2 = h\, f(X + nh, Y + [n-r]\, k_o + rk_1)$$

Similarly,

$$k_3 = h \cdot f(X + ph, Y + [p-s-t]\, k_o + sk_1 + tk_2$$

The weighted average of k_o, k_1, k_2, and k_3 is the desired $k = \delta y$:

$$\delta y = y(X + h) - y(X) = c_o k_o + c_1 k_1 + c_2 k_2 + c_3 k_3$$

where $c_o + c_1 + c_2 + c_3 = 1$.

For a system of equations, the same four steps given above are made for each equation and

$$\delta y_i = c_o k_{io} + c_1 k_{i1} + c_2 k_{i2} + c_3 k_{i3} \text{ where } c_o + c_1 + c_2 + c_3 = 1.$$

The above process is, for certain values of m, n, p, s, t, c_o, c_1, c_2, and c_3, the Runge-Kutta process. The Gill process was derived, with application to machine use in mind, by minimizing the number of storage cells required. For the Gill Method the above constants are

$$m = 1/2, \qquad r = 1 - \sqrt{1/2}, \qquad c_o = 1/6$$

$$n = 1/2, \qquad s = -\sqrt{1/2}, \qquad c_1 = (1/3)(1 - \sqrt{1/2})$$

$$p = 1, \qquad t = 1 + \sqrt{1/2}, \qquad c_2 = (1/3)(1 + \sqrt{1/2})$$

$$c_3 = 1/6$$

The Gill process further systematizes the calculation so as to increase the accuracy and simplify the coding.

The Subroutine. As used in the Gill Method Subroutine, the process is as follows:

It is assumed that the $f_i(x, y_{10}, y_{20}, \cdots, y_{no})$ and the y_i are available.

1st pass:

Advance x by (1/2)h

$$k_{io} = h \cdot f_i (x, y_{10}, y_{20}, \ldots, y_{no})$$

$$r_{i1} = (1/2)k_{io} - q_{io}$$

$$q_{i1} = q_{io} + 3r_{i1} - (1/2)k_{io}$$

$$y_{i1} = y_{io} + r_{i1}$$

Calculate $f_i (x, y_{11}, y_{21}, \ldots, y_{n1})$ in programmer's own coding.

2nd pass:

$$k_{i1} = h\, f_i (x, y_{11}, y_{21}, \ldots, y_{n1})$$

$$r_{i2} = (1 - \sqrt{1/2})(k_{i1} - q_{i1})$$

$$q_{i2} = q_{i1} + 3r_{i2} - (1 - \sqrt{1/2})k_i$$

$$y_{i2} = y_{i1} + r_{i2}$$

Calculate $f_i (x, y_{12}, y_{22}, \ldots, y_{n2})$ in programmer's own coding.

3rd pass:

Advance x by (1/2)h

$k_{i2} = h \cdot f_i\ (x, y_{12}, y_{22}, \ldots, y_{n2})$

$r_{i3} = (1 + \sqrt{1/2})\ (k_{i2} - q_{i2})$

$q_{i3} = q_{i2} + 3r_{i3} - (1 + \sqrt{1/2})\ k_{i2}$

$y_{i3} = y_{i2} + r_{i3}$

Calculate $f_i\ (x, y_{13}, y_{23}, \ldots, y_{n3})$

4th pass:

$k_{i3} = h \cdot f_i\ (x, y_{13}, y_{23}, \ldots, y_{n3})$

$r_{i4} = (1/6)(k_{i3} - 2q_{i3})$

$q_{i4} = q_{i3} - 3r_{i4} - (1/2)k_{i3}$

$y_{i4} = y_{i3} + r_{i4}$

Calculate $f_i\ (x, y_{14}, y_{24}, \ldots, y_{n4})$ in programmer's own coding.

Machine Checking

The following system of two equations was solved using this routine:

$$\frac{dy_1}{dx} = \cos x$$

$$\frac{dy_2}{dx} = -\sin x$$

The initial conditions, at $x = 0$, were

$$y_1 = 0 \quad \text{and} \quad y_2 = 1$$

The interval, Δx, used was $2\pi/360$ radians. At $x = 360^\circ$ the results were accurate to 8 decimal digits.

```
D           GIL00 01024
D           GIM00 51921
GIM00   MS  00000 GIL00
GIM01   MJ  00000 00000
GIM02   MJ  00000 GIL49
GIM03   MJ  00000 GIL08
GIM04   RA  GIL71 00016
GIM05   EJ  GIL69 GIL73
GIM06   EJ  GIL68 GIL01
GIM07   MJ  00000 GIL18
GIM08   TP  00016 GIL71
GIM09   TU  GIL72 GIL20
GIM10   TP  00000 GIL88
GIM11   TP  00000 00024
GIM12   TP  GIL88 00002
GIM13 ADNO  00024 00000
GIM14   TP  00002 GIL87
GIM15   TP  GIL75 00031
GIM16 ADMP  00024 00031
GIM17   TP  00002 00000
GIM18   TV  00000 GIL70
GIM19   RP  30003 GIL21
GIM20   TP  00000 00023
GIM21   RA  GIL20 GIL67
GIM22   TU  GIL66 GIL25
GIM23   TV  GIL66 GIL44
GIM24   RP  30003 GIL26
GIM25   TP  00000 00026
GIM26   TP  00024 00002
GIM27 MPNO  00028 00000
GIM28   TP  00002 00029
GIM29   TP  GIL88 00002
GIM30 MPNO  00026 00000
GIM31   TP  00002 00030
GIM32 MPSU  00023 00029
GIM33   TP  00002 00029
GIM34 ADNO  00027 00000
GIM35   TP  00002 00027
GIM36   TN  00025 00002
GIM37 MPAD  00030 00028
GIM38   TP  00002 00030
GIM39   TP  GIL85 00031
GIM40   TP  00029 00002
GIM41 DVAD  00031 00030
GIM42   TP  00002 00028
```

```
02000  00 00000 00000
67221  00 00000 00000
67221  56 00000 02000
67222  45 00000 00000
67223  45 00000 02061
67224  45 00000 02010
67225  21 02107 00020
67226  43 02105 02111
67227  43 02104 02001
67230  45 00000 02022
67231  11 00020 02107
67232  15 02110 02024
67233  11 00000 02130
67234  11 00000 00030
67235  11 02130 00002
67236  14 04030 00000
67237  11 00002 02127
67240  11 02113 00037
67241  14 04030 14037
67242  11 00002 00000
67243  16 00000 02106
67244  75 30003 02025
67245  11 00000 00027
67246  21 02024 02103
67247  15 02102 02031
67250  16 02102 02054
67251  75 30003 02032
67252  11 00000 00032
67253  11 00030 00002
67254  14 14034 00000
67255  11 00002 00035
67256  11 02130 00002
67257  14 14032 00000
67260  11 00002 00036
67261  14 14027 10035
67262  11 00002 00035
67263  14 04033 00000
67264  11 00002 00033
67265  13 00031 00002
67266  14 14036 04034
67267  11 00002 00036
67270  11 02125 00037
67271  11 00035 00002
67272  14 20037 04036
67273  11 00002 00034
```

```
GIM43   RP  30003 GIL45
GIM44   TP  00026 00020
GIM45   RA  GIL25 GIL67
GIM46   RA  GIL44 GIL69
GIM47   RS  GIL70 00016
GIM48   ZJ  GIL24 00000
GIM49   TP  GIL01 A0000
GIM50   LA  A0000 00015
GIM51   TU  A0000 GIL52
GIM52   TP  00000 A0000
GIM53   TV  A0000 GIL48
GIM54   TU  A0000 GIL18
GIM55   AT  00015 A0000
GIM56   TU  A0000 GIL10
GIM57   AT  00015 A0000
GIM58   TU  A0000 GIL11
GIM59   TU  A0000 GIL66
GIM60   LA  A0000 00057
GIM61   TV  A0000 GIL17
GIM62   TV  A0000 GIL66
GIM63   RA  GIL66 00017
GIM64   RA  GIL01 00016
GIM65   MJ  00000 GIL01
GIM66   00  00000 00000 B
GIM67   00  00003 00000 B
GIM68   00  00000 00005 B
GIM69   00  00000 00003 B
GIM70   00  00000 00000 B
GIM71   00  00000 00000 B
GIM72   00  GIL75 00000 BRB
GIM73   TP  GIL87 00002
GIM74   MJ  00000 GIL17
GIM75   05  00000 00000 -01 F
GIM76   01  00000 00000  00 F
GIM77   05  00000 00000 -01 F
GIM78   02  92893 21881 -01 F
GIM79   02  92893 21881 -01 F
GIM80   02  92893 21881 -01 F
GIM81   01  70710 67812  00 F
GIM82   01  70710 67812  00 F
GIM83   01  70710 67812  00 F
GIM84   01  66666 66667 -01 F
GIM85   03  33333 33333 -01 F
GIM86   05  00000 00000 -01 F
GIM87   00  00000 00000 B
GIM88   00  00000 00000 B
START
```

```
67274   75  30003 02055
67275   11  00032 00000
67276   21  02031 02103
67277   21  02054 02105
67300   23  02106 00020
67301   47  02030 00000
67302   11  02001 20000
67303   54  20000 00017
67304   15  20000 02064
67305   11  00000 20000
67306   16  20000 02060
67307   15  20000 02022
67310   35  00017 20000
67311   15  20000 02012
67312   35  00017 20000
67313   15  20000 02013
67314   15  20000 02102
67315   54  20000 00071
67316   16  20000 02021
67317   16  20000 02102
67320   21  02102 00021
67321   21  02001 00020
67322   45  00000 02001
67323   00  00000 00000
67324   00  00003 00000
67325   00  00000 00005
67326   00  00000 00003
67327   00  00000 00000
67330   00  00000 00000
67331   00  02113 00000
67332   11  02127 00002
67333   45  00000 02021
67334   20  04000 00000
67335   20  14000 00000
67336   20  04000 00000
67337   17  74537 30314
67340   17  74537 30314
67341   17  74537 30314
67342   20  16650 11714
67343   20  16650 11714
67344   20  16650 11714
67345   17  65252 52525
67346   17  75252 52525
67347   20  04000 00000
67350   00  00000 00000
67351   00  00000 00000
        45  00000 00000
```

THE RAMO-WOOLDRIDGE CORPORATION
Los Angeles 45, California

FLOATING POINT SINE-COSINE

Specifications

Identification Tag:	SIN-4
Type:	Subroutine
Assembly Routine Spec:	SUB 51856 06510
Storage:	65 words total program storage
	5 words temporary storage pool used, addresses 27 b through 33 b.
	The constant pool is used by this routine.
Entrance and Exit:	RJ SUB01 SUB02 for the sine
	RJ SUB01 SUB03 for the cosine
Machine Time:	3.9 ms average, 4.8 ms maximum

Coded by:	M. Perry	May, 1956
Approved by:	W. Bauer	May 15, 1956

Description

When supplied with an argument X in SNAP form, this routine will evaluate sin X or cos X (depending on which of the two entrances is used) using a Rand Polynomial Approximation, producing the answer in SNAP form.

Programming Instructions

This routine can be inserted into a program by CMP-0 by the use of a "SUB" card in the input deck.

1. Place the double length extension of X in the accumulator.

   X must be in radians and must be in SNAP form.

2. Return jump to the subroutine. Assuming that the subroutine was assigned to region SUB00 for assembly, use either the instruction RJ SUB01 SUB02 for the sine, or the instruction RJ SUB01 SUB03 for the cosine.

3. At the time of exit from the subroutine, the double length extension of sin X (or cos X) in SNAP form will be in the accumulator.

Error Analysis

Sin X or cos X is computed to 26 bits of accuracy or to as many correct bits as there are in the Fractional portion of X, whichever is less. For $X \geq 2^{27}$, this routine substitutes zero for the argument. The alarm exit is not used.

Mathematical Method

1. Let $y = (2/\pi)X$, then $\sin X = \sin(\pi/2)(y)$

$$\cos X = \sin(\pi/2)(y + 1)$$

2. Divide y (or y + 1) into an integral part R, and a fractional part S.

3. R defines the quadrant into which X falls. Let R' be the two low order positions of R, since in binary notation, any other positions merely define a number of complete revolutions.

4. R' is a number one less than the number of the quadrant into which X falls.

5. S defines the displacement (in a position direction) within the quadrant indicated by R'.

6. Therefore, if
   R' = 00 Let Z = S first quadrant
   R' = 01 Let Z = (1-S) second quadrant
   R' = 10 Let Z = (-S) third quadrant
   R' = 11 Let Z = (1-S) fourth quadrant

7. Sin (or cos) X = $\sin(\pi/2)Z$.

8. $(1/z)\sin(\pi/2)z$ is approximated by the Rand Polynomial Approximation Number 16, using argument z.

9. If $x<1/2$, $(2/\pi)x$, which is in floating form, is substituted for z before doing step 10.

10. Multiply the approximation from step 8 by z giving the result, sin x (or cos x).

Range of Variable

No alarm condition is recognized by this routine. However, as X approaches $\pm 2^{27}$ the number of significant digits in Sine X (or Cosine X) approaches zero and X merely defines a number of revolutions and does not significantly designate an angle.

```
D          02S00 00023                          00027  00 00000 00000
D          00S00 01024                          02000  00 00000 00000
D          01S00 01079                          02067  00 00000 00000
D          D0S00 51856                          67120  00 00000 00000
D          D1S00 51911                          67207  00 00000 00000
D0S00   RJ 00000 00000   ALARM                  67120  37 00000 00000
D0S01   MJ 00000 00000   NORMAL EXIT            67121  45 00000 00000
D0S02   RP 20002 00S04   SIN ENTRY             67122  75 20002 02004
D0S03   TP 00013 02S04   COS ENTRY             67123  11 00015 00033
D0S04   TU 00S02 00S51   SET FOR POS           67124  15 02002 02063
D0S05   LA A0000 00008                          67125  54 20000 00010
D0S06   TM B0000 02S00   EXP PLUS 200          67126  12 30000 00027
D0S07   LA A0000 00001                          67127  54 20000 00001
D0S08   LQ A0000 00035                          67130  55 20000 00043
D0S09   MP Q0000 01S05             69           67131  71 10000 02074
D0S10   TP B0000 Q0000             34           67132  11 30000 10000
D0S11   TP Q0000 02S01                          67133  11 10000 00030
D0S12   RS 02S00 01S08   EXP                    67134  23 00027 02077
D0S13   SJ 00S14 00S21                          67135  46 02016 02025
D0S14   SA 01S07 00000                          67136  32 02076 00000
D0S15   SJ 00S18 00S16                          67137  46 02022 02020
D0S16   AT 00S53 00S17                          67140  35 02065 02021
D0S17   LA Q0000 00007                          67141  54 10000 00007
D0S18   TP B0000 Q0000                          67142  11 30000 10000
D0S19   TP 02S04 A0000                          67143  11 00033 20000
D0S20   ZJ 00S36 00S26                          67144  46 02044 02032
D0S21   TJ 01S07 00S23                          67145  42 02076 02027
D0S22   CC Q0000 A0000                          67146  27 10000 20000
D0S23   TV A0000 00S24                          67147  16 20000 02030
D0S24   LA Q0000 00000                          67150  54 10000 00000
D0S25   IJ 02S04 00S28   SIN                    67151  41 00033 02034
D0S26   TN Q0000 A0000   COS                    67152  13 10000 20000
D0S27   AT 01S04 Q0000                          67153  35 02075 10000
D0S28   QT 01S05 02S01                          67154  51 02075 00030
D0S29   CC 02S00 A0000                          67155  27 00027 20000
D0S30   QJ 00S31 00S32                          67156  44 02037 02040
D0S31   RS 00S51 00015                          67157  23 02063 00017
D0S32   QJ 00S33 00S35                          67160  44 02041 02043
D0S33   TP 01S06 A0000                          67161  11 02075 20000
D0S34   ST 02S01 02S01                          67162  36 00030 00030
D0S35   TP 02S01 Q0000                          67163  11 00030 10000
```

```
D0S36   MP  Q0000  Q0000
D0S37   SA  01S06  00001
D0S38   TP  B0000  02S02          SQUARED    34
D0S39   PM  01S01  01S00
D0S40   RP  20003  00S42
D0S41   PM  01S02  02S02                     69
D0S42   MP  B0000  02S01                     68
D0S43   TP  B0000  A0000          FINAL MANT 33
D0S44   ZJ  00S45  00S01
D0S45   SF  A0000  00S54
D0S46   LA  A0000  00027
D0S47   TP  B0000  Q0000
D0S48   RA  02S00  00S54
D0S49   SA  01S09  00027
D0S50   CC  A0000  Q0000
D0S51   RP  00000  00S01
D0S52   TN  A0000  A0000
D0S53   LA  Q0000  00007
D0S54   00  00000  00000
D1S00   01  51484  19000  -04   38  C9
D1S01   -4  67376  55700  -03   36  C7
D1S02   07  96896  79280  -02   35  C5
D1S03   -6  45963  71106  -01   34  C3
D1S04   01  57079  63185         33  C1
D1S05   06  36619  77225  -01   34  2 OVER PI
D1S06   17  77777  77777  B          MASK
D1S07   00  00000  00034  B          28
D1S08   00  00000  00200  B          128
D1S09   00  00000  00072  B
START
```

```
67164   71  10000  10000
67165   32  02075  00001
67166   11  30000  00031
67167   24  02070  02067
67170   75  20003  02052
67171   24  02071  00031
67172   71  30000  00030
67173   11  30000  20000
67174   47  02055  02001
67175   74  20000  02066
67176   54  20000  00033
67177   11  30000  10000
67200   21  00027  02066
67201   32  02100  00033
67202   27  20000  10000
67203   75  00000  02001
67204   13  20000  20000
67205   54  10000  00007
67206   00  00000  00000
67207   00  02366  57391
67210   77  54666  31633
67211   02  43150  53663
67212   65  52420  76491
67213   14  44176  65102
67214   12  13714  06667
67215   17  77777  77777
67216   00  00000  00034
67217   00  00000  00200
67220   00  00000  00072
        45  00000  00000
```

REMINGTON RAND UNIVAC

FLEXIE (RR-86 Rev. 8/56)

Type: Service Routine

I. Description:

This routine is a revised version of the original FLEXIE (RR-86). It is designed to load, by means of a Ferranti Reader, a Flexcode tape prepared on a Flexowriter in the conventional fashion for translating to bioctal. FLEXIE reads at the full speed of the Ferranti, hesitating only on insert addresses, check addresses, or when the temporary storage is full of data. FLEXIE provides a check address test and a check sum test on the data read in.

II. Tape Preparation:

The tape should be prepared in the manner described in the original FLEXIE write up. A few remarks are appropriate here however. A check address should be given following the last information on the tape and before the 7th level punch stop code. If there is no check address prior to the 7th level punch, the 7th level punch will in general be ignored.

For a check sum test of data on the tape, the following four words should be on the tape after the data to which the sum applies:

(1) insert address 75202,
(2) high order 36 bits of check sum,
(3) low order 36 bits of check sum,
(4) check address 75204.

The check sum must be the sum of all the data on the tape following the preceding check sum. The check sum will NOT be loaded into 75202 and 75203. These two words will not be disturbed at all. Note that a check sum test is performed whenever a check address of 75204 is encountered. Thus 75204 should not be used for any other check address.

III. Operating Instructions:

Since the coding is in Reco II form, all operating data will be given relative to the regions used in the code.

To load a tape, place it in the reader, turn the reader on and START at bb0. At the completion of the loading (if a 7th level punch is present on the end of the tape) a stop-re-enter bb0 is given. If there is no 7th level punch present, let the tape pass through the reader, then FORCE STOP, MASTER CLEAR, START at ee0 (ee0 will be 00022 in absolute form). FLEXIE can also be used as a subroutine to load data. To do this, place a 7th level punch after each section of the tape and perform the instruction 37 bbll bb0 whenever it is desired to load a section of the tape.

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Three different alarm conditions can occur when using FLEXIE. If one of these does occur, a tag letter is typed on the typewriter and the computer stops on a manual stop. These three conditions are now listed according to their tags.

(1) "t": FLEXIE has not been transferred to HSS correctly. START causes another transfer. If "t" occurs again, reload FLEXIE onto MD.

(2) "c": a check address has failed to check. START causes FLEXIE to ignore error and proceed to read the rest of the tape.

(3) "m": the check sum given on the tape does not agree with the sum as computed by FLEXIE. START causes FLEXIE to ignore the error.

IV. Coding:

FLEXIE requires 166 (octal) words of storage on MD, i.e., relative addresses bb0 through bb165. The region bb can be assigned any drum address except 75612 through 77777. The reason for this exception is that 76000-77777 is used for an image region of HSS and if bb has a value greater than 75612, part or all of FLEXIE will be in the image region and consequently be destroyed when FLEXIE is used. The rest of the regions used in the coding must be assigned the following values:

cc	00001
dd	00010
ee	00022
gg	00045
hh	00052
ii	00061
jj	00074
kp	00116
ws	00147
ts	00154
xx	01624

Thus one can place FLEXIE on any part of the drum by assigning a value to only one of the relative addresses, i.e., bb.

```
re bb 74520
re cc1
re dd10
re ee22
re gg45
re ii61
re hh52
re jj74
re kp116
re ws147
re ts154
re xx1624
```

```
bb0          tp   00000  76000    Entrance - store 00000
 1           tp   bb52   00000    Set up 00000
 2           rp   31777  bb4      Store HSS
 3           tp   00001  76001         on MD
 4           rp   30151  cc       Load routine
 5           tp   bb15   cc            into HSS
 6           rp   31777  bb10     Restore
 7           tp   76001  00001         HSS from
 10          tp   76000  00000         MD image
 11          rj   bb11   bb12     Subroutine exit
 12          ms   0      bb       Service routine exit - re-enter
 13          00   0      0        Flexie check sum, Lo order
 14          00   0      0                         Hi order

 15   cc0    sp   00000  0        Compute check
 16    1     rp   20151  cc3           sum of
 17    2     sa   cc     0             routine
 20    3     ss   bb13   44       Test check
 21    4     ej   bb14   dd            sum
 22    5     pr   0      jj2      Error, print t
 23    6     ms   0      bb4      Stop - reload routine

 24   dd0    rs   ws3    ws3      Clear check
 25    1     rs   ws4    ws4           sum cells
 26    2     tp   kp26   ii       Set up
 27    3     ef   0      kp3      Start reader
 30    4     rj   dd4    ws       One shot switch
 31    5     er   0      a        Read to A

 32    6     rp   20010  dd10     Digit
 33    7     ej   kp6    gg            test
 34    10    ej   kp5    hh       Period test
 35    11    tj   kp16   dd5      Ignore or 7th level

 36   ee0    ef   0      kp4      Stop reader
 37    1     tp   ii     a        Set up number of
 40    2     ss   kp26   17            words to transfer
 41    3     at   kp27   ee7      Set up transfer
 42    4     tp   ws1    a        Is data destined
 43    5     tj   kp     ee15          for HSS or MD?
 44    6     tv   a      ee10     Set up transfer
 45    7     rp   30000  ee11     Transfer
 46    10    tp   ts     0             data
 47    11    tp   ws2    a        Test period code
 50    12    ej   kp22   ee17          is this ED?
```

```
51   13      ej   kp23   ee21      is this IA?
52   14      mj   0      bb6       Return to MD
53   15      at   kp1    a         Modify IA to MD image
54   16      mj   0      ee6       Jump to set up and transfer
55   17      ra   ws1    kp2       Modify IA
56   20      mj   0      dd2       Return to read
57   21      tp   ws     ws1       Store IA
60   22      mj   0      dd2       Return to read

61   gg0     sp   ws2    1         Assemble period code
62    1      tp   a      ws2       Store period code
63    2      sp   ws     3         Assemble
                                      data digit
64    3      qa   kp17   ws
65    4      mj   0      dd5       Return to read

66   hh0     sp   ws2    1         Assemble period code
67    1      at   kp21   ws2           and store
70    2      tp   ws2    a         Period code to A
71    3      ej   kp22   ii        Is this ED code?
72    4      ej   kp23   ee        Is this IA code?
73    5      ej   kp24   jj        Is this CA code?
74    6      mj   0      dd5       Return to read

75   ii0     tp   ws     ts        Store data word temporarily
76    1      ra   ii     kp20      Set up for next word
77    2      sp   ws3    44        Add assembled
100   3      sa   ws4    0             word to computed
101   4      sa   ws     0             check sum
102   5      tp   a      ws4       Store computed
103   6      la   a      44            check
104   7      tp   a      ws3           sum
105  10      tp   ii     a         Is HSS filled
106  11      ej   kp25   ee            with data?
107  12      mj   0      dd5       Return to read

110  jj0     ef   0      kp4       Stop reader
111   1      tp   ii     a7        Compute number
112   2      st   kp26   a1            of words read in
113   3      at   ws1    a16       Add to IA
114   4      ej   ws     jj7       Does this equal CA?
115   5      pr   0      jj3       Error - print c
116   6      ms   0      jj7       Stop - ignore error
117   7      tp   ws     a         Is sum check test
120  10      ej   kp30   jj12          specified?
121  11      mj   0      dd3       No, return to read
122  12      sp   ws3    44        Yes, computed check
123  13      sa   ws4    0             sum to A
124  14      ss   ts     0         Correct computed
```

```
125        15          ss tsl   0          check sum
126        16          ss tsl   44         Subtract lo - order part of
127        17          ej ts    dd           given sum and test difference
130        20          pr 0     jjl        Error - print M
131        21          ms 0     dd         Stop - ignore error

132        kp0         00 0     02000      Constant for test
133         1          00 0     76000      Constant
134         2          00 0     xx         Maximum block size
135         3          00 6     00000      Reader start code
136         4          00 5     00000      Reader stop code
137         5          00 0     42         Flex codes - period
140         6          00 0     72                    7
141         7          00 0     66                    6
142        10          00 0     62                    5
143        11          00 0     64                    4
144        12          00 0     70                    3
145        13          00 0     74                    2
146        14          00 0     52                    1
147        15          00 0     37                    0
150        16          00 0     100        Constant for test
151        17          00 0     7          Mask
152        20          00 0     1          Constant
153        21          00 100   00000      Constant to set up period code
154        22          20 00100 00000      ED code
155        23          40 20100 00000      IA code
156        24          40 04100 00000      CA code
157        25          tp ws    02000      Constant for test
160        26          tp ws    ts         Constants for
161        27          rp 30000 eell            set up
162        30          00 00000 75204      Sum check CA

163   ws    0          er 0     q          Clear IOA
164         1          mj 0     dd5        Return to regular read
165         2          00 0     0          Period code space
```

Working Space Uses:

```
ws 0  Assembly space for data
   1  Storage for IA
   2  Period code space
   3  Hi-order part of computed check sum
   4  Lo-order part of computed check sum
```

Notes: (1) Three of the working spaces are stored on MD and transferred to HSS with the rest of the program. Two of these are used initially for a one-shot clear IOA. Then they are used as indicated above throughout the rest of the program.

(2) The FLEXIE check sum cells, bbl3 and bbl4, are blank since the check sum depends on the value assigned to bb. The check

sum may be obtained from the tape assembled by Reco II as follows: load the tape and START at bb0; the computer will stop with a "t" alarm as mentioned above; at this point A-left contains the Lo-order part of the check sum and A-right the Hi-order part.