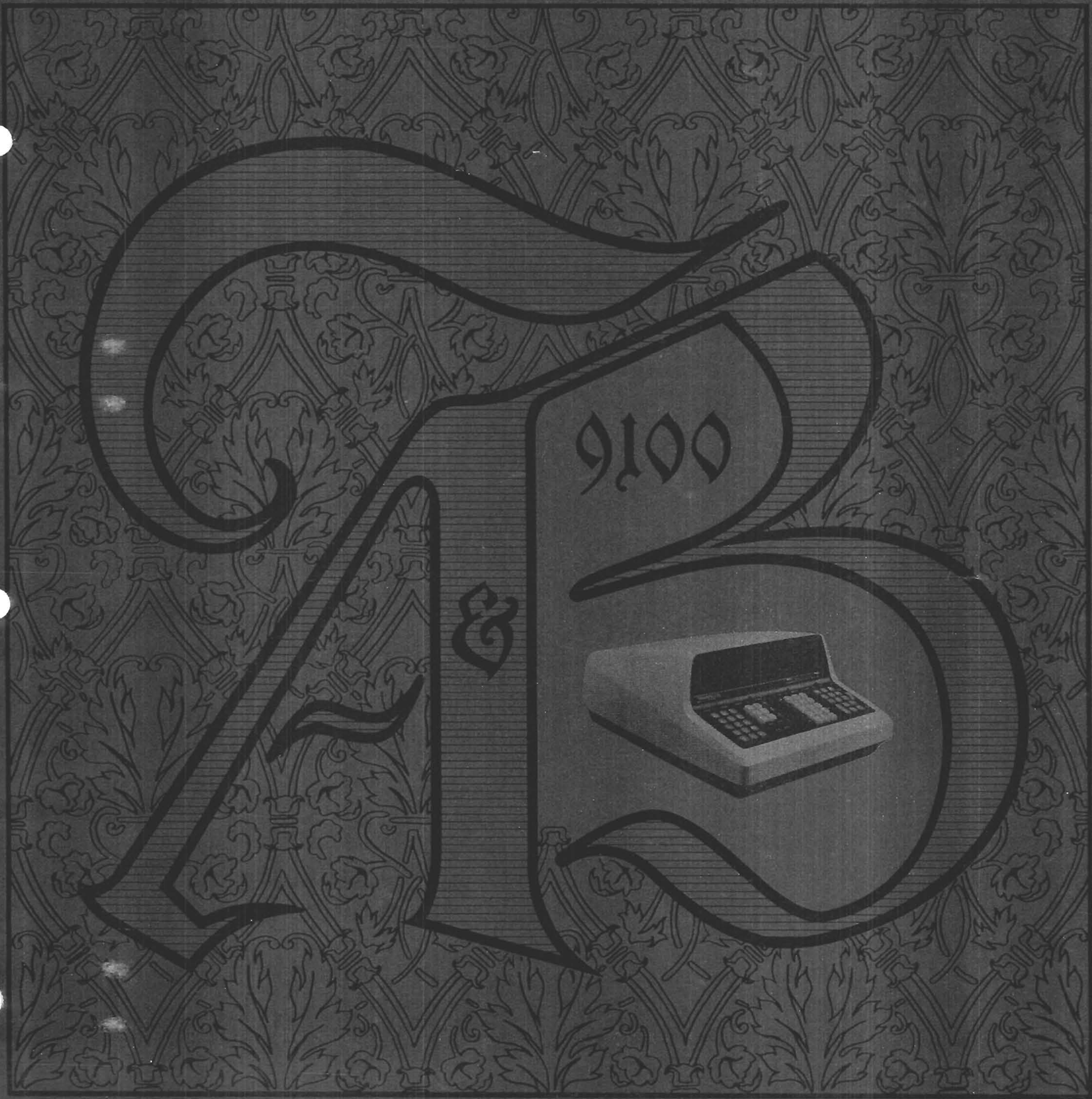
HEWLETT-PACKARD

KEYBOARD

WINTER 1970



TO HEWLETT-PACKARD CALCULATOR USERS

The *HP KEYBOARD* is published quarterly to make the latest programs and application ideas available to all HP 9100 calculator owners.

Your programs, both of general interest and in specialized applications categories, will help to keep other calculator owners better informed and increase the efficiency with which the HP system 9100 is utilized throughout the world. Please send your programs to the *HP KEYBOARD* editor.

LIFE SCIENCE PROGRAMS NEEDED

Do you have programs for the Hewlett-Packard calculator in a life science category such as zoology, pathology, radiology, bioengineering, cardiology, or others? Other calculator owners are interested in sharing software in this field. You can contribute to this endeavor by sending us any programs you feel would be of use to other life scientists.

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COVER

Blending the modern with the traditional, our artist surrounded an HP Calculator with 17th-Century tapestry.

Hewlett-Packard has made calculator systems for several years, and electronic test instruments for 30 years. With the addition of the HP Model 2570A Coupler described in the feature article, the new HP System 9100 will accept and process data inputs from dependable HP instruments and other sources, blending modern and traditional products.

HEWLETT-PACKARD CALCULATOR SYSTEM 9100 WILL SOLVE YOUR PROBLEM

OFFERS VERSATILITY THROUGH LARGER MEMORY AND PERIPHERALS

The new Hewlett-Packard calculator system now offers you a choice of two programmable desktop calculators, along with a variety of peripherals. Although this versatile system is relatively inexpensive and does not require special computer training, it outperforms some computers, and gives direct operator-system interface. You may choose either the HP Model 9100A Calculator, capable of solving many of your engineering and scientific problems, or the Model 9100B which has additional memory plus subroutine capability.

COMPATIBLE PERIPHERALS

All peripherals are compatible with either calculator, and simply plug in. Two of the peripherals currently available are the HP Model 9125A Calculator Plotter and the HP Model 9120A Printer featured in the Summer and Fall 1969 issues of *KEYBOARD*.

The HP 9160A Marked Card Reader is also available now. It inputs program steps or data to the calculator using cards marked with a soft lead pencil. The card allows you to record programs or data away from the calculator; machine time is used only for program execution. A group of students can write their programs at the same time before entering them sequentially, so one calculator serves the needs of many individuals. Similarly, experimental or field data can be recorded on cards for later processing.

Other accessories to be added this year will include:

HP Model 9150A Large Screen Display, with a 17-inch diagonal cathode ray tube for use in classrooms or for display to any large group.

HP Model 9101A Extended Memory, which will plug into either the 9100A or 9100B, adding 248 registers capable of storing 3472 additional program steps.

HP Model 2570A Instrumentation Coupler, which will enable either calculator to accept a variety of inputs and provide output in a number of formats, adding to the system's versatility. Types of coupler inputs to the calculator will include punched tape, teletypewriter keyboard, or BCD input in real time directly from instruments. Output choices will include normal CRT display, plotted curves, printed formatted pages on a teletypewriter, or punched tape.

SYSTEM 9100 FEATURES

The HP Model 9100A Computing Calculator was designed to be part of a system which will increase in usefulness and versatility as more peripherals become available. The Model 9100B was designed as a planned addition to the calculator family; its input and output connections were made the same as those in the 9100A, so that both models are equally compatible with each peripheral. The Model 9101A Memory Extender will add an equal number of registers to either model, although it is not practical to modify a Model 9100A to change it to a 9100B. The Memory Extender will also add to the 9100A the important features incorporated in the 9100B such as subroutine capability, and the following additional ones:

. . . All 248 extended memory registers can be used as accumulators.

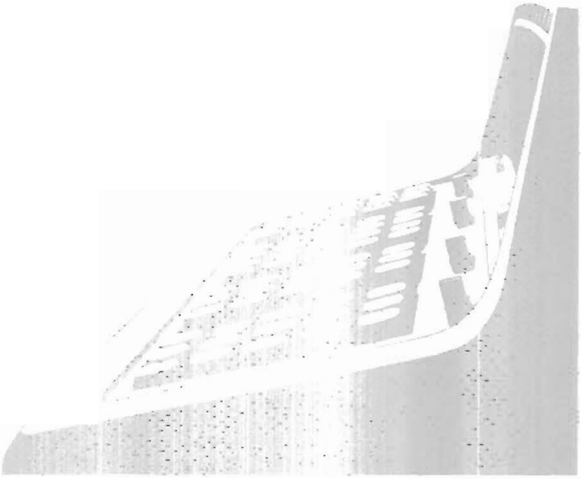
. . . Storage of up to 3472 additional program steps.

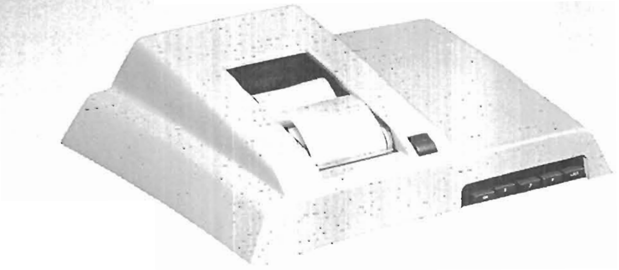
. . . Indirect addressing.

. . . Multiple storage of up to 100 programs.

. . . Memory protection.

Full details about the Model 9101A Memory Extender will be available later this spring.

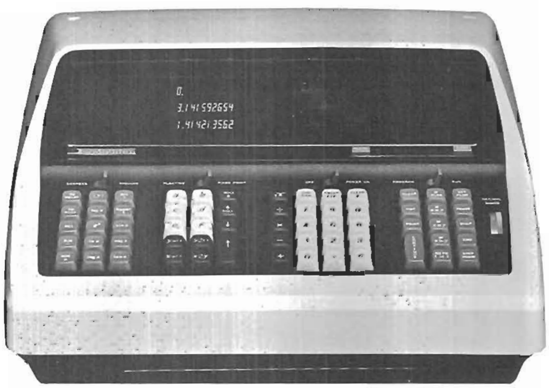




The Model 9120A provides permanent printed records of input data and results.

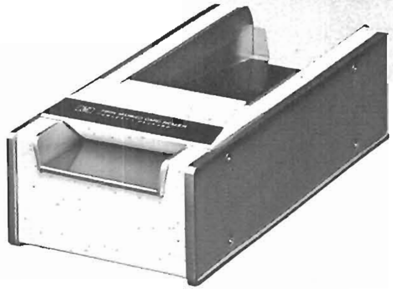
Memory capability of the HP System 9100 will be enhanced by 248 added registers with the Model 9101A Memory Extender, available mid-1970.

A Computing Calculator is the



Model 9100A has 16 registers, 196 program steps.

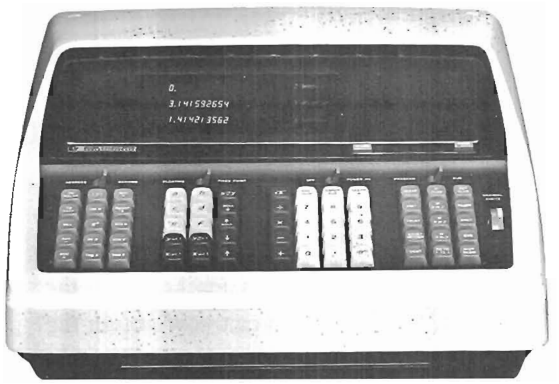
Large audiences see blackboard-clear pictures of the X, Y, Z register contents with the HP Model 9150A Display.



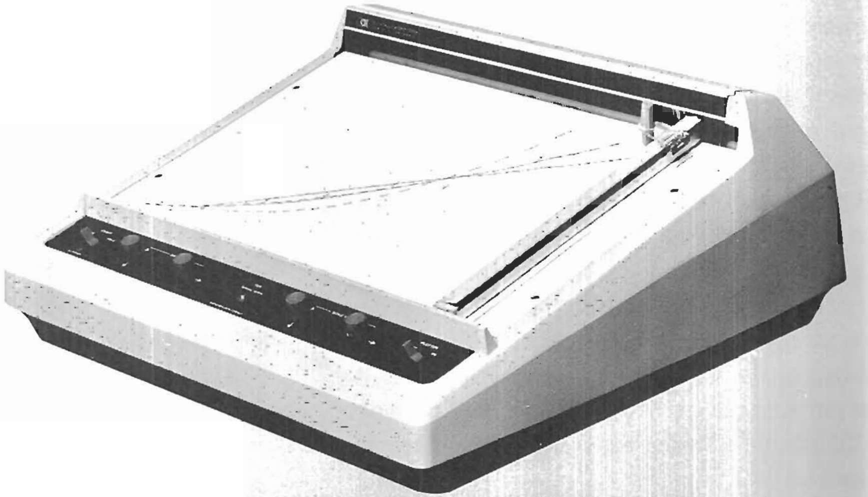
The HP Model 9160A Marked Card Reader inputs data and programs using pencil-marked cards.

heart of the HP System 9100

HP SYSTEM 9100



Model 9100B has 32 registers, 392 program steps.



The HP Model 9125A Calculator Plotter provides graphic output for the System 9100.

SOFTWARE COMPATIBILITY

New programs are continually being developed to add to the usefulness of the program library. Programs, both new and those now in the program library, will be compatible with both the Model 9100A and the Model 9100B, with some minor exceptions. The new programs will be available at nominal cost in the form of permanently-bound category libraries, each providing solutions for a particular application such as statistics.

LARGER MEMORY

A programmable memory with 32 registers gives the Model 9100B added power. This memory is divided into a (+) page, made up of 16 registers; 0 through 9 and a through f, identical to the 0 through f registers in the 9100A; and a similar (—) page, with registers (—) 0 through (—) f.

In the Model 9100B Calculator, the X, Y, and Z registers and the (+) 0 through f registers are used exactly as they are in the Model 9100A. Only the (+) e and the (+) f accumulator registers are affected by the ACC+, ACC— and RCL keys; these registers are cleared, as are the X, Y, and Z registers, by the CLEAR command via the keyboard or a program step. The (—) e and (—) f registers are not affected by the CLEAR command, so they may be used for more permanent data storage; they cannot be used for program storage.

SUBROUTINE KEY

Built-in subroutine capability is another important feature of the Model 9100B. A subroutine is a sequence of steps which is stored in the memory only once but which may be used several times in a program. The subroutine may be called from any point in the program. When it is completed, the program returns automatically to the point from which the call was made. Since a subroutine may be used a number of times in a program, this results in a significant saving of program space and enhances the 9100B's extra memory capability. Instructions to call a subroutine or return from it are given through the SUB/RETURN key.

During execution of the subroutine, the 9100B Calculator has the capability of calling other subroutines. This nesting of subroutines, as it is termed, can be up to five deep. In other words, as many as five subroutines can be used at any time during a program; the calculator can remember up to five return addresses at once. As soon as the program returns from a subroutine, that return address is 'forgotten', allowing the calculator to remember another return address.

The Model 9101A Memory Extender will add subroutine capability to either the 9100A or the 9100B with nesting possible to 14 deep.

NEW RECALL KEY

A new 'to X from' $x \leftarrow (\ )$ key on the 9100B allows the operator to recall data to the X register rapidly from any storage register. The data also remains in the register from which it was recalled, so it does not need to be restored. The $x \leftarrow (\ )$ key is especially useful in recalling data from the numerical registers. The alphabetic (+) page register contents can be recalled to the X register with one keystroke by pressing the letter key desired, as on the 9100A.

EASIER EDITING

Editing a program involves looking at each step, using the STEP PROGRAM key with the calculator in the PROGRAM mode. The 9100B has a unique feature showing the present address and instruction code in the X register, and at the same time showing the next sequential address and instruction code in the Z register. The operator can change the instruction in the upcoming step by pressing the appropriate instruction key without having to readdress the calculator to that step.

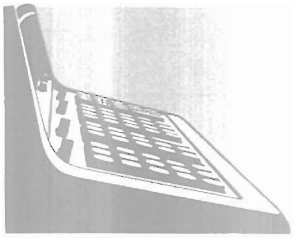
PURCHASE UNDER GSA CONTRACT

Offices which are eligible to buy materal through the U. S. General Service Administration can now obtain the HP System 9100 under GSA contract number GS-00S-76504.

Special Item No.	Description
50-278-1	HP Model 9100A Computing Calculator HP Model 9100B Computing Calculator HP Model 9120A Calculator Printer HP Model 9160A Marked Card Reader HP Model 9125A Calculator Plotter
50-381	Repair parts for above.
50-211	Repair services for above.

ADDITIONAL EQUIPMENT

If you already own a Hewlett-Packard calculator but find your needs are increasing, you may want to purchase additional calculators or peripherals. Ask your local HP calculator salesman to help you determine the best system configuration to solve your current and future problems.



ROOTS OF 4TH DEGREE POLYNOMIAL

9100B ONLY
PART NO.
09100-70403

This program determines the real and complex roots of the fourth degree polynomial

$$f(X) = X^4 + a_1X^3 + a_2X^2 + a_3X + a_4,$$

where the coefficients a_i are real. The program uses the Lin-Bairstow method which determines a quadratic factor $(X^2 + rX + s)$ such that

$$f(X) = (X^2 + rX + s)\ (X^2 + b_1X + b_2) + RX + S$$

The variables r and s are obtained by an iteration scheme which reduces the remainder terms R and S to zero. The user can specify the remainder which he can tolerate.

The program applies the following recursive relationships:

$$b_1 = a_1 - r \qquad c_1 = b_1 - r$$
$$b_2 = a_2 - rb_1 - s \qquad c_2 = b_2 - rc_1$$
$$b_3 = a_3 - rb_2 - sb_1 \qquad \overline{c_3} = -rc_2 - sc_1$$
$$b_4 = a_4 - rb_3 - sb_2 \qquad R = b_3$$
$$S = b_4 + rb_3$$

These quantities (b_i and c_i) are required for the determination of Δ r and Δ s in the equations:

$$c_2\,\Delta r + c_1\,\Delta s = b_3$$
$$\overline{c_3}\,\Delta r + c_2\,\Delta s = b_4$$

The quantities Δr and Δs are obtained by solving the above pair of linear equations.

The terms r and s are incremented by Δr and Δs respectively and the remainder terms are tested against the tolerance. If the remainders are small enough to pass the test, then the two quadratics $(X^2 + rX + s)$ and $(X^2 + b_1X + b_2)$ are solved by the quadratic formula. If the remainder is too large, the iteration is repeated and the test repeated.

- – – Locations (–)00 through (–)03 are used for storing the tolerance on $|R|$ and $|S|$.
- – – The program employs a *subroutine* for obtaining the roots of the quadratic factors.
- – – The program displays and prints $|R|$, $|S|$, r, s, b_1, b_2 and the four roots.
- – – If the user wants only the roots, CONTINUES should be placed in steps (–)12, (–)13, (–)17, (–)18, (–)25, (–)26, and (–)27.
- – – This program takes optimum advantage of the 9100B features in that 12 registers are used for storage, a quadratic equation subroutine is applied, and the $x \leftarrow (\ )$ key is used 6 times.

USER INSTRUCTIONS

PRESS: X , Y , Z on 9120A
PRESS: END
ENTER PROGRAM: Side A followed by Side B
→ PRESS: CONTINUE
DISPLAY

O ———— Z
O ———— Y
O ———— X

ENTER DATA: $a_4 \rightarrow$ Z, $a_3 \rightarrow$ Y, $a_2 \rightarrow$ X
PRESS: CONTINUE
DISPLAY

1 ———— Z
1 ———— Y
1 ———— X

ENTER DATE: $a_1 \rightarrow$ Z, $s' \rightarrow$ Y, $r' \rightarrow$ X *
PRESS: CONTINUE
DISPLAY

$|S|$ ———— Z
$|R|$ ———— Y
O ———— X

PRESS: CONTINUE
DISPLAY

s ———— Z
r ———— Y
1 ———— X

PRESS: CONTINUE
Real Roots

O ———— Z
R_2 ———— Y
R_1 ———— X

or
Complex Roots

R = a + bj
+ Imaginary Part — Z
– Imaginary Part — Y
Real Part of R —— X

Reference: *NUMERICAL ANALYSIS* Kaiser S. Kunz, 1957 McGraw-Hill Book Company

USER INSTRUCTIONS (CON'T)

PRESS: CONTINUE

DISPLAY

b_2 ———— Z
b_1 ———— Y
2 ———— X

PRESS: CONTINUE

Real Roots

O ———— Z
R_4 ———— Y
R_3 ———— X

or

Complex Roots

$R = a + bj$
+ Imaginary Part — Z
− Imaginary Part — Y
Real Part of R ——— X

To run another case:

PRESS: END

---

* s′ and r′ are initializing constants for the recursive formulas.

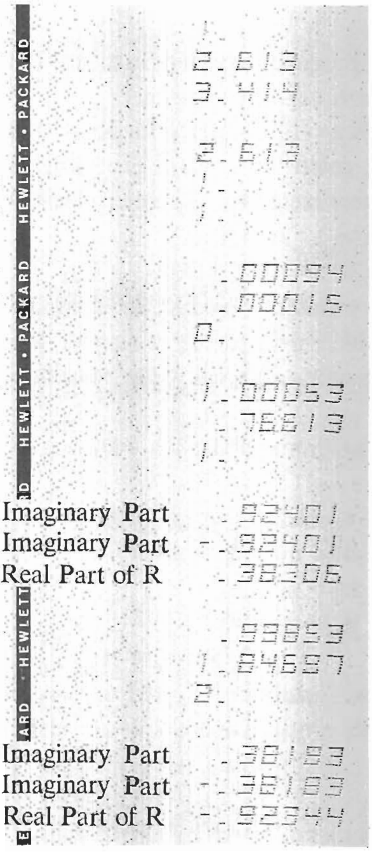
Both r′ and s′ must be non-zero.

EXAMPLE

Fourth Order Butterworth Polynomial

$F(s) = s^4 + 2.613 s^3 + 3.414 s^2 + 2.613 s + 1$

Tolerance is set as .001.



```
                                          Actual**
a4 =                    1.
a3 =                    2.613
a2 =                    3.414

a1 =                    2.613
s' =                    1.
r' =                    1.
Solution
|S| =                    .00094
|R| =                    .00015
                        0.

s  =                    1.00053           1.0
r  =                     .76613           0.7654
                        1.

root1  + Imaginary Part   .92401
root2  − Imaginary Part  -.92401
         Real Part of R   .38306

b2 =                      .99853          1.0
b1 =                    1.84697           1.8478
                        2.

root3  + Imaginary Part   .38183
root4  − Imaginary Part  -.38183
         Real Part of R  -.92344
```

** *Network Analysis and Synthesis*
Franklin F. Kuo, 1962,
John Wiley & Sons

PART NO. 09100-70403

```
00  CLR  20   Plus Page
01  STP  41   ENTRY
02  PNT  45
03  PNT  45
04  XTO  23
05   7   07
06  YTO  40
07   8   10
08  DN   25
09  YTO  40
0a   9   11
0b   1   01
0c  UP   27
0d  UP   27

10  STP  41   ENTRY
11  PNT  45
12  PNT  45
13  AC+  60
14  RDN  31
15  YTO  40
16   6   06
17  RUP  22
18  RUP  22
19  XEY  30
1a   -   34
1b  YTO  40
1c   d   17
1d   X   36

20  DN   25
21   +   33
22  UP   27
23  XFR  67
24   7   07
25  RUP  22
26   -   34
27  YTO  40
28   c   16
29   f   15
2a   X   36
2b   e   12
2c  UP   27
2d   d   17

30   X   36
31  DN   25
32   +   33
33  UP   27
34  XFR  67
35   8   10
36  RUP  22
37   -   34
38  YTO  40
39   b   14
3a   f   15
3b   X   36
3c   e   12
3d  UP   27
```

```
40   c   16
41   X   36
42  DN   25
43   +   33
44  UP   27
45  XFR  67
46   9   11
47  RUP  22
48   -   34
49  YTO  40
4a   a   13
4b   b   14
4c  UP   27
4d   f   15

50  XEY  30
51   X   36
52  RDN  31
53   +   33
54  |Y|  55
55  DN   25
56  |Y|  55
57  UP   27
58  CNT  47
59  CNT  47
5a  GTO  44
5b   -   34
5c   0   00
5d   0   00
```

```
00   .   21   Minus Page
01   0   00
02   0   00
03   1   01
04  X<Y  52
05   3   03
06   5   05
07  RUP  22
08  X>Y  53
09   3   03
0a   5   05
0b  RDN  31
0c  DN   25
0d  XEY  30

10  UP   27
11   0   00
12  PNT  45   DISPLAY
13  PNT  45
14  RCL  61
15  UP   27
16   1   01
17  PNT  45   DISPLAY
18  PNT  45
19  XEY  30
1a  RUP  22
1b  GTO  44
1c  SUB  77
1d   9   11
```

```
20   b   14
21   c   16
22  UP   27
23   d   17
24  UP   27
25   2   02
26  PNT  45   DISPLAY
27  PNT  45
28   1   01
29  XEY  30
2a  RUP  22
2b  GTO  44
2c  SUB  77
2d   9   11

30   b   14
31  GTO  44
32   +   33
33   0   00
34   0   00
35   d   17
36  UP   27
37   f   15
38   -   34
39  YTO  40
3a   d   17
3b   X   36
3c   c   16
3d  XEY  30

40   -   34
41  YTO  40
42   c   16
43   f   15
44   X   36
45   d   17
46  UP   27
47   e   12
48   X   36
49  DN   25
4a   +   33
4b  DN   25
4c  CHS  32
4d  UP   27
```

+	−	+	−
		a_3	
		a_4	
		b_4	
		b_3	
		b_2 / c_2	
		b_1 / c_1	
a_1		s	s
a_2		r	r

```
50   f    15    Minus Page
51  XTO   23
52   -    34
53   f    15
54   e    12
55  XTO   23
56   -    34
57   e    12
58   0    00
59  XTO   23
5a   e    12
5b  XTO   23
5c   f    15
5d   c    16

60  UP    27
61   a    13
62  RUP   22
63  DIV   35
64  RUP   22
65  XEY   30
66  DIV   35
67  DN    25
68  IFG   43
69   7    07
6a   7    07
6b  AC+   60
6c  SFL   54
6d   c    16

70  UP    27
71   d    17
72  UP    27
73   b    14
74  GTO   44
75   6    06
76   2    02
77  AC-   63
78  XEY   30
79  YE    24
7a   e    12
7b   f    15
7c  DIV   35
7d   e    12

80  XEY   30
81   X    36
82  RDN   31
83   -    34
84  XFR   67
85   -    34
86   f    15
87   +    33
88  YTO   40
89   f    15
8a  DN    25
8b  XFR   67
8c   -    34
8d   e    12
```

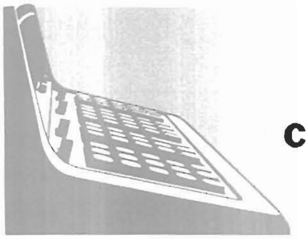
```
90   +    33
91  YTO   40
92   e    12
93   f    15
94  UP    27
95  XFR   67
96   6    06
97  GTO   44
98   +    33
99   1    01
9a   9    11
9b  RUP   22
9c  DIV   35
9d  RUP   22

a0  XEY   30
a1  DIV   35
a2   2    02
a3  CHS   32
a4  DIV   35
a5  DN    25
a6  UP    27
a7   X    36
a8  RDN   31
a9  XEY   30
aa   -    34
ab  CLX   37
ac  X=Y   50
ad   c    16

b0   c    16
b1  X>Y   53
b2   c    16
b3   3    03
b4  DN    25
b5   √    76
b6  UP    27
b7  CHS   32
b8  RUP   22
b9   +    33
ba  RUP   22
bb   +    33
bc  CLX   37
bd  RDN   31

c0  PNT   45    DISPLAY
c1  PNT   45
c2  RTN   77
c3  DN    25
c4  CHS   32
c5   √    76
c6  UP    27
c7  CHS   32
c8  RUP   22
c9  GTO   44
ca   c    16
cb   0    00
cc  DN    25
cd  CLX   37
```

```
d0  RDN   31
d1  GTO   44
d2   c    16
d3   0    00
d4  END   46
```



POPULATION ESTIMATE AND CONFIDENCE LIMITS OF REMOVAL TRAPPING

PART NO. 09100-75202

by Dr. Joel D. Weintraub

This is one of the animal ecology programs being used at the California State College at Fullerton. It estimates the population of animals in an area using data from the removal trapping method.

In the removal trapping method, animals are removed on a series of occasions, and it is expected that the number caught on subsequent occasions will diminish in a predictable manner. There are certain assumptions behind this model which should be realized in order for the results to be valid. The program outlined here is based on a maximum likelihood technique, in which one factor, q, must be determined on a trial and error basis unless you can solve for it in equation (4).

The equations used in the computations are:

(1)

$$T = n_1 + n_2 + \dots n = \sum_{1}^{n} n_i$$

T = total catch
n_i = number caught on i^{th} occasion

(2)

$$\sum_{i=1}^{k} (i-1)y_i = (1-1)n_1 + (2-1)n_2 + \dots + (k_i-1)n_i$$

k = number of occasions
y_i = the catch on the i^{th} occasion

(3)

$$R = \frac{\sum_{i=1}^{k} (i-1)y_i}{T}$$

(4)

$$R = \frac{q}{p} - \frac{kq^k}{(1-q^k)}$$

p = probability of capture on a single occasion
$q = 1 - p$

(5)

$$P = \frac{T}{(1-q^k)}$$

P = total population

(6)

$$\text{S.E. of } P = \sqrt{\frac{P(P-T)T}{T^2 - P(P-T)[(kp^2)/(1-p)]}}$$

S.E. = standard error of population

USER INSTRUCTIONS

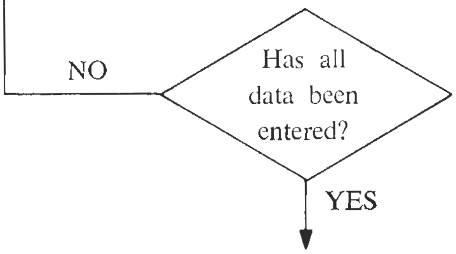
PRESS X on 9120A PRINTER
PRESS: END

9100A and 9100B: ENTER PROGRAM A at location 00
9100B: ENTER PROGRAM B at location (−)00

PRESS: END
PRESS: CONTINUE
DISPLAY

0 ———— Z
0 ———— Y
i ———— X

ENTER DATA: n_i → X
PRESS: CONTINUE



PRESS: SET FLAG
PRESS: CONTINUE
DISPLAY

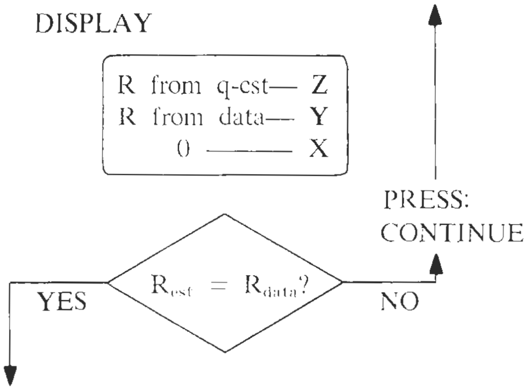
0 ———— Z
0 ———— Y
2 ———— X

Try new q value

PRESS: Y and Z on 9120A PRINTER (Leave X pressed)
ENTER DATA: Estimate of q → X (Less than 1)
PRESS: CONTINUE

Reference: *ECOLOGICAL METHODS* by T. R. E. Southwood 1966 Methuen & Co. Ltd., London

USER INSTRUCTIONS (CON'T)



PRESS: SET FLAG

PRESS: CONTINUE

DISPLAY

P_{est} ———— Z
0 ———— Y
0 ———— X

9100A:
PRESS: END
ENTER PROGRAM B
PRESS: END

9100B: PRESS: GO TO (−) (0) (0)

PRESS: CONTINUE

DISPLAY

P + 1.96 S.E.— Z
P − 1.96 S.E.— Y
P_{est} ———— X

NOTE: If printout is not desired, replace each PRINT instruction with CONTINUE.

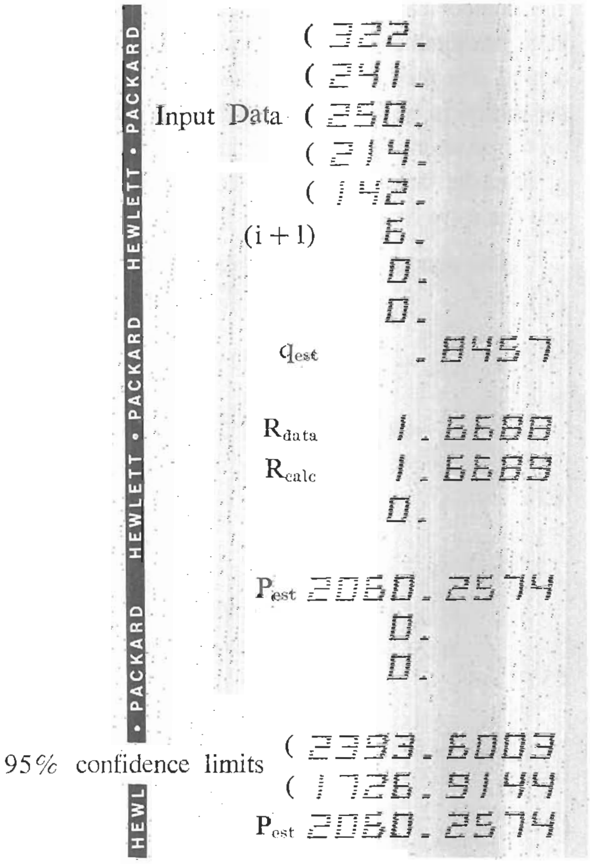
EXAMPLE

In an actual laboratory set-up, 2,000 beetles were placed in a wheat medium and a removal trapping method was started. At ten minute intervals for fifty minutes, beetles were removed from the wheat. The numbers of beetles removed in order of time were:

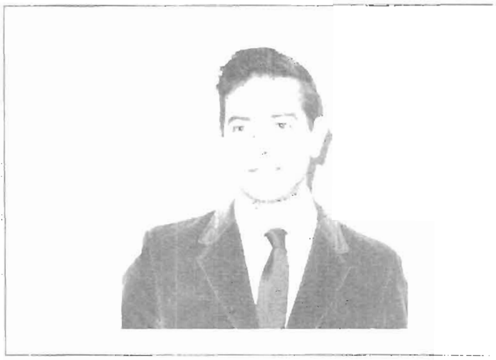
322, 241, 250, 214, 142

How many beetles were there initially in the box, calculated by the removal method?

1. Calculation of q = .8457 (by trial and error).
2. Estimated population = 2,060; confidence limits (95%) = 1727 to 2394.



```
              ( 322.
              ( 241.
Input Data    ( 250.
              ( 214.
              ( 142.
(i + 1)          6.
                 0.
                 0.
q_est               .8457
R_data             1.6688
R_calc             1.6689
                   0.
P_est      2060.2574
                 0.
                 0.
95% confidence limits  ( 2393.6003
                       ( 1726.9144
P_est      2060.2574
```



Joel D. Weintraub is an assistant professor of zoology in the Department of Biology at California State College, Fullerton, California. He received a B.S. degree from City College of New York in 1963, and the Ph.D. in Zoology in June, 1968, from the University of California, Riverside.

Dr. Weintraub says, "These programs have saved the students in the laboratory many needless hours of calculation."

PROGRAM A PART NO. 09100-75202

```
00  CLR  20   Plus Page   40  RUP  22
01   1   01               41  LN   65
02  XTO  23               42   +   33
03   d   17               43  RDN  31
04  STP  41    ENTRY      44  EXP  74
05  PNT  45               45  XEY  30
06  IFG  43               46  EXP  74
07   2   02               47  UP   27
08   4   04               48   1   01
09  AC+  60               49  XEY  30
0a  RDN  31               4a   -   34
0b   d   17               4b  YTO  40
0c  XEY  30               4c   c   16
0d   1   01               4d  RDN  31

10   -   34               50  DIV  35
11  RDN  31               51  RUP  22
12   X   36               52   1   01
13  CLX  37               53  XEY  30
14  AC+  60               54   f   15
15  CLX  37               55   -   34
16  RDN  31               56   f   15
17   d   17               57  XEY  30
18  XEY  30               58  DIV  35
19   1   01               59  RDN  31
1a   +   33               5a  XEY  30
1b  YTO  40               5b   -   34
1c   d   17               5c   b   14
1d  CLX  37               5d  UP   27

20  XEY  30               60  CLX  37
21  GTO  44               61  STP  41   DISPLAY
22   0   00               62  PNT  45
23   4   04               63  PNT  45
24   d   17               64  IFG  43
25  UP   27               65   6   06
26   1   01               66   b   14
27   -   34               67  CLR  20
28  YTO  40               68  GTO  44
29   d   17               69   3   03
2a  RCL  61               6a   4   04
2b  DIV  35               6b   a   13
2c  XTO  23               6c  UP   27
2d   a   13               6d   c   16

30  YTO  40               70  DIV  35
31   b   14               71  CLX  37
32  CLR  20               72  UP   27
33   2   02               73  PNT  45
34  STP  41    ENTRY      74  PNT  45
35  PNT  45               75  END  46
36  PNT  45
37  AC+  60
38  LN   65
39  UP   27
3a   d   17
3b   X   36
3c  XEY  30
3d  UP   27
```

PROGRAM B

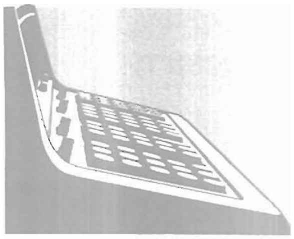
PART NO. 09100-75202

```
00   RDN   31     Minus Page
01   AC+   60
02    a    13
03    -    34
04    X    36
05    e    12
06    X    36
07   YTO   40
08    b    14
09    1    01
0a   UP    27
0b    f    15
0c    -    34
0d    d    17

10    X    36
11   RDN   31
12   UP    27
13    X    36
14    f    15
15   DIV   35
16   RUP   22
17   XEY   30
18    a    13
19   DIV   35
1a   RDN   31
1b    X    36
1c   DN    25
1d   RDN   31

20    X    36
21   RDN   31
22   XEY   30
23    -    34
24    b    14
25   XEY   30
26   DIV   35
27   RDN   31
28    √    76
29   UP    27
2a    1    01
2b    .    21
2c    9    11
2d    6    06

30    X    36
31   RUP   22
32   DN    25
33    e    12
34    +    33
35   RUP   22
36    -    34
37    e    12
38   PNT   45
39   END   46      DISPLAY
```



PRIMARY AND SECONDARY TRANSMISSION LINE PARAMETERS

by Thomas K. McManus

PART NO. 09100-71019

This program calculates and prints the transmission characteristics of a cable at a given sinusoidal frequency. In particular, the characteristic impedance, impedance angle, attenuation, phase change, and velocity of propogation are evaluated.

The input data required are the primary parameters (resistance, inductance, conductance, and capacitance), at the frequency of interest. The program will accept these data in the form of apparent values, obtained by open and short-circuited measurements on a known length of cable. These values should be obtained for a length of cable $l < \frac{\lambda}{4}$ (quarter wavelength) to assure the phase change remains in the first quadrant $(-\frac{\pi}{2} < \beta < \frac{\pi}{2})$ and therefore does not require first estimates of the velocity of propagation.

Program A is completely independent from Program B, and may be used repeatedly to determine Z_0, θ_0, α, and β for various cases. If further calculation is required to determine γ, V.P., R, L, G and C, then Program B is used immediately after using Program A. Program B is not independent, but relies on the computation from Program A to supply certain intermediate data.

The equations used, derived from well-known transmission line equations in terms of voltage and current at sending and receiving ends*, are:

$$\overline{Z_0} = \sqrt{\frac{|Z_{sc}|}{|Y_{oc}|}} \ \underline{/\theta_0} = \frac{(\theta_{sc} - \theta_{oc})}{2}$$

$$\overline{Z_{sc}} = \sqrt{R_{sc}^2 + \omega^2 L_{sc}^2} \ \underline{/\tan^{-1}} \ \frac{\omega L_{sc}}{R_{sc}}$$

$$\overline{Y_{oc}} = \sqrt{G_{oc}^2 + \omega^2 C_{oc}^2} \ \underline{/\tan^{-1}} \ \frac{\omega C_{oc}}{G_{oc}}$$

$$\alpha = \frac{1}{2l} \tanh^{-1} \frac{2A}{1 + A^2 + B^2}, \text{ and}$$

$$\beta = \frac{1}{2l} \tanh^{-1} \frac{2B}{1 - A^2 - B^2},$$

where $A = \sqrt{|Z_{sc}|\ |Y_{oc}|}\cos\theta_1$;

and $B = \sqrt{|Z_{sc}|\ |Y_{oc}|}\sin\theta_1$;

$$\theta_1 = \frac{(\theta_{sc} + \theta_{oc})}{2}$$

$$\gamma = \sqrt{\alpha^2 + \beta^2}$$

$$\text{V.P.} = \frac{\omega}{\beta}$$

$$R = |\gamma|\ |Z_0| \ \cos(\theta_\gamma + \theta_0)$$

$$L = \frac{|\gamma|\ |Z_0|}{\omega} \ \sin(\theta_\gamma + \theta_0)$$

$$G = \frac{|\gamma|}{|Z_0|} \ \cos(\theta_\gamma - \theta_0)$$

$$C = \frac{|\gamma|}{|Z_0|\ \omega} \ \sin(\theta_\gamma - \theta_0)$$

where $\theta_\gamma = \tan^{-1}\frac{\beta}{\alpha}$

NOMENCLATURE

R = distributed resistance Ω/ft.

L = distributed inductance H/ft.

G = distributed conductance $\frac{1/\Omega}{\text{ft.}}$

C = distributed capacitance F/ft.

α = attenuation dB/ft. = 8.686 x attenuation in nepers/ft.

β = phase change radians/ft.

VP = velocity of propogation ft/sec.

Z_o = characteristic Impedance Ω

θ_o = characteristic Impedance angle radians

ω = angular frequency radians/sec.

θ_{sc} = short circuit impedance angle radians

θ_{oc} = open circuit impedance angle radians

R_{sc} = short circuit resistive component

L_{sc} = short circuit inductive component

G_{oc} = open circuit conductive component

C_{oc} = open circuit capacitive component

l = cable length feet

*Reference: *COMMUNICATION ENGINEERING* by W. L. Everitt, Second Edition McGraw-Hill

USER INSTRUCTIONS

NOTE: If printout is not desired, replace each PRINT instruction with CONTINUE.

SET: RADIANS, FLOATING POINT, RUN

PRESS: Y Z on 9120A

PRESS: END

ENTER: PROGRAM A

9100A: PRESS: END

9100B:
PRESS: GO TO (−) (0) (0)
ENTER PROGRAM B
PRESS: END

PRESS: CONTINUE
DISPLAY 02

0 — Z
0 — Y
1 — X

ENTER DATA: f → X
PRESS: CONTINUE
DISPLAY 0c

0 — Z
0 — Y
2 — X

ENTER DATA: R_{se} → Y L_{se} → X
PRESS: CONTINUE
DISPLAY 0c

0 — Z
0 — Y
3 — X

ENTER DATA: G_{oc} → Y C_{oc} → X
PRESS: CONTINUE
DISPLAY 37

Z_0 — Z
θ_0 — Y
4 — X

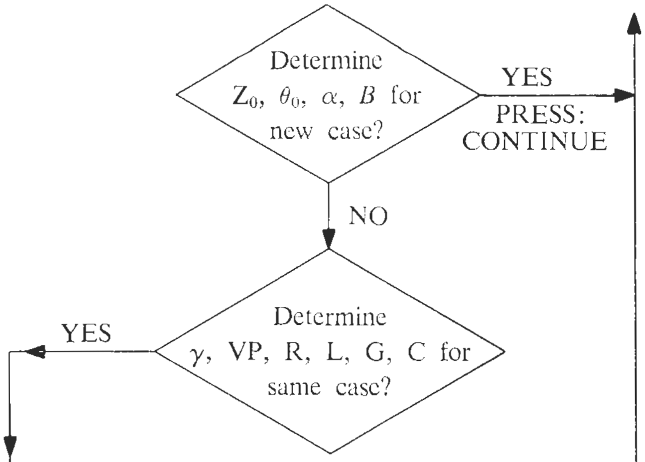
PRESS: CONTINUE
DISPLAY 6a

0 — Z
0 — Y
5 — X

ENTER DATA: l → X
PRESS: CONTINUE
DISPLAY 9d

α — Z
B — Y
6 — X

USER INSTRUCTIONS (CON'T)



9100A:
PRESS: END (Do not use CLEAR)
ENTER PROGRAM B
PRESS: END
PRESS: CONTINUE

9100B:
PRESS: GO TO (−) (0) (0)
PRESS: CONTINUE

DISPLAY (−)04

0 — Z
0 — Y
7 — X

PRESS: CONTINUE
DISPLAY (−)26

R — Z
L — Y
8 — X

PRESS: CONTINUE
DISPLAY (−)39

G — Z
C — Y
9 — X

PRESS: CONTINUE
DISPLAY (−)43

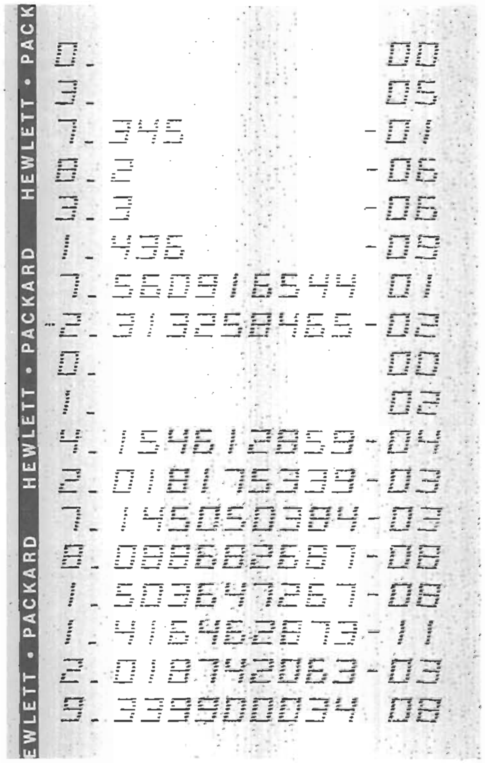
γ — Z
VP — Y
10 — X

TO ENTER NEW DATA:

9100A: REENTER PROGRAM A AT LOCATION 00 AND PROCEED AS BEFORE.

9100B: PRESS: CONTINUE →

EXAMPLE



```
Input data:      0.                  00
         f_in    3.                  05
         R_sc    7.345              -01
         L_sc    8.2                -06
         G_oc    3.3                -06
         C_oc    1.436              -09
Results: Z_0     7.560916544         01
         θ_0    -2.313258465        -02
Input data:      0.                  00
         ( l     1.                  02
Results: α       4.154612859        -04
         β       2.018175339        -03
         R       7.145050384        -03
         L       8.088682687        -08
         G       1.503647267        -08
         C       1.416482873        -11
         γ       2.018742063        -03
         V.P.    9.339000034         08
```

Thomas McManus attended Queen's University in Belfast, Ireland, where he graduated in 1966 with honors in physics. He presently is employed by Northern Electric Company, Ltd., in Lachine, Quebec, in mathematics research and development applications and computer work.

PROGRAM A **PART NO. 09100-71019**

```
00  CLR  20   Plus Page
01   1   01
02  STP  41   ENTRY
03  UP   27
04  PNT  45
05   +   33
06   π   56
07   X   36
08  YTO  40
09   a   13
0a  CLR  20
0b   2   02
0c  STP  41   ENTRY
0d  UP   27

10  PNT  45
11   a   13
12   X   36
13  DN   25
14  XEY  30
15  POL  62
16  IFG  43
17   2   02
18   5   05
19  YTO  40
1a   b   14
1b  XTO  23
1c   c   16
1d  CLR  20

20  SFL  54
21   3   03
22  GTO  44
23   0   00
24   c   16
25  YTO  40
26   d   17
27  UP   27
28   c   16
29  XEY  30
2a  DIV  35
2b  DN   25
2c   √   76
2d  UP   27

30   b   14
31  RUP  22
32   -   34
33   2   02
34  DIV  35
35   4   04
36  PNT  45
37  STP  41   DISPLAY
38  YEX  24
39   d   17
3a   b   14
3b   +   33
3c   2   02
3d  DIV  35
```

```
40   c   16
41  RUP  22
42  XTO  23
43   c   16
44  DIV  35
45  DN   25
46  RCT  66
47  YTO  40
48   b   14
49  XTO  23
4a   e   12
4b  UP   27
4c   X   36
4d   b   14

50  UP   27
51   X   36
52  DN   25
53   +   33
54   e   12
55  YTO  40
56   e   12
57  UP   27
58   +   33
59   1   01
5a  RUP  22
5b   +   33
5c  DN   25
5d  DIV  35

60  DN   25
61  ARC  72
62  HYP  67
63  TAN  71
64  XTO  23
65   f   15
66   0   00
67  UP   27
68  UP   27
69   5   05
6a  STP  41   ENTRY
6b  UP   27
6c  PNT  45
6d   +   33

70   f   15
71  YTO  40
72   f   15
73  XEY  30
74  DIV  35
75   b   14
76  YTO  40
77   b   14
78  UP   27
79   +   33
7a   1   01
7b  UP   27
7c   e   12
7d   -   34
```

```
80  DN   25
81  DIV  35
82   0   00
83  X>Y  53
84   π   56
85  CNT  47
86  XEY  30
87  ARC  72
88  TAN  71
89   +   33
8a   f   15
8b  DIV  35
8c  YTO  40
8d   e   12

90   b   14
91  UP   27
92   8   10
93   .   21
94   6   06
95   8   10
96   6   06
97   X   36
98  DN   25
99  XEY  30
9a  UP   27
9b   6   06
9c  PNT  45
9d  END  46   DISPLAY
```

ω

θ_{sc} B α

Z_{sc} Z_0

θ_{oc} θ_0

A A^2+B^2 β

$2\alpha l$ $2l$

PROGRAM B

PART NO. 09100-71019

```
00    0    00    Minus Page     40    1    01
01   UP    27                   41    0    00
02   UP    27                   42   PNT   45
03    7    07                   43   END   46     DISPLAY
04   STP   41    DISPLAY
05    a    13
06   CLX   37
07    e    12
08   DIV   35
09   YTO   40
0a    f    15
0b    e    12
0c   UP    27
0d    b    14

10   POL   62
11   YTO   40
12    e    12
13   XTO   23
14    b    14
15   UP    27
16    c    16
17    X    36
18    d    17
19   RUP   22
1a    +    33
1b   DN    25
1c   XEY   30
1d   RCT   66

20   XEY   30
21   UP    27
22    a    13
23   DIV   35
24    8    10
25   PNT   45
26   STP   41    DISPLAY
27    e    12
28   UP    27
29    d    17
2a    -    34
2b    b    14
2c   UP    27
2d    c    16

30   DIV   35
31   DN    25
32   RCT   66
33   XEY   30
34   UP    27
35    a    13
36   DIV   35
37    9    11
38   PNT   45
39   STP   41    DISPLAY
3a    b    14
3b   UP    27
3c    f    15
3d   UP    27
```

ω

α γ

Z_0

θ_0

β θ_γ

$2l$ VP

NEW CALCULATOR SYSTEM ACCESSORIES

BLACK PENS AVAILABLE FOR 9125A PLOTTER

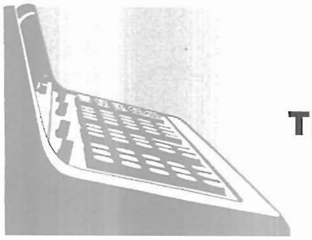
After considerable development work, our engineers have perfected black ink for the pens used with the HP Model 9125A Plotter. The black pens are now in production, and are available as HP part number 5080-7994.

You can obtain the following colors:

Part Number	Color	Price	
5080-7979	Red	Package of 3	$4.50
5080-7980	Blue	Package of 3	4.50
5080-7981	Green	Package of 3	4.50
5080-7994	Black	Package of 3	4.50

NEW FEATURE

TEACHER'S CORNER will be a feature of each *KEYBOARD,* starting with this issue. Articles in this series will be of general interest, although they are designed to help the high school and college instructor teach topics in Mathematics and Science. The first article describes an approach to calculus using the HP System 9100 as a graphic instruction medium.



THE INTEGRAL: A FUNDAMENTAL APPROACH

9100B ONLY
PART NO.
09100-75804

In most beginning calculus courses, the introduction of the integral includes a theoretical discussion of the integral as the area under a curve. These discussions state that the area may be approximated as a sum of rectangles or as a further refinement, by a trapezoidal rule or Simpson's Method. However, the formidable arithmetic operations required preclude a thorough examination of the 'sum of incremental areas' concept, and the course of study moves on to obtaining integrals in closed form. This procedure denies the student thorough exposure to an increasingly important aspect of mathematics, numerical integration, while at the same time never fully reinforcing the fundamental idea of the integral as an area.

Using an approach which plots any given function, then constructs rectangles under the function and plots their areas, this program is a powerful analytic and illustrative tool for teaching the concepts of integration. It provides the means to see an integral develop point by point as the accumulated sum of incremental areas for a wide variety of functions.

To use the plotter paper format most effectively, the following examples are oriented with the Y scale horizontal with value increasing to the left, and the X scale vertical with value increasing upward.

OPERATION OF THE INTEGRAL FINDER PROGRAM

EXAMPLE 1

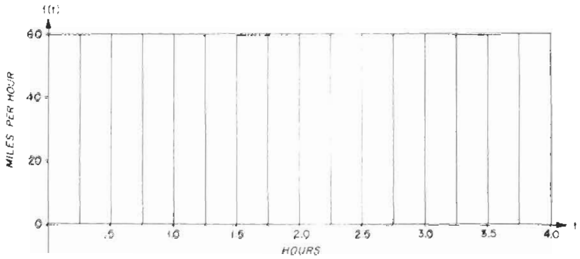
Find the distance traveled by an automobile moving at a constant velocity of 60 mph. We know that

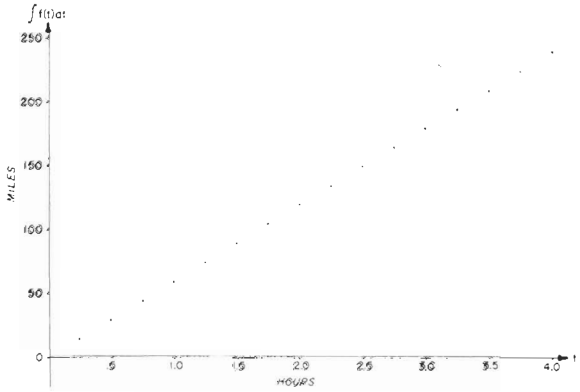
$x(t)$: distance traveled $= \int_0^T v(t)dt$: the integral of the velocity.

To use the integral finder for this problem, we have $v(t) = f(t) = 60$ mph and we wish to know the distance traveled at any time. Following the user instructions, enter $f(t) = 60$.

Use: Independent variable scale = . 5 hour per inch
Function x scale = 20 mph per inch
Integral x scale = 50 miles per inch
Δ t = .25 hour

The resulting plot:





Identical independent variable scales for both $f(t)$ and $\int f(t)dt$ plots make comparisons between the two graphs simple and easy.

Now, from the resulting plot, we observe that accumulated sums under the line $f(t) = 60$ form a straight line of slope = 60.

Hence, we may say that the $\int_0^T f(t)\,dt = \int_0^T 60\,dt = 60T$. Upon reflection, we can notice that the integral of any constant $\int_0^T Adt$ will be At.

EXAMPLE 2

Suppose we wish to know the position of a charged particle under a constant acceleration. Assume the initial velocity of the particle to be $v_0 = -4$ cm/sec and the acceleration $= +1$ cm/sec^2.

For the purposes of the program:

$v(t) = f(t) = (-4+t)$ cm/sec

The position of the particle is:

$$x(t) = \int_0^T v(t)\ dt = \int_0^T (t-4)\ dt$$

Enter the integral program and use:

$f(t) = t-4$

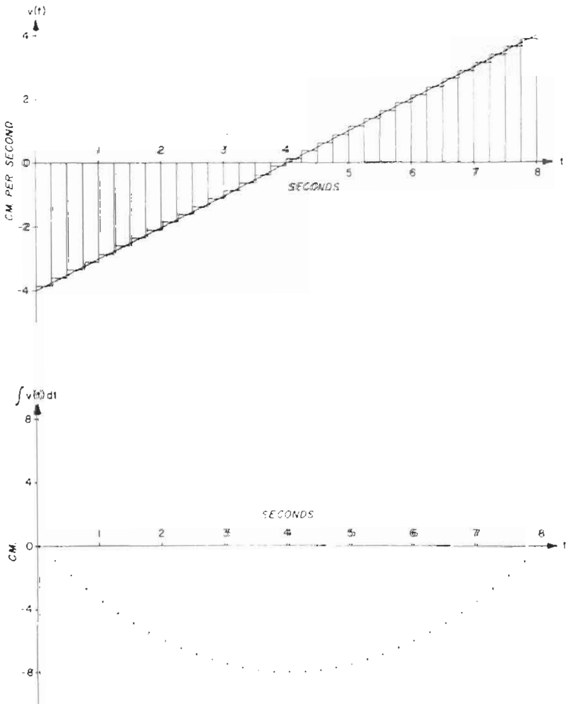
Independent variable scale = 0.5 sec/cm

Function x scale $= \dfrac{1\ \text{cm/sec}}{\text{cm}}$

Integral x scale = 2 cm/cm

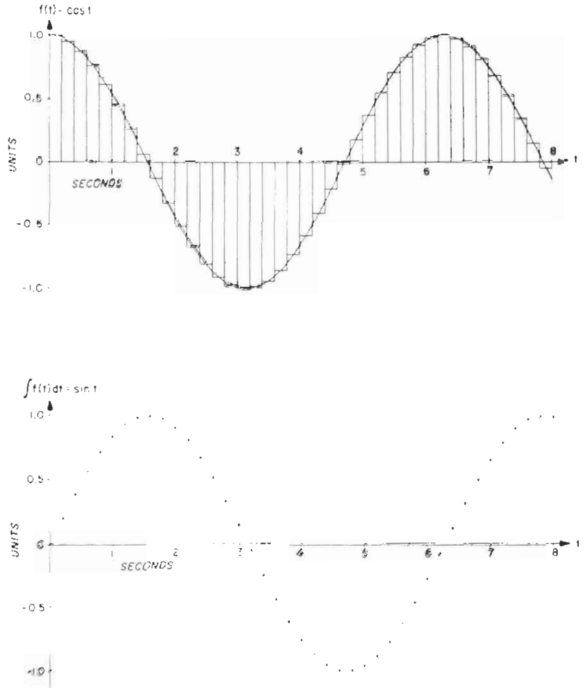
$\Delta t = .25$ sec

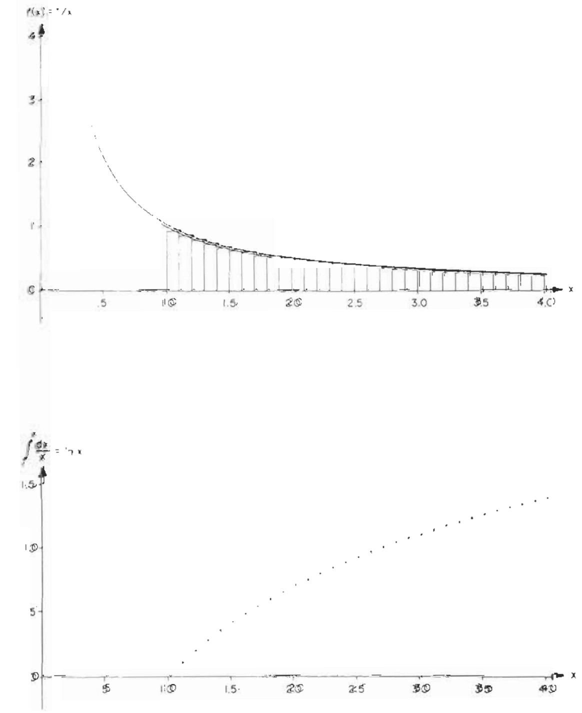
The resulting plot:



From the plot, notice that the graph of x(t) is parabolic with its minimum at t=4. This corresponds to the zero crossing of the plot of f(t). Also for t=8, the value of x(t)=0, implying that $\int_0^8 (t-4)dt=0$.

Other interesting examples using the integral plot:





More complete lesson plans giving additional programs and teaching suggestions on this topic are available. Contact your local HP Sales and Service office.

USER INSTRUCTIONS

Set Decimal Wheel at 4

Press X and Y on the 9120A Printer

Plotter pen origin at lower left corner of paper

ENTER PROGRAM A at location (−)00

ENTER PROGRAM B

SET: PROGRAM MODE

Enter the program steps to describe f(x) taking the independent variable (x) from the x register and leaving f(x) in the y register. Steps (−)00 through (−) 1d are available to enter f(x). After last step, key: SUB RETURN

SET: DEGREES/RADIANS as appropriate

SET: RUN MODE

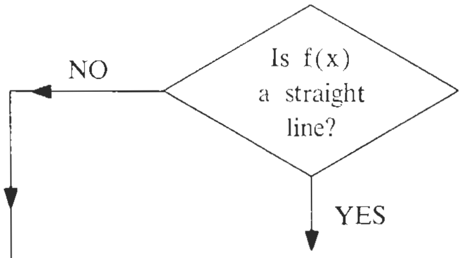
PRESS: GO TO (2) (0)

PRESS: CONTINUE

DISPLAY:

0 ———————— Z
0 ———————— Y
1 ———————— X

ENTER DATA: Scale in problem units/inch*
independent variable → Y
function dependent variable → X



PRESS: SET FLAG

PRESS: CONTINUE – f(x) is plotted

DISPLAY

0 ———————— Z
0 ———————— Y
2 ———————— X

ENTER DATA: Scale in problem units/inch*
integral dependent variable → X

USER INSTRUCTIONS (CON'T)

PRESS: CONTINUE

DISPLAY

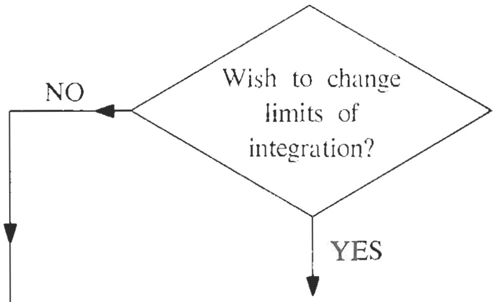
0 ———————— Z
0 ———————— Y
3 ———————— X

ENTER DATA:
independent variable increment → X

PRESS: CONTINUE

DISPLAY

0 ———————— Z
Upper limit
of integration — Y
0 ———————— X



ENTER DATA: Upper limit → Y
Lower limit → X

PRESS: CONTINUE — Integral is plotted

Printer will print for each increment
Sum of rectangular areas → Y
x → X

If printer is not used, change PRINT statements to CONTINUE statements in locations:

(+)05	(+)1c
(+)06	(+)a4
(+)0c	(+)a5
(+)0d	(−)53
(+)1b	(−)54

---

*To plot in metric units, change the step instruction from 5 (Code 05) to 2 (Code 02) in steps (−) ab, (−) ba, and (−) c5.

PROGRAM A

PART NO. 09100-75804

Minus
Page

```
00  CNT  47
01  CNT  47
02  CNT  47
03  CNT  47
04  CNT  47
05  CNT  47
06  CNT  47
07  CNT  47
08  CNT  47
09  CNT  47
0a  CNT  47
0b  CNT  47
0c  CNT  47
0d  CNT  47

10  CNT  47
11  CNT  47
12  CNT  47
13  CNT  47
14  CNT  47
15  CNT  47
16  CNT  47
17  CNT  47
18  CNT  47
19  CNT  47
1a  CNT  47
1b  CNT  47
1c  CNT  47
1d  CNT  47

20  CLR  20
21  FMT  42
22  DN   25
23   2   02
24  EEX  26
25   3   03
26  FMT  42
27  DN   25
28  UP   27
29   4   04
2a  EEX  26
2b   3   03
2c  XEY  30
2d  FMT  42

30  DN   25
31  XEY  30
32  DN   25
33  FMT  42
34  DN   25
35   5   05
36  EEX  26
37   3   03
38  FMT  42
39  DN   25
3a  UP   27
3b   4   04
3c  EEX  26
3d   3   03

40  XEY  30
41  FMT  42
42  DN   25
43  XEY  30
44  DN   25
45  FMT  42
46  DN   25
47   7   07
48  EEX  26
49   3   03
4a  FMT  42
4b  DN   25
4c  FMT  42
4d  UP   27

50  CLR  20
51   1   01
52  STP  41
53  PNT  45
54  PNT  45
55  XTO  23
56   d   17
57  YTO  40
58   -   34
59   e   12
5a   f   15
5b  GTO  44
5c  SUB  77
5d   0   00

60   0   00
61  GTO  44
62  SUB  77
63   a   13
64   6   06
65   f   15
66  UP   27
67  GTO  44
68  SUB  77
69   c   16
6a   1   01
6b  DN   25
6c  XEY  30
6d  FMT  42

70  DN   25
71  IFG  43
72   9   11
73   2   02
74   f   15
75  UP   27
76  XFR  67
77   -   34
78   e   12
79  UP   27
7a   5   05
7b   .   21
7c  DIV  35
7d  DN   25

80   +   33
81  XFR  67
82   -   34
83   e   12
84  UP   27
85   8   10
86   X   36
87  DN   25
88  X<Y  52
89   9   11
8a   d   17
8b  YTO  40
8c   f   15
8d  GTO  44

90   5   05
91   a   13
92  XFR  67
93   -   34
94   e   12
95  UP   27
96   8   10
97   X   36
98  YTO  40
99   f   15
9a  GTO  44
9b   5   05
9c   a   13
9d  CLR  20

a0  FMT  42
a1  UP   27
a2  GTO  44
a3   +   33
a4   0   00
a5   0   00
a6   d   17
a7  DIV  35
a8   4   04
a9  XEY  30
aa   -   34
ab   5   05
ac   0   00
ad   0   00
```

```
b0   X     36
b1   RTN   77
b2   XFR   67
b3   -     34
b4   d     17
b5   DIV   35
b6   1     01
b7   0     00
b8   XEY   30
b9   -     34
ba   5     05
bb   0     00
bc   0     00
bd   X     36

c0   RTN   77
c1   XFR   67
c2   -     34
c3   e     12
c4   DIV   35
c5   5     05
c6   0     00
c7   0     00
c8   X     36
c9   RTN   77
ca   END   46
```

PROGRAM B

```
00   CLR   20
01   FMT   42
02   UP    27
03   2     02
04   STP   41
05   PNT   45
06   PNT   45
07   XTO   23
08   -     34
09   d     17
0a   3     03
0b   STP   41
0c   PNT   45
0d   PNT   45

10   XTO   23
11   -     34
12   f     15
13   XFR   67
14   -     34
15   e     12
16   UP    27
17   8     10
18   X     36
19   0     00
1a   STP   41
1b   PNT   45
1c   PNT   45
1d   XTO   23
```

Minus
Page

```
20   f     15
21   YTO   40
22   -     34
23   3     03
24   UP    27
25   GTO   44
26   SUB   77
27   -     34
28   c     16
29   1     01
2a   2     02
2b   EEX   26
2c   3     03
2d   FMT   42

30   DN    25
31   XFR   67
32   -     34
33   f     15
34   UP    27
35   2     02
36   DIV   35
37   f     15
38   +     33
39   XFR   67
3a   -     34
3b   3     03
3c   X<Y   52
3d   0     00
```

Plus
Page

```
40   0     00
41   DN    25
42   GTO   44
43   SUB   77
44   -     34
45   0     00
46   0     00
47   XFR   67
48   -     34
49   f     15
4a   XEY   30
4b   X     36
4c   RDN   31
4d   XEY   30

50   0     00
51   AC+   60
52   DN    25
53   GTO   44
54   SUB   77
55   -     34
56   a     13
57   6     06
58   f     15
59   UP    27
5a   GTO   44
5b   SUB   77
5c   -     34
5d   c     16
```

```
60   1     01
61   DN    25
62   XEY   30
63   FMT   42
64   DN    25
65   RDN   31
66   f     15
67   XEY   30
68   XFR   67
69   -     34
6a   f     15
6b   +     33
6c   YTO   40
6d   f     15

70   GTO   44
71   SUB   77
72   -     34
73   c     16
74   1     01
75   DN    25
76   XEY   30
77   FMT   42
78   DN    25
79   2     02
7a   EEX   26
7b   3     03
7c   FMT   42
7d   DN    25

80   e     12
81   UP    27
82   GTO   44
83   SUB   77
84   -     34
85   b     14
86   2     02
87   f     15
88   UP    27
89   GTO   44
8a   SUB   77
8b   -     34
8c   c     16
8d   1     01
```

```
90  DN   25
91  XEY  30
92  FMT  42
93  UP   27
94  FMT  42
95  DN   25
96  FMT  42
97  UP   27
98   2   02
99  EEX  26
9a   3   03
9b  FMT  42
9c  DN   25
9d   0   00

a0  UP   27
a1   e   12
a2  UP   27
a3   f   15
a4  PNT  45
a5  PNT  45
a6  GTO  44
a7   3   03
a8   1   01
a9  CNT  47
aa  CNT  47
ab  CNT  47
ac  CNT  47
ad  CNT  47

b0  CNT  47
b1  CNT  47
b2  CNT  47
b3  CNT  47
b4  CNT  47
b5  CNT  47
b6  CNT  47
b7  CNT  47
b8  CNT  47
b9  CNT  47
ba  CNT  47
bb  CNT  47
bc  CNT  47
bd  CNT  47

c0  CNT  47
c1  CNT  47
c2  CNT  47
c3  CNT  47
c4  CNT  47
c5  CNT  47
c6  CNT  47
c7  CNT  47
c8  CNT  47
c9  CNT  47
ca  CNT  47
cb  CNT  47
cc  CNT  47
cd  CNT  47
```

Plus
Page

```
d0  CNT  47
d1  CNT  47
d2  CNT  47
d3  CNT  47
d4  CNT  47
d5  CNT  47
d6  CNT  47
d7  CNT  47
d8  CNT  47
d9  CNT  47
da  CNT  47
db  CNT  47
dc  CNT  47
dd  CNT  47
```

USE OF y⇄() KEY

Calculating a moving average of a set of data points requires that as the newest data point is entered into the calculation of the average, the oldest data point is discarded. The easiest way to do this is to rotate the data through storage, so the new data entry is always stored in the same register.

Assuming the program calculates the moving average of four data points, the storage would appear as follows:

	Storage register			
	a	*b*	*c*	*d*
After fourth data entry	X_1	X_2	X_3	X_4
After fifth data entry	X_2	X_3	X_4	X_5
After nth data entry	X_{n-3}	X_{n-2}	X_{n-1}	X_n

The y⇄() key can be used very effectively for the rotation technique, as shown in this program.

USER INSTRUCTIONS

PRESS: END
ENTER PROGRAM
PRESS: END
PRESS: CONTINUE
DISPLAY

```
0 ———————— Z
X̄———————— Y
i ———————— X
```

i indicates number of next data points to be entered.

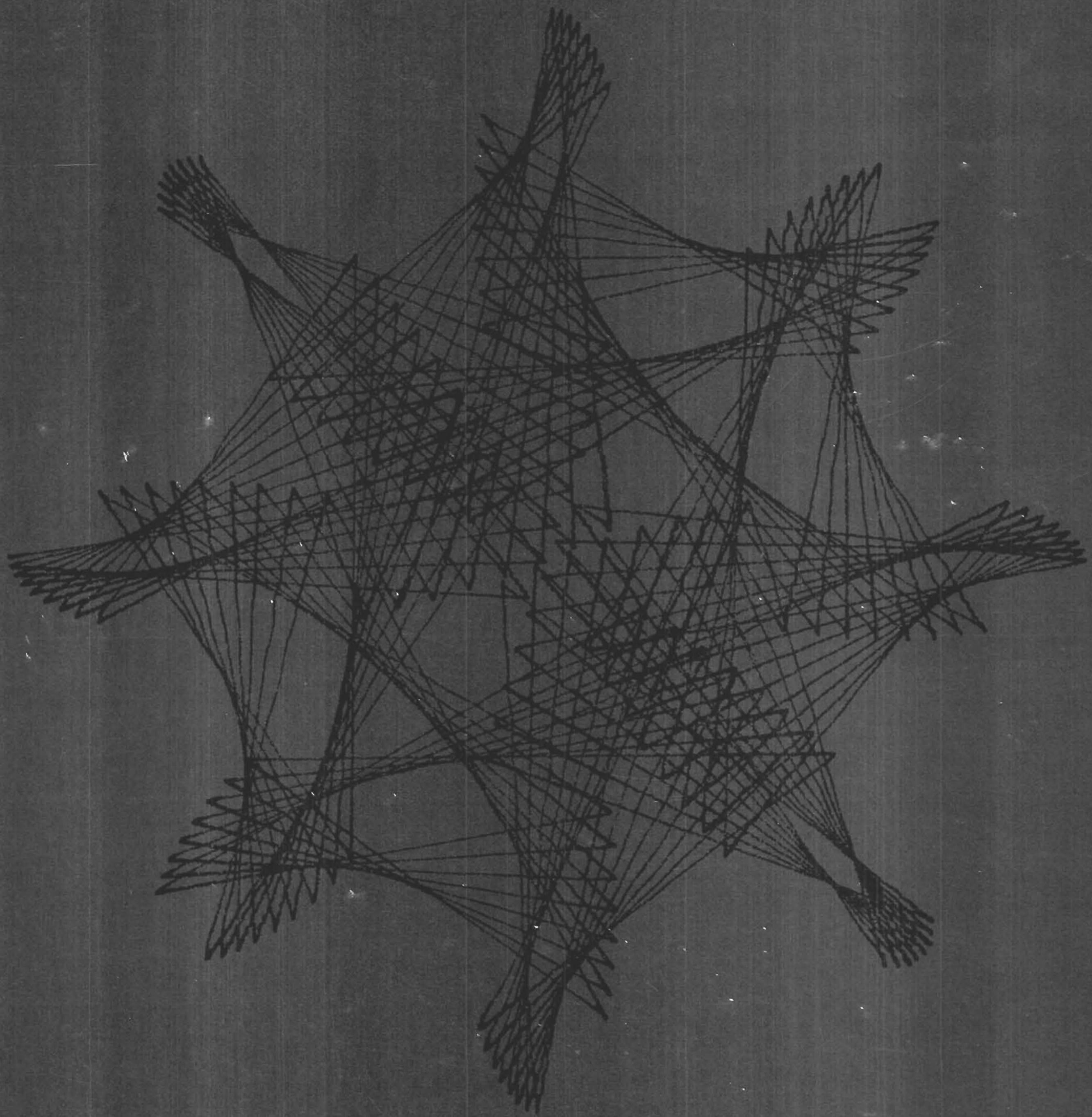
NOTE: Y register will show 0 until fourth data point has been entered.

ENTER DATA: X_i → X
PRESS: CONTINUE

```
00  CLR  20
01  DN   25
02   1   01
03  AC+  60
04   f   15
05  STP  41
06  XEY  30
07  YE   24
08   a   13
09  YE   24
0a   b   14
0b  YE   24
0c   c   16
0d  YE   24

10   d   17
11   4   04
12  XEY  30
13   f   15
14  X<Y  52
15   0   00
16   1   01
17  DN   25
18   a   13
19   +   33
1a   b   14
1b   +   33
1c   c   16
1d   +   33

20   d   17
21   +   33
22   4   04
23  DIV  35
24  GTO  44
25   0   00
26   2   02
27  END  46
```



Plot R = cos 4θ made with HP 9100B Computing Calculator and HP 9125A Plotter, incrementing θ 2 radians at a time.

KEYBOARD WINTER 1970 Volume 2 Number 1
APPLICATIONS INFORMATION FOR HEWLETT-PACKARD CALCULATORS PUBLISHED AT P.O.BOX 301,LOVELAND,COLORADO 80537
Editor: A.B.SPERRY Art Director: L.E.BRADEN