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DIGITAL COMPUTER IMPLEMENTATION OF A DISCRETE-TIME DISTURBANCE---ETC(U)
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Results are presented which demonstrate the performance of a discrete controller with disturbance-absorbing capability. The design approach is explained and the implementation of the design on a PDP 11/34 computer is documented, along with performance plots showing results with several types of disturbances. Applications of this approach include pointing and tracking problems, missile autopilots, and isolation of guns mounted on helicopters.

FOREWORD

Shortly after submitting this report for publication, Larmon Isom departed this life. His years of dedicated work in the Guidance and Control Directorate of the US Army Missile Command are fondly recalled and appreciated by his associates. This report documents his final task.

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I. INTRODUCTION

The US Army Missile Command (MICOM) is engaged in a research program to develop an advanced guidance and control system for future (1990's) Army modular missiles. Principal investigators have defined several technical areas in which government and contractor personnel are contributing to the overall program objectives. One of these technical areas is the Disturbance Accommodating Control (DAC) theory and the design of discrete-time disturbance-accommodating controllers for discrete-time, sampled-data control problems.

The DAC method of design, using a combination of waveform-mode distrubance modeling and state-variable control techniques, was developed by Dr. C. D. Johnson of the University of Alabama in Huntsville. As a tool for design of controllers, the DAC approach permits three primary modes of distrubance accommodation: (1) cancellation (absorption) of disturbance effects, (2) minimization of disturbance effects, or (3) constructive utilization of the disturbances as an aid in accomplishing the primary control task. These disturbance accommodations are realized in addition to the usual control efforts required to satisfy system performance requirements without disturbances.

This report describes the digital computer implementation and the results obtained from the design of a discrete-time disturbance-accommodating controller. The digital computer implementation and the results presented in this report were obtained by using the disturbance cancellation mode of the discrete-time DAC design on a linear, time-invariant plant. The controllers obtained via this design method are termed *disturbance absorption* controllers for regulating the plant state to zero.

II. DIGITAL COMPUTER IMPLEMENTATION

This section of the report presents the details of the discrete-time DAC program design method. The first section presents the equations of the total system to be implemented. However, these equations may be considered to consist of three groups: (1) continuous-time disturbances, (2) continuous-time plant (system), and (3) discrete-time DAC. The second section presents the FORTRAN program implementation of this DAC design method for execution on the PDP-11/34 digital computer.

A. THE DAC DESIGN EXAMPLE

The discrete-time DAC design program example to be considered is a *regulator problem* that involves a first-order controlled plant acted upon by a constant piecewise disturbance. The complete block diagram of the continuous-time system (plant) with the continuous-time DAC design is as shown in Figure 1. From the block diagram, the following equations may be immediately written.

For the piecewise disturbance,

$$w(t) = c_i e^{\alpha t} \tag{1}$$

For the first-order plant (system),

$$\dot{x}(t) = a\,x(t) + b\,U(nT) + f\,w(t) \tag{2}$$

$$x(t) = \int_0^t \dot{x}(t)\,dt + x(o) \tag{3}$$

$$y(t) = c\,x(t) \tag{4}$$

For the discrete-time DAC controller design,

$$y(nT) = y(t) \tag{5}$$

$$TMP1 = \left[e^{dT}\,(a - d)\;y(nT)\right] / \;cf\left[\left(e^{dT} - e^{aT}\right)\right] \tag{6}$$

$$U_p = K\,y(nT)/c \tag{7}$$

$$\xi(nT) = \left[\frac{1}{E}\right]\xi[(n + 1)T] \tag{8}$$

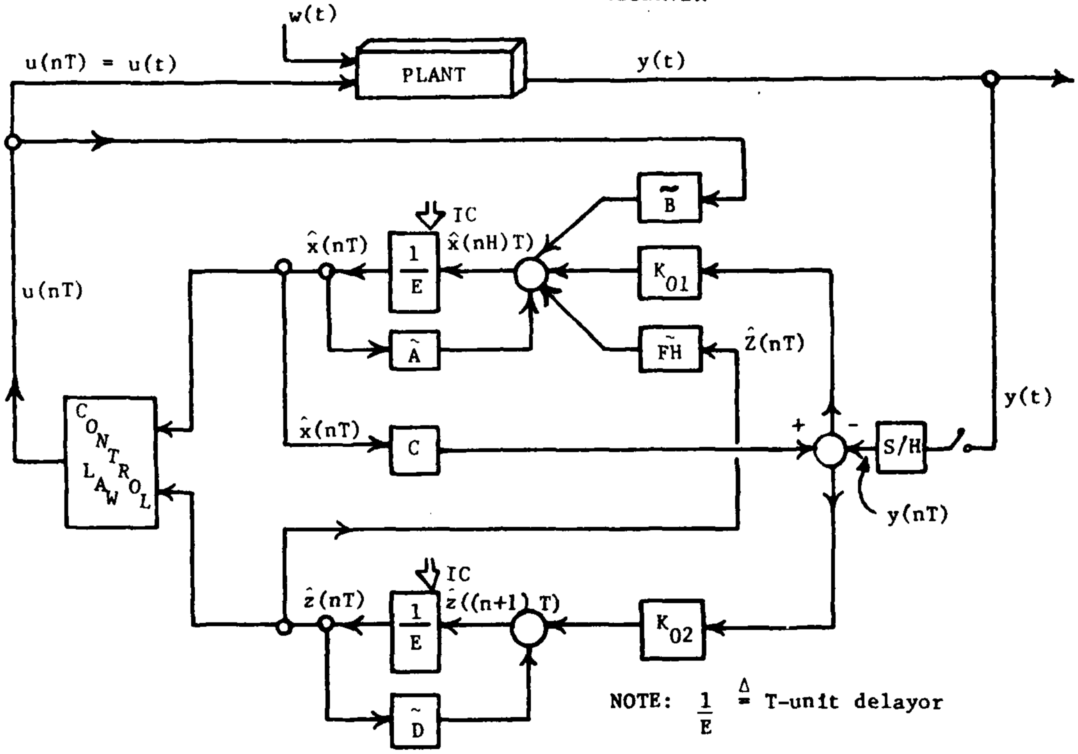
$$\hat{z}(nT) = \xi(nT) - TMP1 \tag{9}$$

$$U_d = \left\{af/[b(a - d)]\right\}\left\{\left(e^{dT} - e^{aT}\right)/\left(e^{aT} - 1\right)\right\}\hat{z}(nT) \tag{10}$$

$$U(nT) = U_p + U_d \tag{11}$$

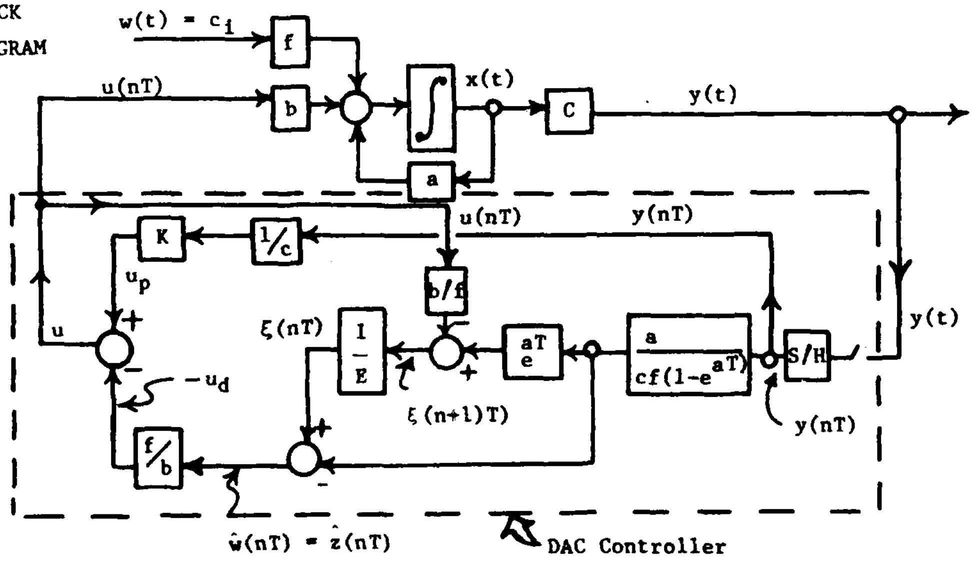
$$\xi[(n + 1)T] = \left[\frac{(a - d)\;e^{(a + d)T}}{cf\left(e^{dT} - e^{aT}\right)}\right] y(nT) + \left[\frac{b(a - d)\;e^{dT}\left(e^{aT} - 1\right)}{af\left(e^{dT} - e^{aT}\right)}\right] U(nT) \tag{12}$$

ORGANIZATION OF PLANT AND DISCRETE-TIME OBSERVER



NOTE: $\frac{1}{E} \triangleq$ T-unit delayor

BLOCK DIAGRAM



NOTE: To achieve plant deadbeat response, design k as:

$$k_{db} = \frac{ae^{aT}}{b(1-e^{aT})}$$

Figure 1. Organization and block diagram of problem.

$$\text{where} \quad K = K_{db} = ae^{aT} / \, b\left(1 - e^{aT}\right) \tag{13}$$

$$E \cong \frac{1}{T} \sim \text{ a unit delayer} \tag{14}$$

Observe that there are three cases to be considered in the use of Eqs. (6), (10), and (12). These three cases are as follows: (1) where $d = 0$, (2) where $d = a$, and (3) where neither case (1) or (2) applies. These cases are considered in the DAC program implementation by using the FORTRAN *IF* statement.

Note that the disturbances $w(t)$ have been experimentally modeled and found to obey a first-order equation of

$$w(t) = z(t) \tag{15}$$

$$\dot{z} = dz + \sigma(t) \tag{16}$$

where the (real) coefficient d is assumed to be known. Now, the disturbance model (given by Eq. (1)) is

$$w(t) = c_i e^{\alpha t} \tag{17}$$

where α is any arbitrary (real) scalar constant. This implies that

$$z(t) = c_i e^{\alpha t} \tag{18}$$

$$z(t) = \alpha c_i e^{\alpha t} \qquad = dz(t) \tag{19}$$

Therefore, $\alpha = d$, which may be obtained from these relationships as shown.

By setting $d = 0$, the case of *constant* disturbances is obtained; setting $d > 0$ yields the case of exponentially *growing* disturbances; and setting $d < 0$ yields the case of exponentially *decaying* disturbances. Thus, this permits a wide range of realistic disturbances to be utilized in the design process of high performance digital controllers.

Also, the above equations have been written in the mathematical notation of Reference 1 as utilized by Dr. Johnson. Table 1 is shown as an aid to understanding the notation of the above equations and their usage in the FORTRAN DAC program implementation; this implementation is described in the next section.

TABLE 1. A CROSS INDEX OF VARIABLES

MATHEMATICAL SYMBOL	FORTRAN SYMBOL	VALUE USED IN CASE 1	MEANING AND/OR USAGE
$\tilde{A}$, a	A	1.0	Coefficient of $x(t)$
α	AWT	0.0	Coefficient of e^{α}
$\tilde{B}$, b	B	1.0	Coefficient of plant equation
C	C	1.0	Coefficient of plant output
C_i	CWT	1.0	Coefficient of Ce^{α}
$\tilde{D}$	D	Calculated	Same as AWT
dt	DT	1/64	Integration interval
f	F	1.0	Coefficient of disturbance
--	ICN	1.0	Case number parameter
--	ITP	0.0	Print interval
k	K	Calculated	Equation (13)
--	$KUTTA$	Calculated	Integration control parameter
--	NX	1.0	Number of variables to integrate
T	ST	$8 \cdot DT$	Sample interval
t	T	0.0	Time
--	$TMP1$	Calculated	Equation (6)
--	$TSTOP$	1.0	Time to stop
U_d	UD	Calculated	Equation (10)
$U(nT) = U(t)$	UNT	Calculated	Equation (11)
U_p	UP	Calculated	Equation (7)
$w(t)$	WT	Calculated	Equation (1)
$\dot{x}(t)$	XDT	Calculated	Equation (2)
$\xi[(n+1)T]$	$XINPT$	Calculated	Equation (12)
$\xi(nT)$	$XINT$	Calculated	Equation (8)
$x(t)$	XT	Calculated	Equation (3)
$y(nT)$	YNT	Calculated	Equation (5)
$y(t)$	YT	Calculated	Equation (4)
$\hat{z}(nT)$	$ZHNT$	Calculated	Equation (9)
--	V	Calculated	Array of graphical plot variables
$1/E$	--	--	Used to denote a unit delayer
e	EXP		Natural logarithm as in Eq. (1)

B. THE PDP 11/34 PROGRAM(S)

This section of the report describes the digital computer implementation of the first-order system (plant) with a constant piecewise disturbance and the associated designed discrete-time DAC controller. These programs have been programmed in the FORTRAN programming language for execution by a PDP 11/34 digital computer and its operating system software. A listing of the main program is as shown in Figure 2, which contains the equations given in the previous section of the report for the constant piecewise disturbance model, the first-order plant (system) model, and the discrete-time DAC controller design model. Also contained in this listing are the equations and necessary statements for the initial conditions, values of variable parameters, and control of the program during execution.

The required plant differential equations (one in this case) are integrated by the fourth-order Runga-Kutta integration scheme as contained in its listing shown in Figure 3. This very familiar and widely used integration scheme is

$$y_{n+1} = y_n + \frac{1}{6}\left(k_0 + 2k_1 + 2k_2 + k_3\right) \tag{20}$$

where $$k_0 = h \cdot f\left(x_n, y_n\right) \tag{21}$$

$$k_1 = h \cdot f\left(x_n + \frac{1}{2}h, y_n + \frac{1}{2}k_0\right) \tag{22}$$

$$k_2 = h \cdot f\left(x_n + \frac{1}{2}h, y_n + \frac{1}{2}k_1\right) \tag{23}$$

$$k_3 = h \cdot f\left(x_n + h, y_n + k_2\right) \tag{24}$$

Table 1 is a cross index of the variables contained in the block diagram (Figure 1 and the mathematical equations written from the block diagram) and the FORTRAN program variable names contained in the listings of the designed discrete-time DAC digital computer implementation. Also, Table 1 presents the value of the variables as used in the execution of the DAC program for case 1.

The graphical plots of the dependent variables versus the independent variable time for the designed DAC controller program were obtained by the execution of the plot program as shown in the listing of Figure 4. A legend

```
C *** DAC PROGRAM EXAMPLE NUMBER 1.
C *** FIRST-ORDER SYSTEM WITH A CONSTANT DISTURBANCE.
C *** UNSTABLE SYSYTEM
      REAL K
      COMMON KUTTA, DT, NX, XT, XDT, YT
      DIMENSION V(12)
      DATA A/1.0/
      DATA B/1.0/
      DATA C/1.0/
      DATA F/1.0/
      DATA UNT/0.0/
      NX = 1
      T = 0.0
      DT = 1.0/64.0
      TSTOP = 1.0
      ITP = 0
      ST = 8.0*DT
      XINPT = 0.0
      PRINT 1021
      PRINT 20
      READ(5,21) ICN
      WRITE(2) ICN
      PRINT 23
      READ(5,1040) XT
      PRINT 80
      READ(5,1040) CWT
      PRINT 81
      READ(5,1040) AWT
      D = AWT
      PRINT 1020
    9 CONTINUE
      DO 51 KUTTA = 1,4
      YT = C*XT
      GO TO (60,50,30,40) KUTTA
   60 CONTINUE
      IF(MOD(ITP,8) .NE. 0) GO TO 62
      V(1) = XT
      V(2) = YNT
      V(3) = UNT
      V(4) = UD
      V(5) = UP
      V(6) = XINT
      V(7) = XINPT
      V(8) = TMP1
      V(9) = ZHNT
      V(10) = XDT
      V(11) = WT
      V(12) = T
      WRITE(2) V
      K = A*EXP(A*ST)/(B*(1.0 - EXP(A*ST)))
      YNT = YT
      IF(D .EQ. 0.0) TMP1 = A*YNT/(C*F*(1.0-EXP(A*ST)))
      IF (D .EQ. A) TMP1 = -((EXP(D*ST)*YNT)/(C*F*ST*EXP(A*ST)))
      IF(D .NE. 0.0 .AND. D .NE. A) TMP1 = EXP(D*ST)*(A-D)*YNT/(C*F*(EXP
     1(D*ST) - EXP(A*ST)))
      UP = (K/C)*YNT
```

Figure 2. Listing of the DAACP1 main program.

```
      XINT = XINPT
      ZHNT = XINT - TMP1
      IF(D .EQ. 0.0) UD = -(F/B)*ZHNT
      IF(D .EQ. A) UD = (A*F*ST*EXP(A*ST)*ZHNT)/(B*(1.0-EXP(A*ST)))
      IF(D .NE. 0.0 .AND. D .NE. A) UD = (A*F*(EXP(D*ST) - EXP(A*ST))*ZH
     1NT)/(B*(A-D)*(EXP(A*ST)-1.0))
      UNT = UP + UD
D     IF(T .LT. ST) UNT = UP
      IF(D .EQ. 0.0) XINPT = EXP(A*ST)*TMP1 - (B/F)*UNT
      IF(D .EQ. A) XINPT = -(EXP((A+D)*ST)*YNT)/(C*F*ST*EXP(A*ST)) -
     1 (B*EXP(D*ST)*(EXP(A*ST) - 1.0)*UNT)/(A*F*ST*EXP(A*ST))
      IF(D .NE. 0.0 .AND. D .NE. A) XINPT = ((A-D)*EXP((A+D)*ST)*YNT)/(C
     1*F*((EXP(D*ST)-EXP(A*ST)))) + (B*(A-D)*EXP(D*ST)*(EXP(A*ST)-1.0)*U
     2NT)/(A*F*EXP(D*ST)-EXP(A*ST))
   62 CONTINUE
      WT = CWT*EXP(AWT*T)
      XDT = A*XT + B*UNT + F*WT
      IF(MOD(ITP,04) .NE. 0) GO TO 61
      PRINT 1010, T, XDT, XT, YNT
      PRINT 1010, UP, UD, UNT, TMP1
      PRINT 1010, XINPT, XINT, ZHNT, K, WT
      PRINT 1021
   61 CONTINUE
      V(1) = XT
      V(2) = YNT
      V(3) = UNT
      V(4) = UD
      V(5) = UP
      V(6) = XINT
      V(7) = XINPT
      V(8) = TMP1
      V(9) = ZHNT
      V(10) = XDT
      V(11) = WT
      V(12) = T
      WRITE(2) V
   30 T = T + 0.50*DT
   40 CONTINUE
   50 CALL RUNGK
   51 CONTINUE
      ITP = ITP + 1
      IF(T .LE. TSTOP) GO TO 9
      PRINT 1030, DT, ST, WT, XT
      STOP
   20 FORMAT(/,T12,'DAC PROGRAM #1, CASE #',$)
   21 FORMAT(I2)
   23 FORMAT(T12,'INPUT XT = ',$)
   80 FORMAT(T12,'FOR EXPONENTIAL DISTURBANCE(S):',/,
     1T12,'INPUT CWT = ',$)
   81 FORMAT(T12,'INPUT AWT = ',$)
 1010 FORMAT(5(4X,E12.5))
 1020 FORMAT(/,/,T12,'DAC PROGRAM EXAMPLE NUMBER 1.',/,T12,
     1'OUTPUT FORMAT:',/,/,
     28X,'TIME',12X,'XDT',13X,'XT = YT',9X,'YNT',/,
     38X,'UP  ',12X,'UD  ',12X,'UNT ',12X,'TMP1',/,
     48X,'XINPT',11X,'XINT',12X,'ZHNT',12X,'K   ',12X,'WT',/)
```

Figure 2. Listing of the DAACP1 main program (Cont'd).

```
1021 FORMAT(1H )
1030 FORMAT(/,    T12,'CASE PARAMETERS:',/,T12,
    1'INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER',/,T12,
    2'INTEGRATION STEP SIZE: DT = ',E12.5,/,T12,
    3'SAMPLE INTERVAL: ST = ',E12.5,/,T12
    4'DISTURBANCE: WT = ',E12.5,/,T12,
    5'EQUATION FOR UNT: UNT = UP + UD',/,T12,
    6'STEADY STATE OUTPUT: X(T) = ',E12.5,/,/,/)
1040 FORMAT(F10.4)
     END
```

```
PROGRAM SECTIONS

 NAME        SIZE                   ATTRIBUTES

$CODE1  003330   876                RW,I,CON,LCL
$PDATA  000012     5                RW,D,CON,LCL
$IDATA  001050   276                RW,D,CON,LCL
$VARS   000204    66                RW,D,CON,LCL
$TEMPS  000010     4                RW,D,CON,LCL
.$$$$.  000024    10                RW,D,OVR,GBL

TOTAL SPACE ALLOCATED = 004652  1237
```

Figure 2. Listing of the DAACP1 main program (Concluded).

```
      SUBROUTINE RUNGK
      COMMON KUTTA, DT, NX, X, DX
      DIMENSION X(1), DX(1), XA(1), DXA(1)
      GO TO (10,30,50,70),KUTTA
   10 DO 20 I = 1,NX
      XA(I) = X(I)
      DXA(I) = DT*DX(I)
   20 X(I) = X(I) + 0.5*DXA(I)
      RETURN
   30 TDT = 2.0*DT
      HDT = 0.5*DT
      DO 40 I = 1,NX
      DXA(I) = DXA(I) + TDT*DX(I)
   40 X(I) = XA(I) + HDT*DX(I)
      RETURN
   50 DO 60 I = 1,NX
      VDT = DT*DX(I)
      DXA(I) = DXA(I) + 2.0*VDT
   60 X(I) = XA(I) + VDT
      RETURN
   70 DO 80 I = 1,NX
   80 X(I) = XA(I) + (DXA(I) + DT*DX(I))/6.0
      RETURN
      END
```

PROGRAM SECTIONS

NAME	SIZE		ATTRIBUTES
$CODE1	000510	164	RW,I,CON,LCL
$PDATA	000012	5	RW,D,CON,LCL
$VARS	000026	11	RW,D,CON,LCL
.$$$$.	000020	8	RW,D,OVR,GBL

TOTAL SPACE ALLOCATED = 000570   188

Figure 3. Listing of Runga-Kutta integration routine.

```
C *** GENERALIZED PLOTTING PROGRAM - FOR DACS.
      DIMENSION V(12)
      DIMENSION PT(1025)
      DIMENSION PXT(1025)
      INTEGER*2 DRAW, LOOP
      REWIND 2
      READ (2) ICN
      PRINT 22, ICN
      PRINT 100
      PRINT 32
      PRINT 23
      READ(5,21) DRAW
      IF(DRAW .EQ. 'Y') CALL HDCOPY
      CALL ST7611
      CALL INITT(240)
      DO 20 J = 1,12
      REWIND 2
      PRINT 30
      READ (5,31) NOP
      READ (2) ICN
      CALL NEWPAG
      PRINT 122, NOP, ICN
      DO 10 I = 1,1025
      READ(2,END=66) V
      PT(I) = V(12)
      PXT(I) = V(NOP)
      NP = I
   10 CONTINUE
   66 CONTINUE
      CALL BINITT
      CALL NPTS(NP)
      CALL SYMBL(1)
      CALL SIZES(0.50)
      CALL CHECK(PT,PXT)
      CALL DSPLAY(PT,PXT)
      CALL MOVABS(100,50)
      CALL ANMODE
      PRINT 23
      READ (5,21) DRAW
      IF(DRAW .EQ. 'Y') CALL HDCOPY
      CALL NEWPAG
      PRINT 33
      READ(5,21) LOOP
      IF(LOOP .EQ. 'Y') GO TO 20
      CALL HT7611
      REWIND 2
      STOP
   20 CONTINUE
   21 FORMAT(A1)
   22 FORMAT(T12,'DAC PROGRAM #1; CASE #',I2)
  122 FORMAT(T15,'PLOT NO. ',I2,'; DAC PROGRAM #1, CASE #',I2,'.')
   23 FORMAT(1X,'*',$)
   30 FORMAT(/,/,1X,'ENTER # OF PLOT(S) WANTED (UP TO 12) ',$)
   31 FORMAT(I3)
   32 FORMAT(1X,'AFTER STAR APPEARS ON THE DISPLAY',/,1X,
     1'ENTER A .Y. AND A .CR. TO DRAW A HARDCOPY OF THE DISPLAY.')
```

Figure 4. Listing of the graphical plot program.

```
0055        33 FORMAT(/,/,' ANY MORE GRAPHS? ',$)
0056       100 FORMAT(/,/,T12,'LEGEND TO THE PLOT(S):',/,T12,
              *'----------------------',/,T12,
              1'PLOT NO.  1: - X(T)  VERSUS TIME.',/,T12,
              2'PLOT NO.  2: - Y(NT) VERSUS TIME.',/,T12,
              3'PLOT NO.  3: - U(NT) VERSUS TIME.',/,T12,
              4'PLOT NO.  4: - UD    VERSUS TIME.',/,T12,
              5'PLOT NO.  5: - UP    VERSUS TIME.',/,T12,
              6'PLOT NO.  6: - XINT  VERSUS TIME.',/,T12,
              7'PLOT NO.  7: - XINPT VERSUS TIME.',/,T12,
              8'PLOT NO.  8: - TMP1  VERSUS TIME.',/,T12,
              9'PLOT NO.  9: - ZHNT  VERSUS TIME.',/,T12,
              A'PLOT NO. 10: - XDT   VERSUS TIME.',/,T12,
              B'PLOT NO. 11: - W(T)  VERSUS TIME.',/,T12,
              C'PLOT NO. 12: - TIME  VERSUS TIME.',/,/,/)
0057           END
```

PROGRAM SECTIONS

NAME	SIZE		ATTRIBUTES
$CODE1	001152	309	RW,I,CON,LCL
$PDATA	000024	10	RW,D,CON,LCL
$IDATA	001452	405	RW,D,CON,LCL
$VARS	020106	4131	RW,D,CON,LCL

TOTAL SPACE ALLOCATED = 022756   4855

Figure 4. Listing of the graphical plot program (Concluded).

to the graphical plots capable of being output by this plot program from the DAC controller program is shown in Table 2.

C. PROGRAM EXECUTION

This section of the report presents the necessary operating system software *control commands* for the PDP-11/34 digital computer to execute the designed DAC controller program implementation. Before the program--any program, for that matter--can be executed by the PDP-11/34 computer, a task for the program must be created. Therefore, included in this section will be the necessary control commands to create the task of the discrete-time DAC controller program described in the previous sections of this report.

The following assumptions are assumed concerning these control commands:

1. The operating system has been *booted in* the computer.
2. The proper user identification code (UIC) has been set.
3. The program(s) exists on the disk pack in source code. (The program name is DDACP1.FTN.)

Then the control commands contained in Table 3 may be input to the operating system by the terminal operator onto which the operating system is *logged in* to create the task for the DDACP1.TSK program.

To execute the task of DDACP1.TSK at the present session, or any future session, the operator must input the control commands shown in Table 4 onto the input terminal.

A similar list of control commands must also be input for the graphical plot program. However, this source and task program is given the file name *DACTKP*. It is further assumed that the DACTKP task is *logged in* by the user onto the graphics display terminal (device TT1:). This list of commands is as shown in Table 5.

III. RESULTS OF EXECUTION

This section of the report presents the results of the DAC design example implementation and its execution by the PDP-11/34 digital computer. The output resulting from the FORTRAN *READ* and *WRITE* statements are as contained in Figure 5. These results are also contained in the plots of the variable versus time as shown in Figures 6 through 17. The significance of the symbol *0* on the plots (graphs) is that the symbol appears at every *DT* seconds; that is, when the value of Kutta = 1.

TABLE 2. LEGEND TO THE GRAPHICAL PLOTS

```
LEGEND TO THE PLOT(S):
----------------------
PLOT NO.  1: - X(T)  VERSUS TIME.
PLOT NO.  2: - Y(NT) VERSUS TIME.
PLOT NO.  3: - U(NT) VERSUS TIME.
PLOT NO.  4: - UD    VERSUS TIME.
PLOT NO.  5: - UP    VERSUS TIME.
PLOT NO.  6: - XINT  VERSUS TIME.
PLOT NO.  7: - XINPT VERSUS TIME.
PLOT NO.  8: - TMP1  VERSUS TIME.
PLOT NO.  9: - ZHNT  VERSUS TIME.
PLOT NO. 10: - XDT   VERSUS TIME.
PLOT NO. 11: - W(T)  VERSUS TIME.
PLOT NO. 12: - TIME  VERSUS TIME.
```

TABLE 3. A TYPICAL LIST OF TASK CREATION COMMANDS

```
F4P DDACP1.OBJ = DDACP1.FTN
TKB DDACP1.TSK = DDACP1.OBJ
PIP DDACP1.*;*/PU
PIP DDACP1.OBJ;*/DE
PIP DDACP1.*;*/LI
```

TABLE 4. A TYPICAL LIST OF TASK EXECUTION COMMANDS

```
INS DDACP1
LUN DDACP1
REA DDACP1 5 TI:
REA DDACP1 6 TI:
LUN DDACP1
RUN DDACP1
PIP FOR002.*;*/PU
```

TABLE 5. GRAPHICAL PLOT PROGRAM TASK CREATION COMMANDS

```
>F4P DACTKP.OBJ=DACTKP.FTN,NEWPAG.FTN
>TKB
TKB>DACTKP.TSK=DACTKP.OBJ,[277,4]AG2.OLB/LB
TKB>/
ENTER OPTIONS:
TKB>ASG = TT1:1
TKB>ASG = TT1*\*\:6
TKB>ASG = TT1:5
TKB>//
>
```

```
DAC PROGRAM #1, CASE #1
INPUT XT = 1.0
FOR EXPONENTIAL DISTURBANCE(S):
INPUT CWT = 1.0
INPUT AWT = 0.0

DAC PROGRAM EXAMPLE NUMBER 1.
OUTPUT FORMAT:

   TIME            XDT             XT = YT         YNT
   UP              UD              UNT             TMP1
   XINPT           XINT            ZHNT            K               WT

 0.00000E+00    -0.14021E+02     0.10000E+01     0.10000E+01
-0.85104E+01    -0.75104E+01    -0.16021E+02    -0.75104E+01
 0.75104E+01     0.00000E+00     0.75104E+01    -0.85104E+01     0.10000E+01

 0.62500E-01    -0.14918E+02     0.10294E+00     0.10000E+01
-0.85104E+01    -0.75104E+01    -0.16021E+02    -0.75104E+01
 0.75104E+01     0.00000E+00     0.75104E+01    -0.85104E+01     0.10000E+01

 0.12500E+00     0.62799E+01    -0.85150E+00    -0.85150E+00
 0.72467E+01    -0.11153E+01     0.61314E+01     0.63951E+01
 0.11153E+01     0.75104E+01     0.11153E+01    -0.85104E+01     0.10000E+01

 0.18750E+00     0.66817E+01    -0.44972E+00    -0.85150E+00
 0.72467E+01    -0.11153E+01     0.61314E+01     0.63951E+01
 0.11153E+01     0.75104E+01     0.11153E+01    -0.85104E+01     0.10000E+01

 0.25000E+00     0.21853E+00    -0.22222E-01    -0.22222E-01
 0.18912E+00    -0.94837E+00    -0.75925E+00     0.16690E+00
 0.94837E+00     0.11153E+01     0.94837E+00    -0.85104E+01     0.10000E+01

 0.31250E+00     0.23251E+00    -0.82408E-02    -0.22222E-01
 0.18912E+00    -0.94837E+00    -0.75925E+00     0.16690E+00
 0.94837E+00     0.11153E+01     0.94837E+00    -0.85104E+01     0.10000E+01

 0.37500E+00    -0.48036E-01     0.66351E-02     0.66351E-02
-0.56467E-01    -0.99820E+00    -0.10547E+01    -0.49832E-01
 0.99820E+00     0.94837E+00     0.99820E+00    -0.85104E+01     0.10000E+01

 0.43750E+00    -0.51109E-01     0.35618E-02     0.66351E-02
-0.56467E-01    -0.99820E+00    -0.10547E+01    -0.49832E-01
 0.99820E+00     0.94837E+00     0.99820E+00    -0.85104E+01     0.10000E+01

 0.50000E+00    -0.25864E-02     0.29179E-03     0.29179E-03
-0.24832E-02    -0.10004E+01    -0.10029E+01    -0.21914E-02
 0.10004E+01     0.99820E+00     0.10004E+01    -0.85104E+01     0.10000E+01

 0.56250E+00    -0.27518E-02     0.12631E-03     0.29179E-03
-0.24832E-02    -0.10004E+01    -0.10029E+01    -0.21914E-02
 0.10004E+01     0.99820E+00     0.10004E+01    -0.85104E+01     0.10000E+01
```

Figure 5. Listing of output results from DAC program #1 execution, case #1.

0.62500E+00	0.35244E-03	-0.49753E-04	-0.49753E-04	
0.42342E-03	-0.10000E+01	-0.99960E+00	0.37366E-03	
0.10000E+01	0.10004E+01	0.10000E+01	-0.85104E+01	0.10000E+01
0.68750E+00	0.37503E-03	-0.27202E-04	-0.49753E-04	
0.42342E-03	-0.10000E+01	-0.99960E+00	0.37366E-03	
0.10000E+01	0.10004E+01	0.10000E+01	-0.85104E+01	0.10000E+01
0.75000E+00	0.26941E-04	-0.32079E-05	-0.32079E-05	
0.27301E-04	-0.10000E+01	-0.99997E+00	0.24093E-04	
0.10000E+01	0.10000E+01	0.10000E+01	-0.85104E+01	0.10000E+01
0.81250E+00	0.28670E-04	-0.14841E-05	-0.32079E-05	
0.27301E-04	-0.10000E+01	-0.99997E+00	0.24093E-04	
0.10000E+01	0.10000E+01	0.10000E+01	-0.85104E+01	0.10000E+01
0.87500E+00	-0.23842E-05	0.35064E-06	0.35064E-06	
-0.29841E-05	-0.10000E+01	-0.10000E+01	-0.26335E-05	
0.10000E+01	0.10000E+01	0.10000E+01	-0.85104E+01	0.10000E+01
0.93750E+00	-0.25034E-05	0.19791E-06	0.35064E-06	
-0.29841E-05	-0.10000E+01	-0.10000E+01	-0.26335E-05	
0.10000E+01	0.10000E+01	0.10000E+01	-0.85104E+01	0.10000E+01
0.10000E+01	-0.35763E-06	0.35856E-07	0.35856E-07	
-0.30515E-06	-0.10000E+01	-0.10000E+01	-0.26929E-06	
0.10000E+01	0.10000E+01	0.10000E+01	-0.85104E+01	0.10000E+01

```
CASE PARAMETERS:
INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER
INTEGRATION STEP SIZE: DT =  0.15625E-01
SAMPLE INTERVAL: ST =  0.12500E+00
DISTURBANCE: WT =  0.10000E+01
EQUATION FOR UNT: UNT = UP + UD
STEADY STATE OUTPUT: X(T) =  0.30268E-07
```

Figure 5. Listing (concluded).

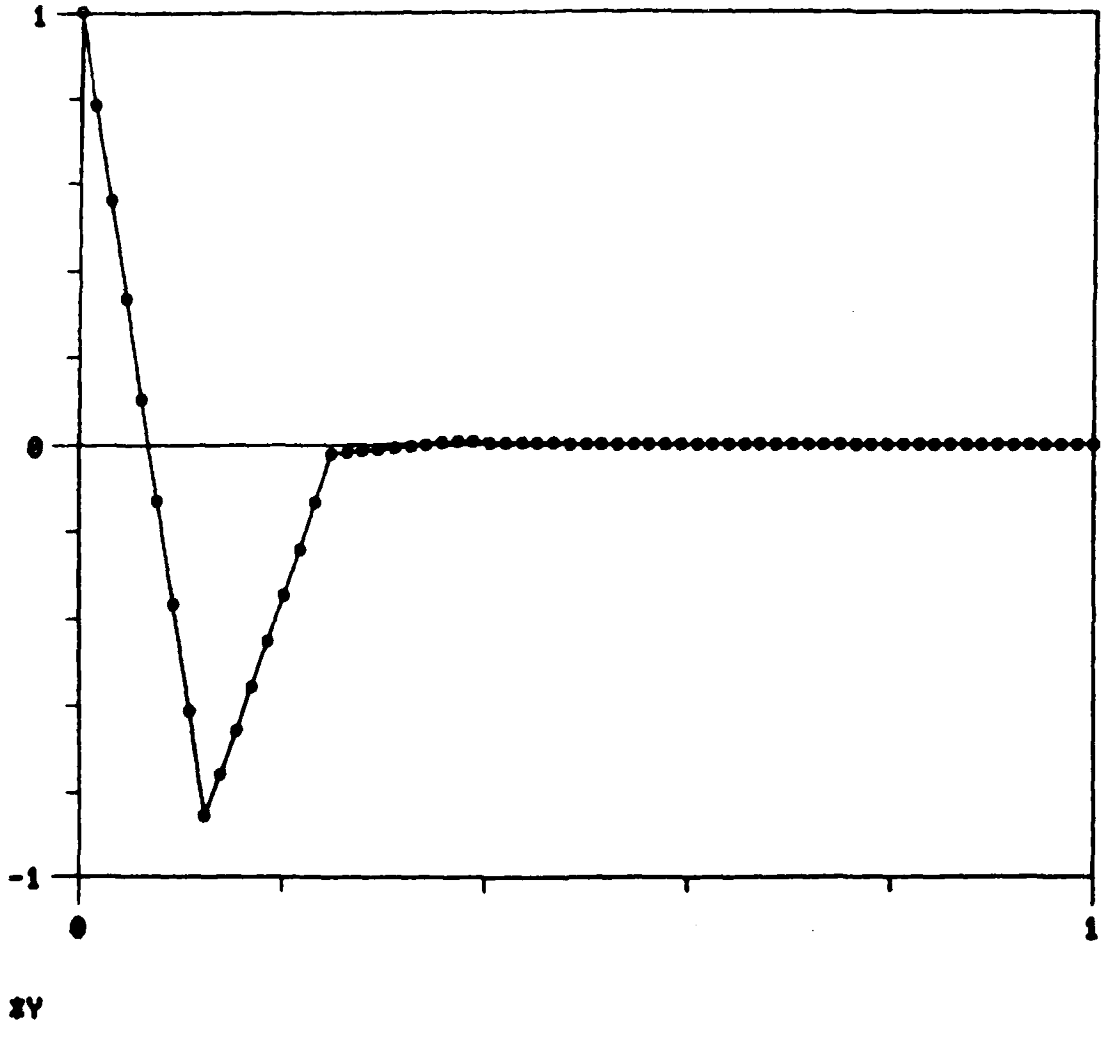


Figure 6. Plot No. 1 DAC program #1, Case #1.

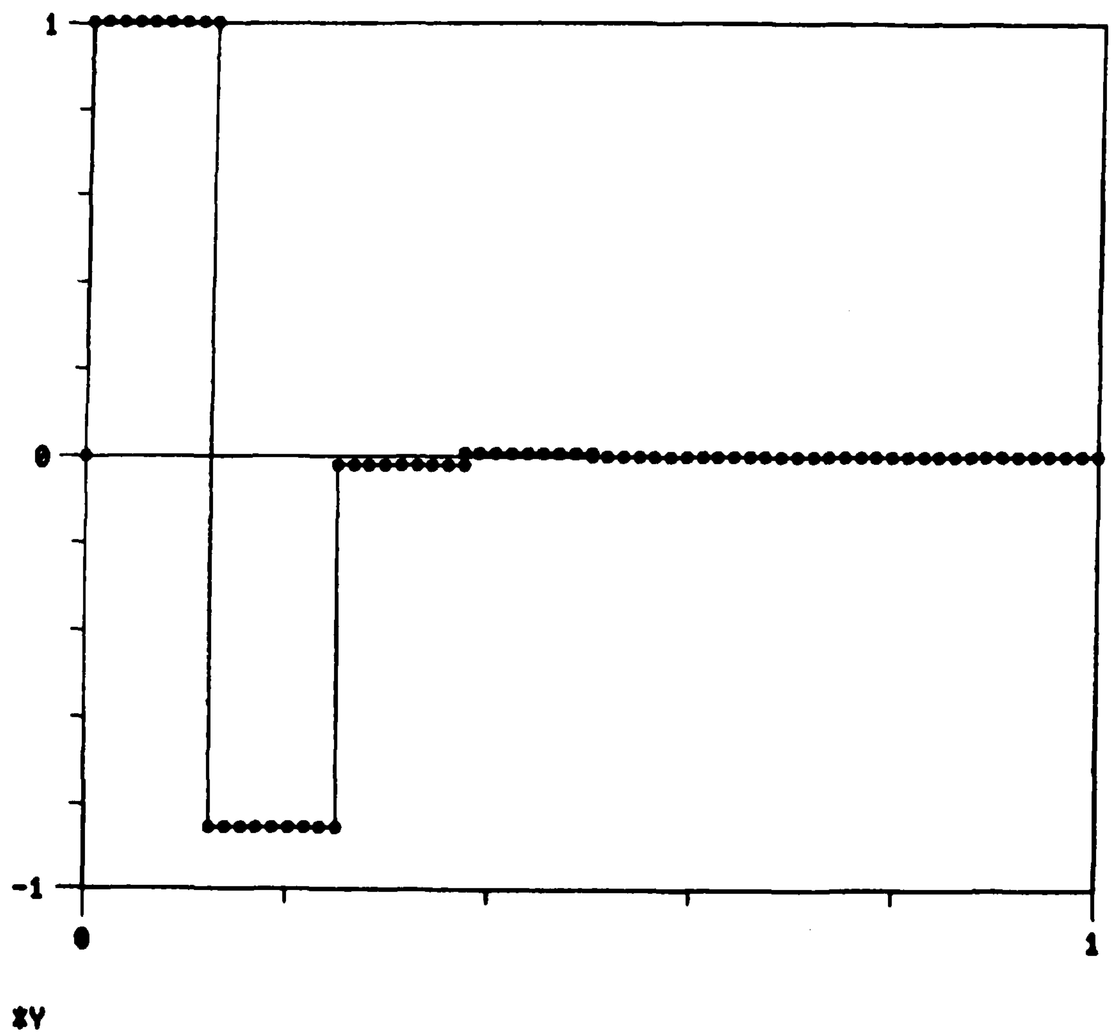


Figure 7. Plot No. 2, DAC program #1, Case #1.

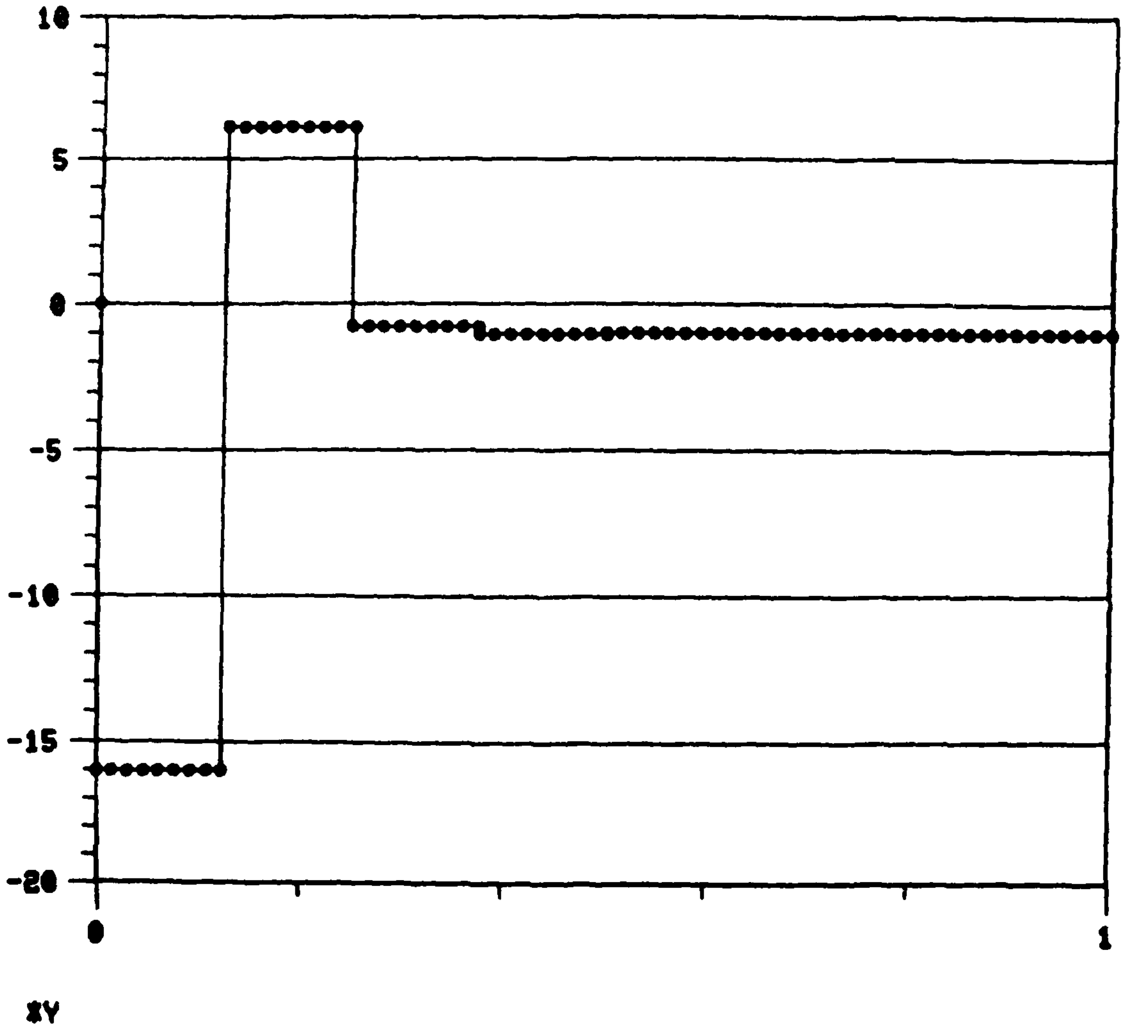


Figure 8. Plot No. 3, DAC program #1, Case #1.

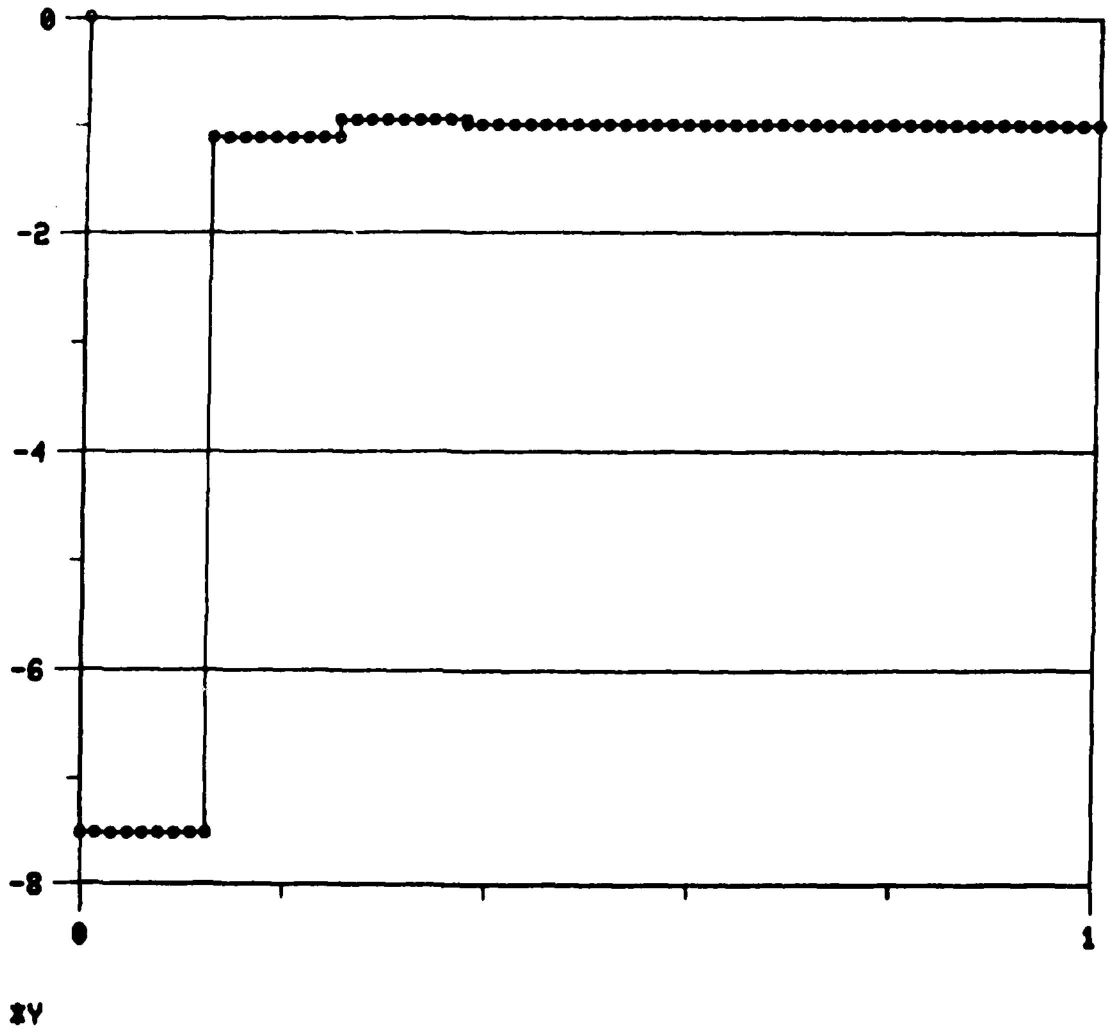


Figure 9. Plot No. 4, DAC program #1, Case #1.

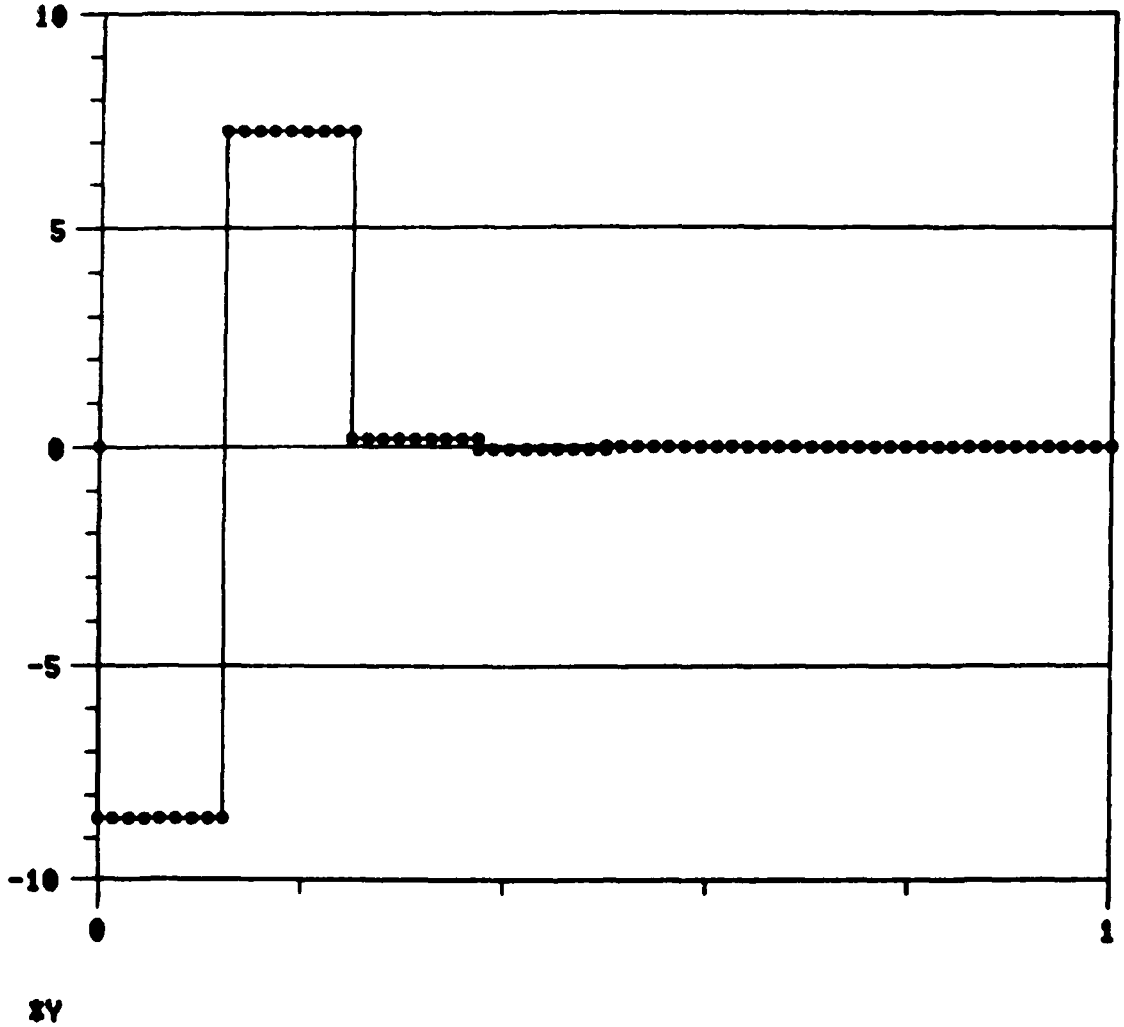


Figure 10. Plot No. 5, DAC program #1, Case #1.

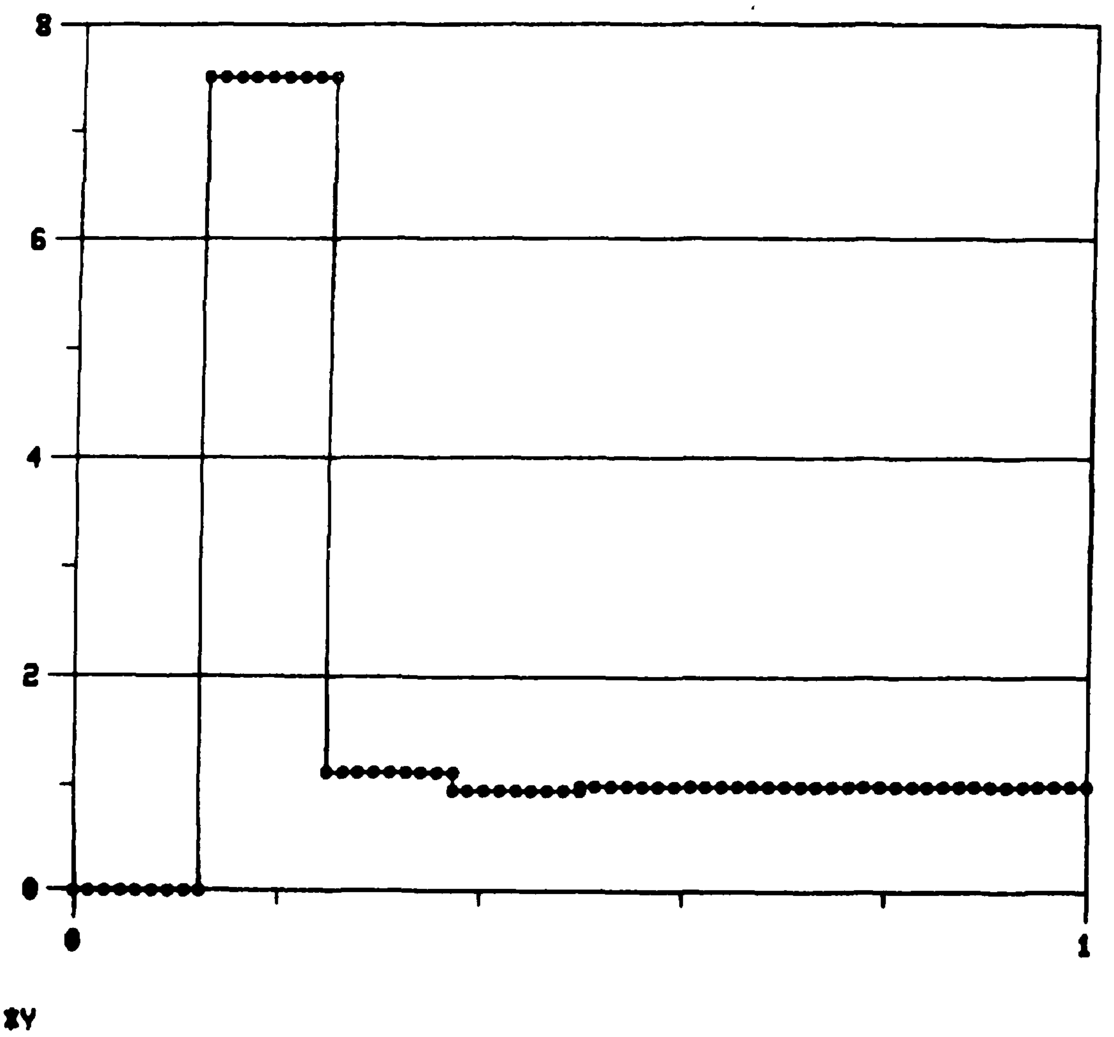


Figure 11. Plot No. 6, DAC Program #1, Case #1.

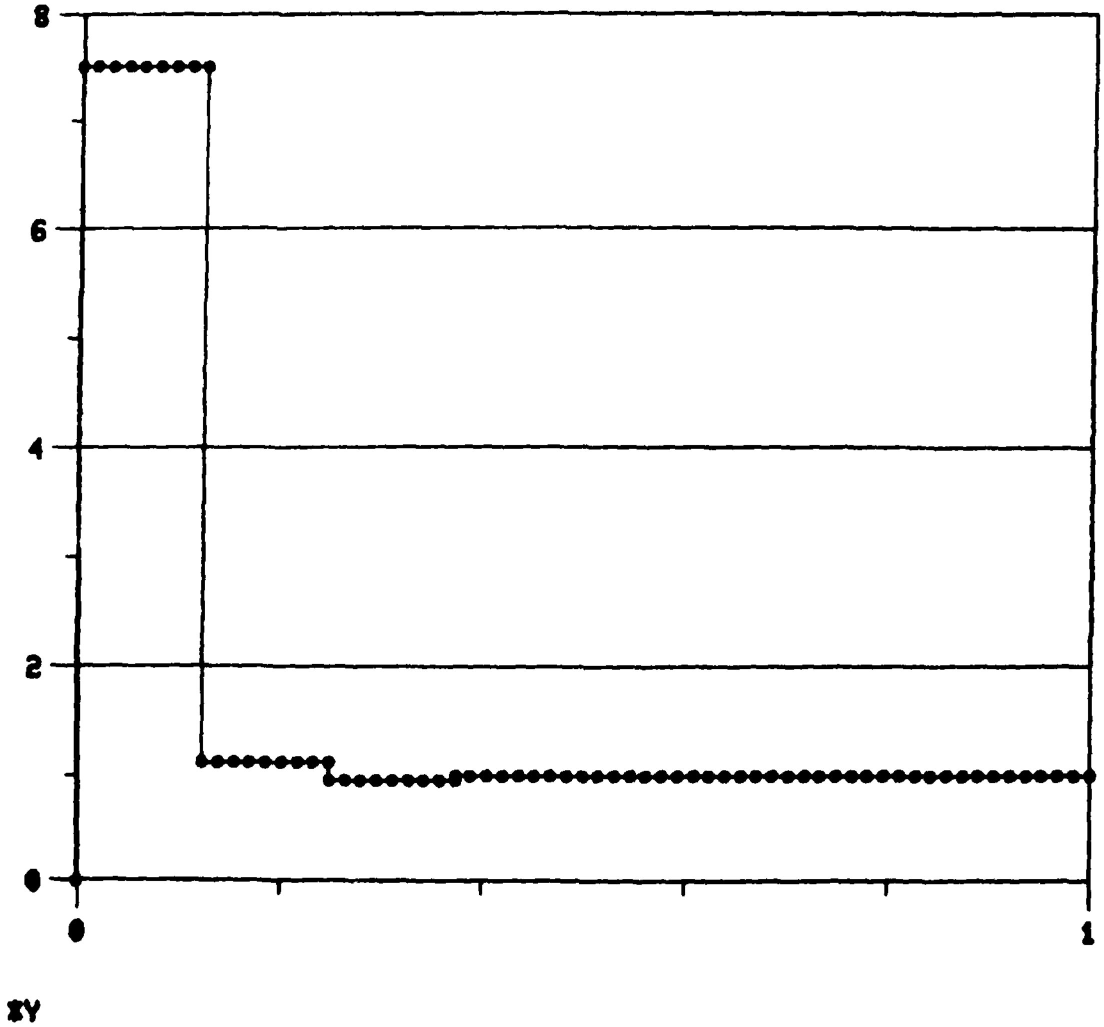


Figure 12. Plot No. 7, DAC Program #1, Case #1.

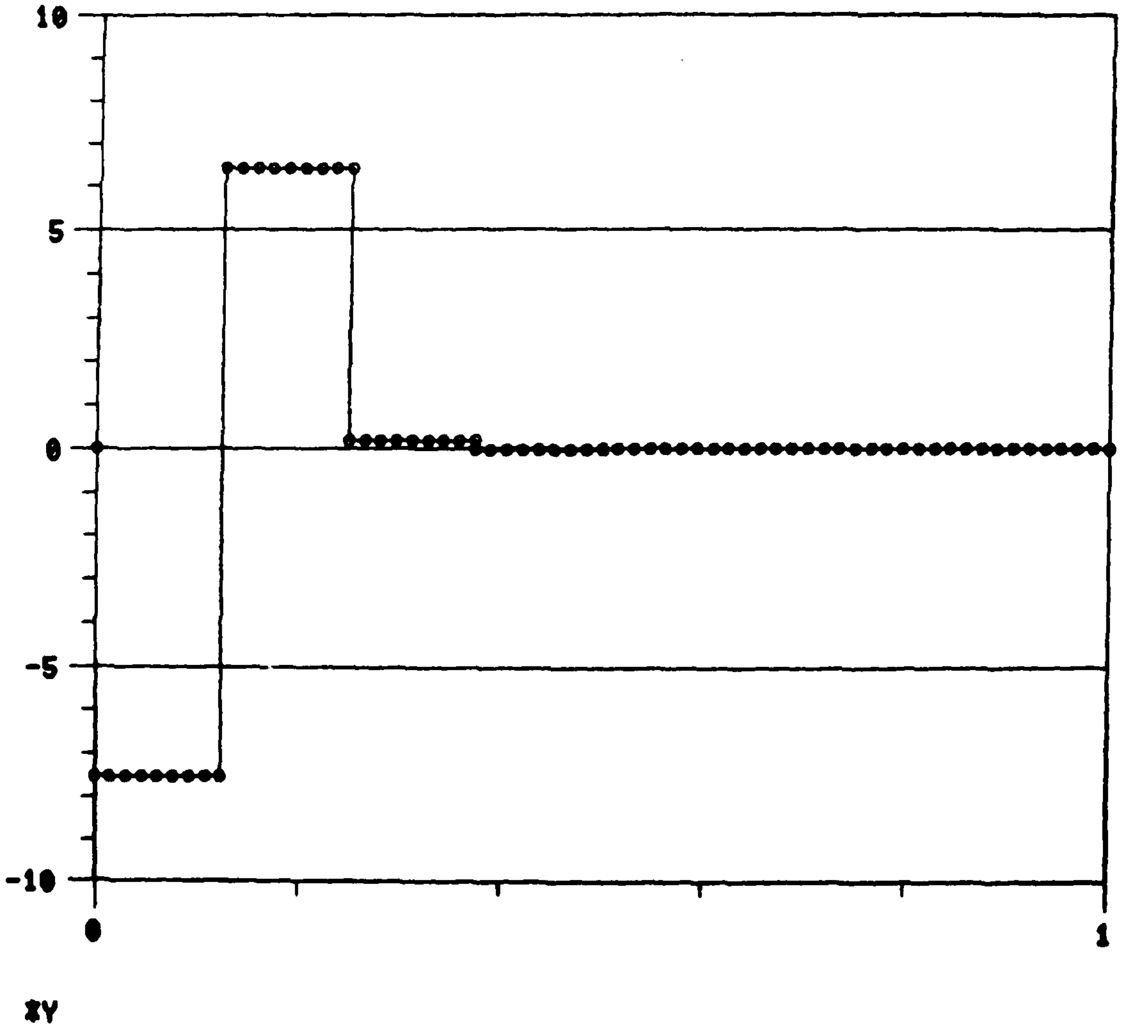


Figure 13. Plot No. 8, DAC program #1, Case #1.

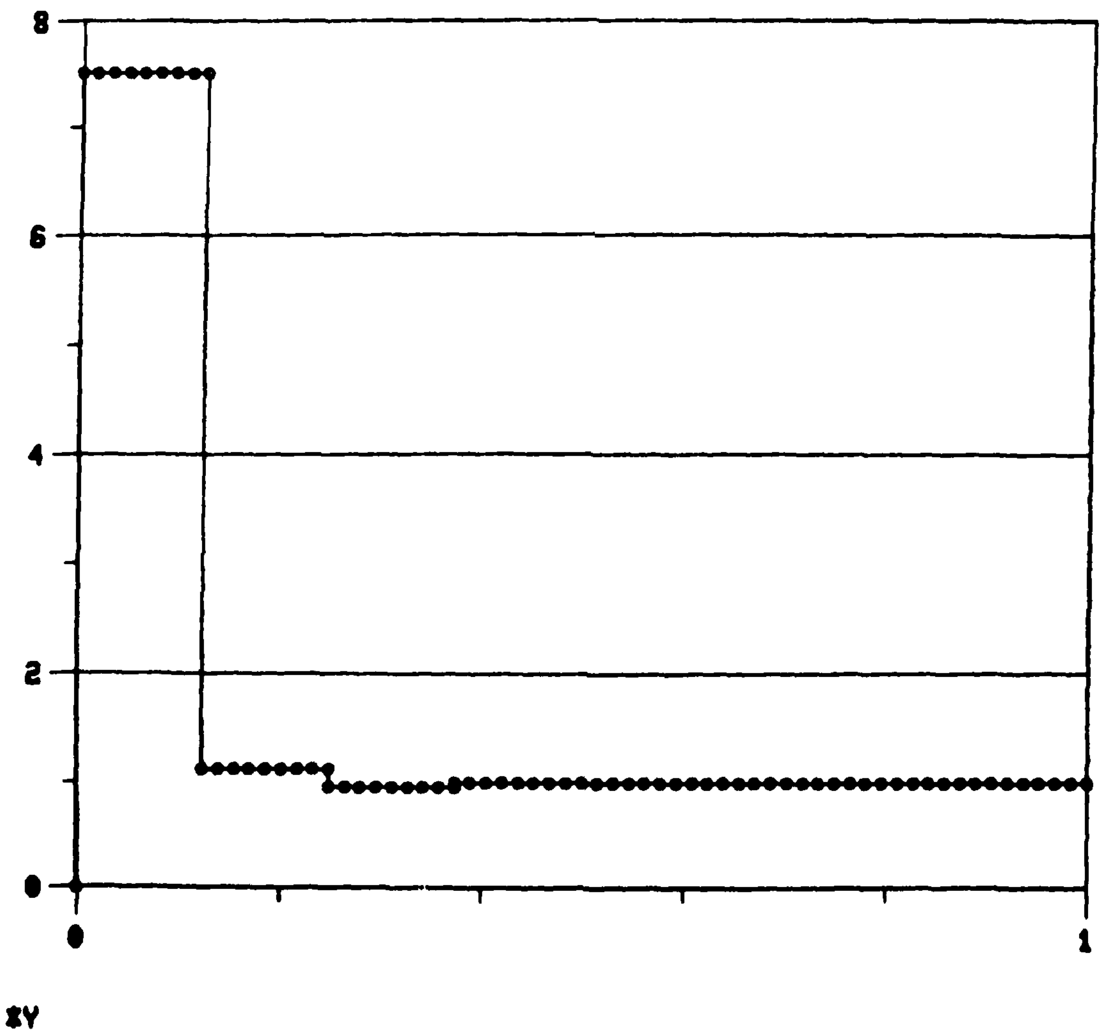


Figure 14. Plot No. 9, DAC program #1, Case #1.

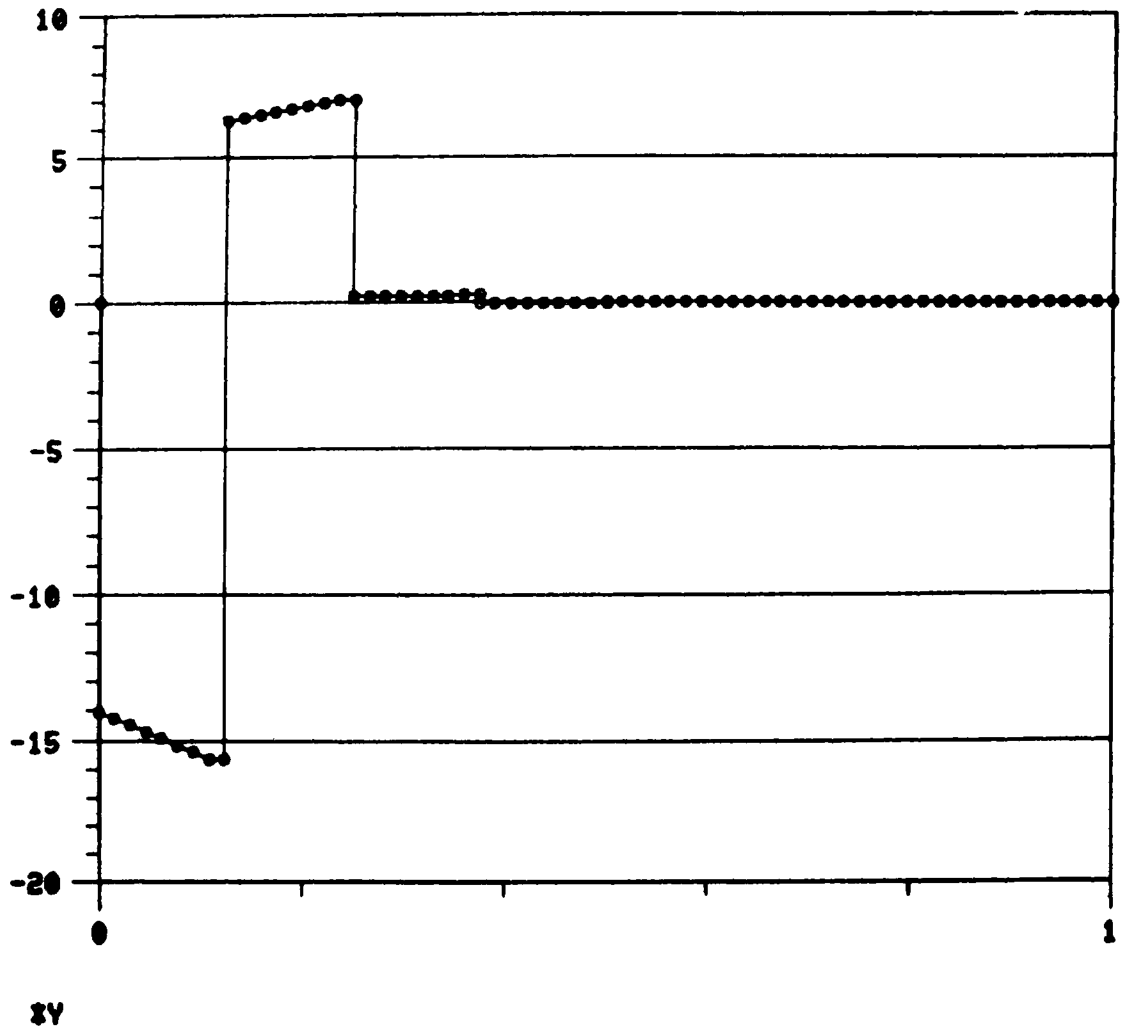


Figure 15. Plot No. 10, DAC program #1, Case #1.

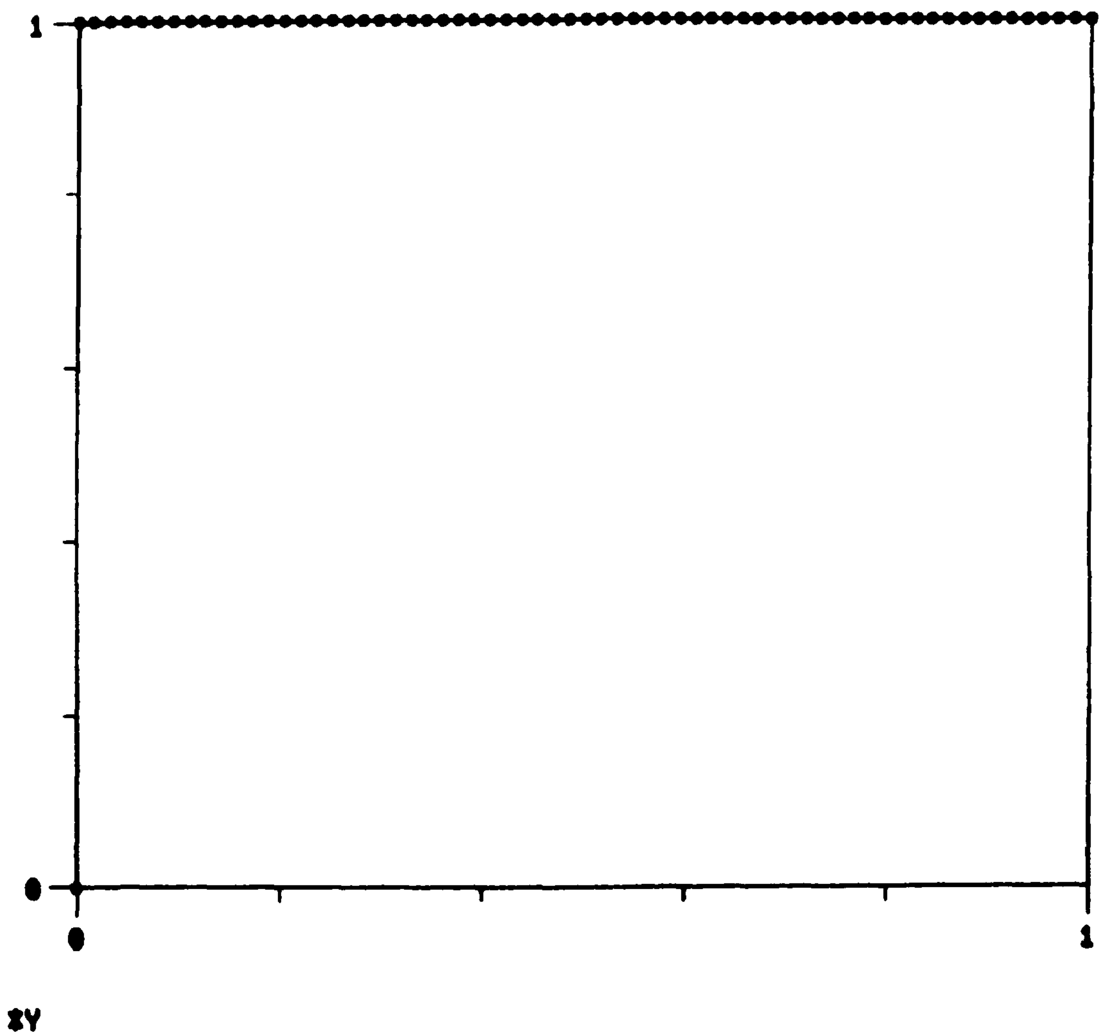


Figure 16. Plot No. 11, DAC program #1, Case #1.

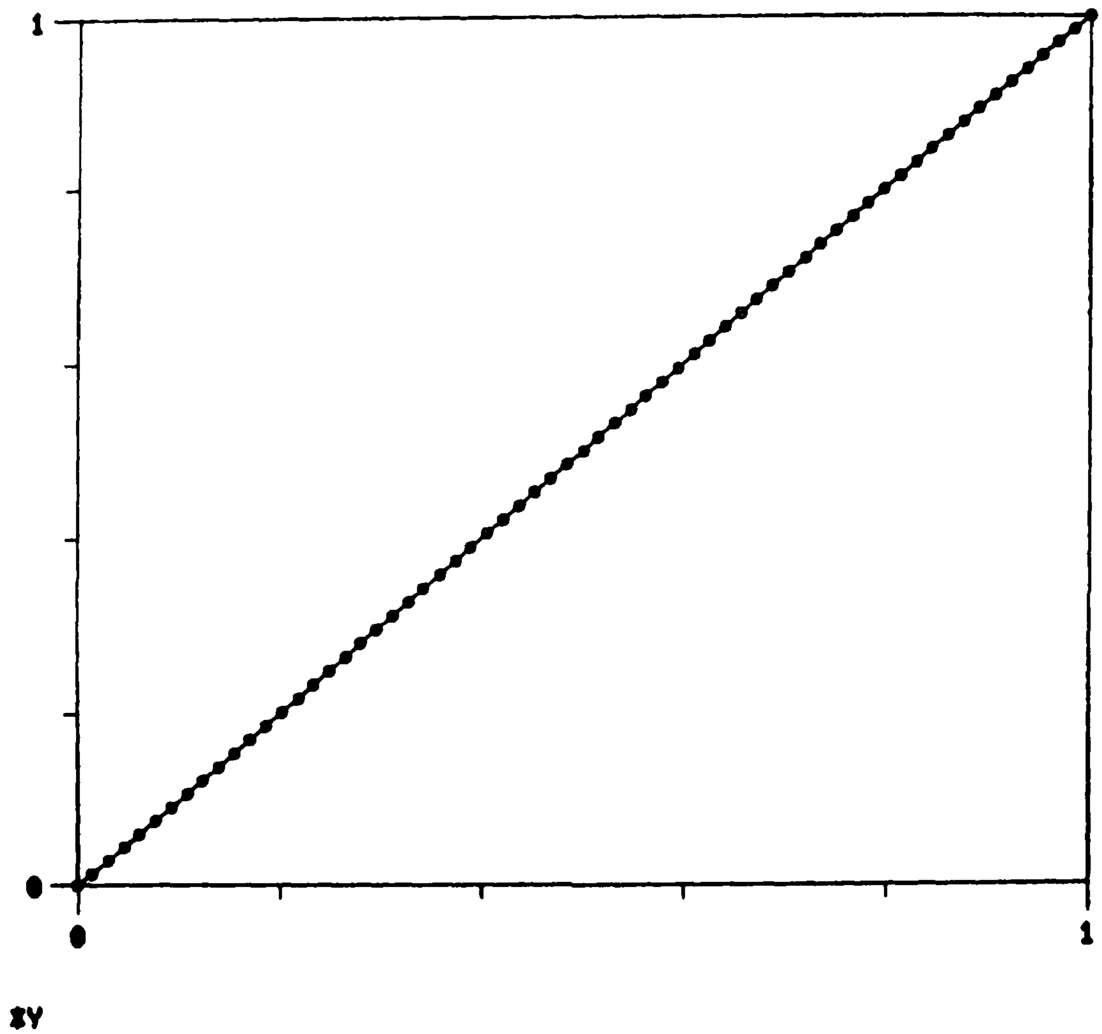


Figure 17. Plot No. 12, DAC program #1, Case #1.

In addition to the previous results, other executions were performed. These executions, along with the previous resulting execution, may be summarized as in Table 6, and the resulting graphical plots output are as shown in the *Associated Figures* column in the table. Other executions have been performed with similar results; however, the resulting plots appear to be of the same general shape and form as those presented within this report.

As can be seen from the comparison of the resultant output listing and plots of Case 1 with Case 46, the results have the same magnitudes of data but are opposite in sign. Notice that Case 46 has the identical input data as Case 1 except for the opposite signs; they are mirror images of each other. Similar results have been obtained for other cases, such as Case 31 when compared to Case 32, the result of which is contained in this report also.

IV. CONCLUSIONS

The study described in this document consititutes the first application and published results of the discrete-time DAC theory to control systems. This section of the report presents the conclusions of this study and offers recommendations for further investigations. The present study has shown the cancellation (absorption) of disturbance effects for the discrete-time DAC applied to a control system for stabilization.

The digital computer implementation for the design of the DAC's arrived at for this example problem (using the methods developed in the appendix) performed, in each case of disturbance, those functions which it was designed to perform. The effects of the disturbance inputs were cancelled out by that portion of the controller which was designed specifically to handle a given waveform mode disturbance. When the impulse train was not of too high a frequency, the errors engendered by the disturbance were settled out very well.

A unique digital computer analysis tool (DDACP1--Discrete-Time Disturbance Accommodating Control Program 1) has been developed for implementing the DAC control laws, the equations of the plant being controlled, and disturbance models. Also, a graphical plot program has been developed, whereby graphical plots of any dependent variable versus time may be obtained. Both of these programs are highly ineractive with the computer user. Additionally, the graphical plot program may be of benefit in obtaining plots of output data from other programs as well as the DAC design program(s).

TABLE 6. SUMMARY OF DAC PROGRAM IMPLEMENTATION EXECUTION RESULTS OBTAINED IN THIS REPORT

				ASSOCIATED FIGURES	
CASE NO.	XT AT T = 0	CWT	AWT	OUTPUT LISTING	GRAPHICAL PLOTS
1	1.0	1.0	0.0	5	6 Through 17
2	1.0	1.0	1.0	18	19 Through 21
3	1.0	1.0	3.0	22	23 Through 25
4	1.0	1.0	10.0	26	27 Through 29
10[1]	1.0	1.0	0.0	30	31 Through 33
20[2]	1.0	-	-	34	35 Through 45
29	0.0	1.0	0.0	46	47 Through 48
31[3]	1.0	1.0	0.0	49	50 Through 59
32[3]	-1.0	-1.0	0.0	60	61 Through 64
46	-1.0	-1.0	0.0	65	66 Through 69

[1] WT includes a random noise between ± 1 input with a random number generator subroutine.

[2] The constant piecewise disturbance was programmed within the main discrete-time DAC program as a function of time by the usage of the FORTRAN IF statement.

[3] The program contains the statement: IF (T . LT. ST) UNT = UP. This statement prevents the "overshoot" in the plant (system) output variable X, and hence, Y.

It is suggested that future study and investigation be directed to the following areas:

1. The non-zero set-point regulator control problem.

2. The servo-tracking control problem.

3. The design of a discrete-time DAC for a general second-order plant (system) with a first-order disturbance.

4. The applications of discrete-time DAC to a discrete control problem. (This would be beneficial in view of the trend toward using sampled-data and microprocessor techniques in future designs.) These may include pointing and tracking of designators, gun pointing, autopilot disturbance compensation and guidance algorithm design.

```
DAC PROGRAM #1, CASE #2
INPUT XT = 1.0
FOR EXPONENTIAL DISTURBANCE(S):
INPUT CWT = 1.0
INPUT AWT = 1.0


DAC PROGRAM EXAMPLE NUMBER 1.
OUTPUT FORMAT:

 TIME            XDT             XT = YT          YNT
 UP              UD              UNT              TMP1
 XINPT           XINT            ZHNT             K                WT

 0.00000E+00    -0.15021E+02     0.10000E+01      0.10000E+01
-0.85104E+01    -0.85104E+01    -0.17021E+02     -0.80000E+01
 0.90652E+01     0.00000E+00     0.80000E+01     -0.85104E+01      0.10000E+01

 0.10000E+01    -0.15099E+00     0.37253E-07      0.37253E-07
-0.31704E-06    -0.28693E+01    -0.28693E+01     -0.29802E-06
 0.30563E+01     0.26972E+01     0.26972E+01     -0.85104E+01      0.27183E+01


CASE PARAMETERS:
INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER
INTEGRATION STEP SIZE: DT =  0.15625E-01
SAMPLE INTERVAL: ST =  0.12500E+00
DISTURBANCE: WT =  0.27183E+01
EQUATION FOR UNT: UNT = UP + UD
STEADY STATE OUTPUT: X(T) = -0.23591E-02
```

Figure 18. Output listing (condensed) of results, Case #2.

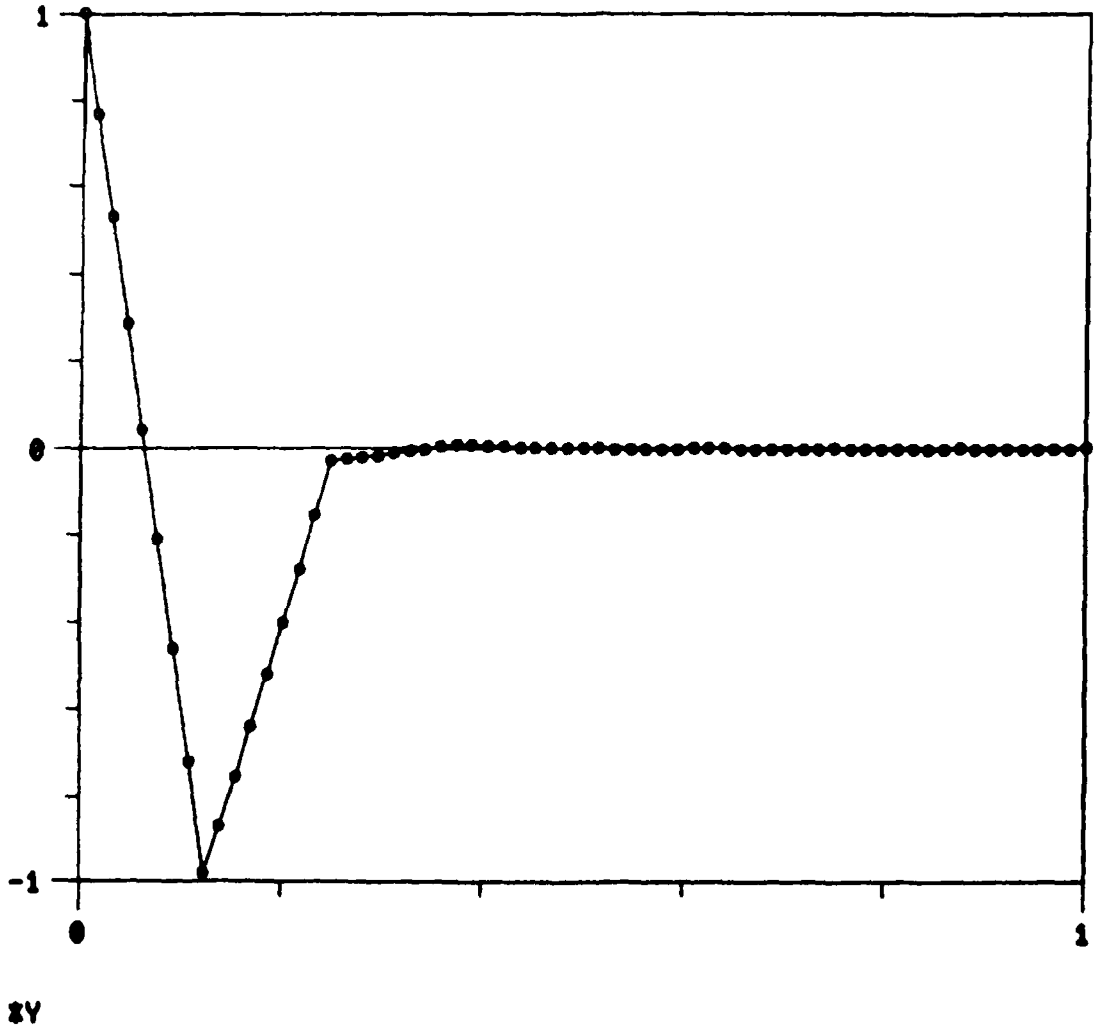


Figure 19. Plot No. 1, DAC program #1, Case #2.

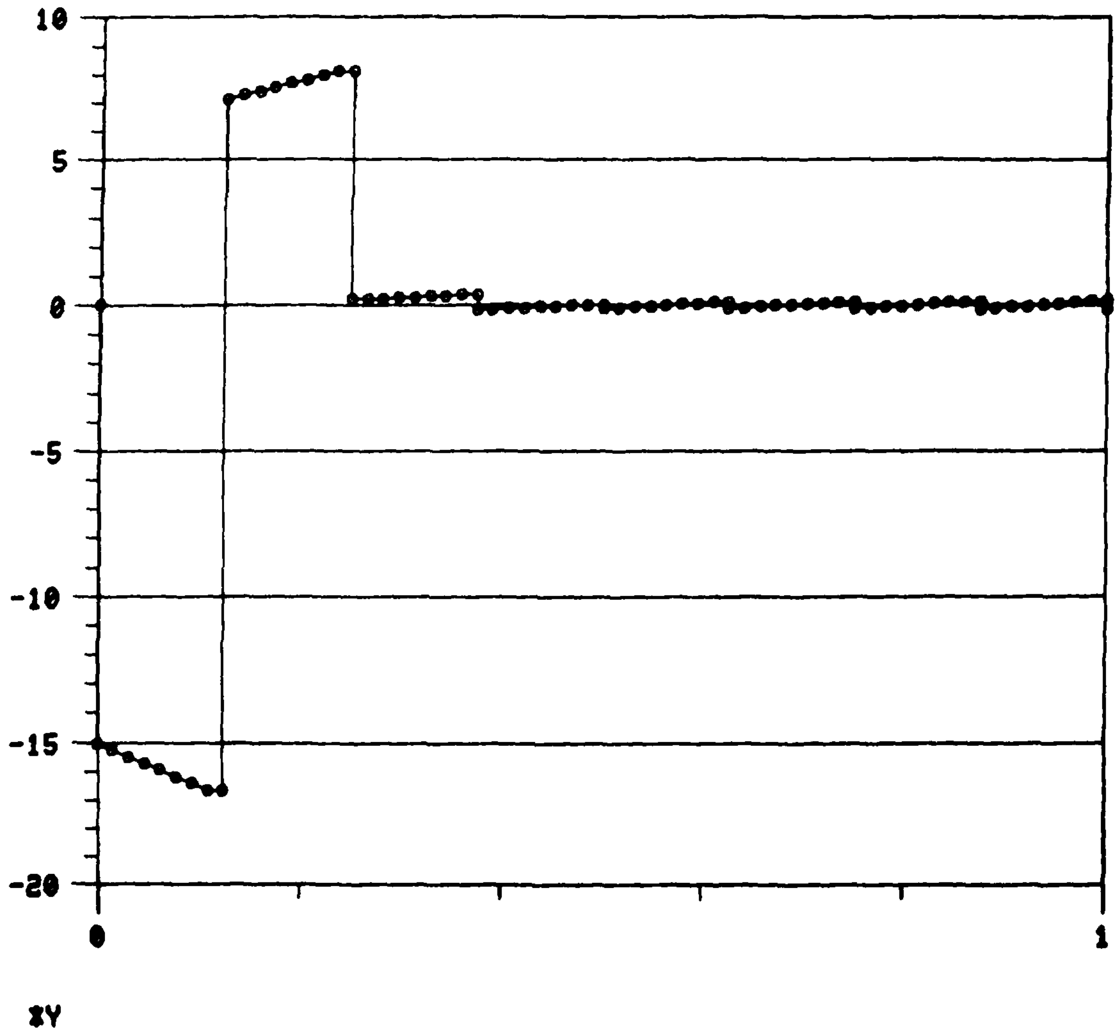


Figure 20. Plot No. 1, DAC program #1, Case #2.

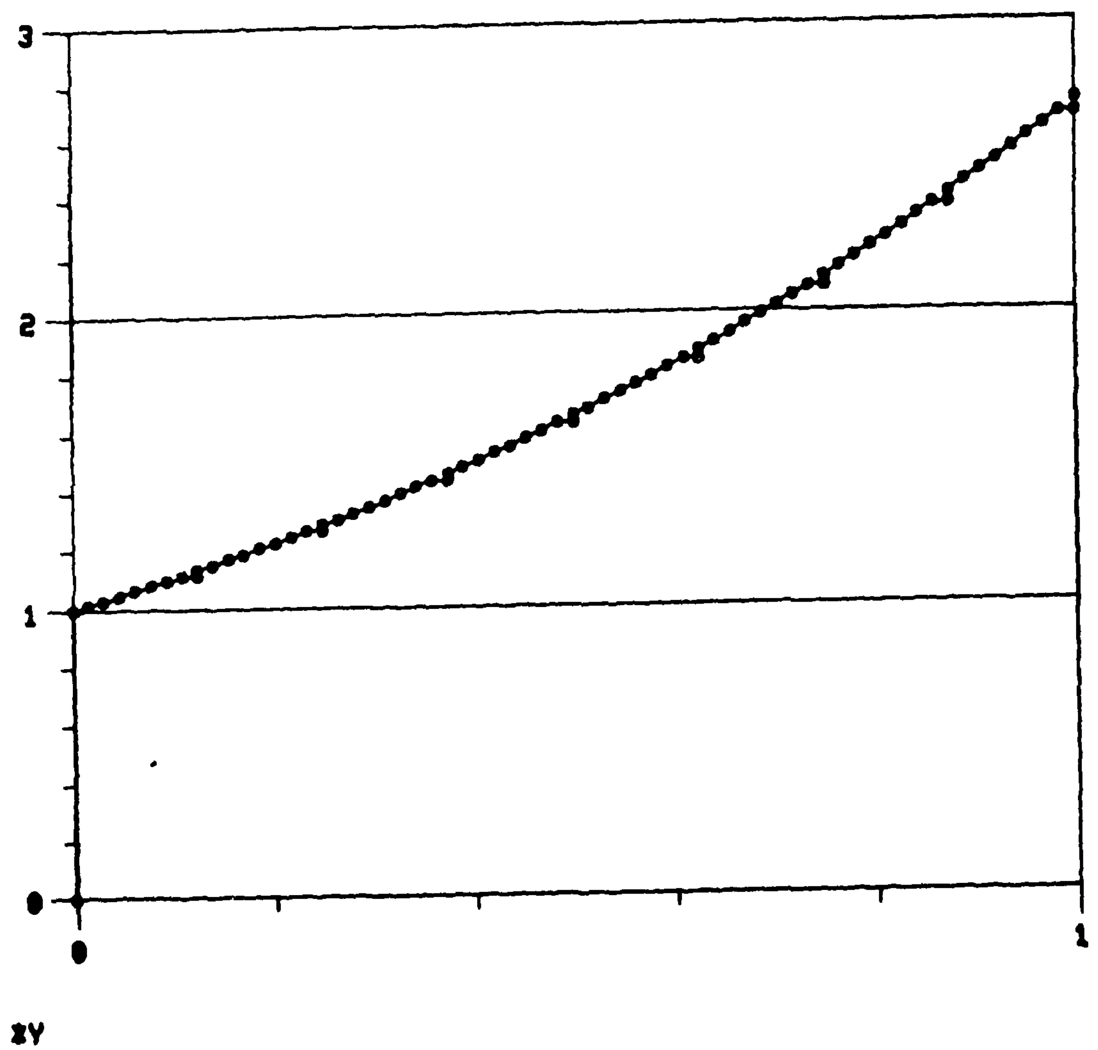


Figure 21. Plot No. 11, DAC program #1, Case #2.

```
DAC PROGRAM #1, CASE #3
INPUT XT = 1.0
FOR EXPONENTIAL DISTURBANCE(S):
INPUT CWT = 1.0
INPUT AWT = 3.0


DAC PROGRAM EXAMPLE NUMBER 1.
OUTPUT FORMAT:

   TIME              XDT               XT = YT           YNT
   UP                UD                UNT               TMP1
   XINPT             XINT              ZHNT              K                 WT

0.00000E+00      -0.17438E+02       0.10000E+01       0.10000E+01
0.85104E+01      -0.10928E+02      -0.19438E+02      -0.90416E+01
0.13155E+02       0.00000E+00       0.90416E+01      -0.85104E+01       0.10000E+01

0.10000E+01      -0.36272E+01      -0.22352E-07      -0.22352E-07
0.19022E-06      -0.23713E+02      -0.23713E+02       0.20210E-06
0.28547E+02       0.19620E+02       0.19620E+02      -0.85104E+01       0.20086E+02


CASE PARAMETERS:
INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER
INTEGRATION STEP SIZE: DT =  0.15625E-01
SAMPLE INTERVAL: ST =  0.12500E+00
DISTURBANCE: WT =  0.20086E+02
EQUATION FOR UNT: UNT = UP + UD
STEADY STATE OUTPUT: X(T) = -0.56675E-01
```

Figure 22. Output listing (condensed) of results, Case #3.

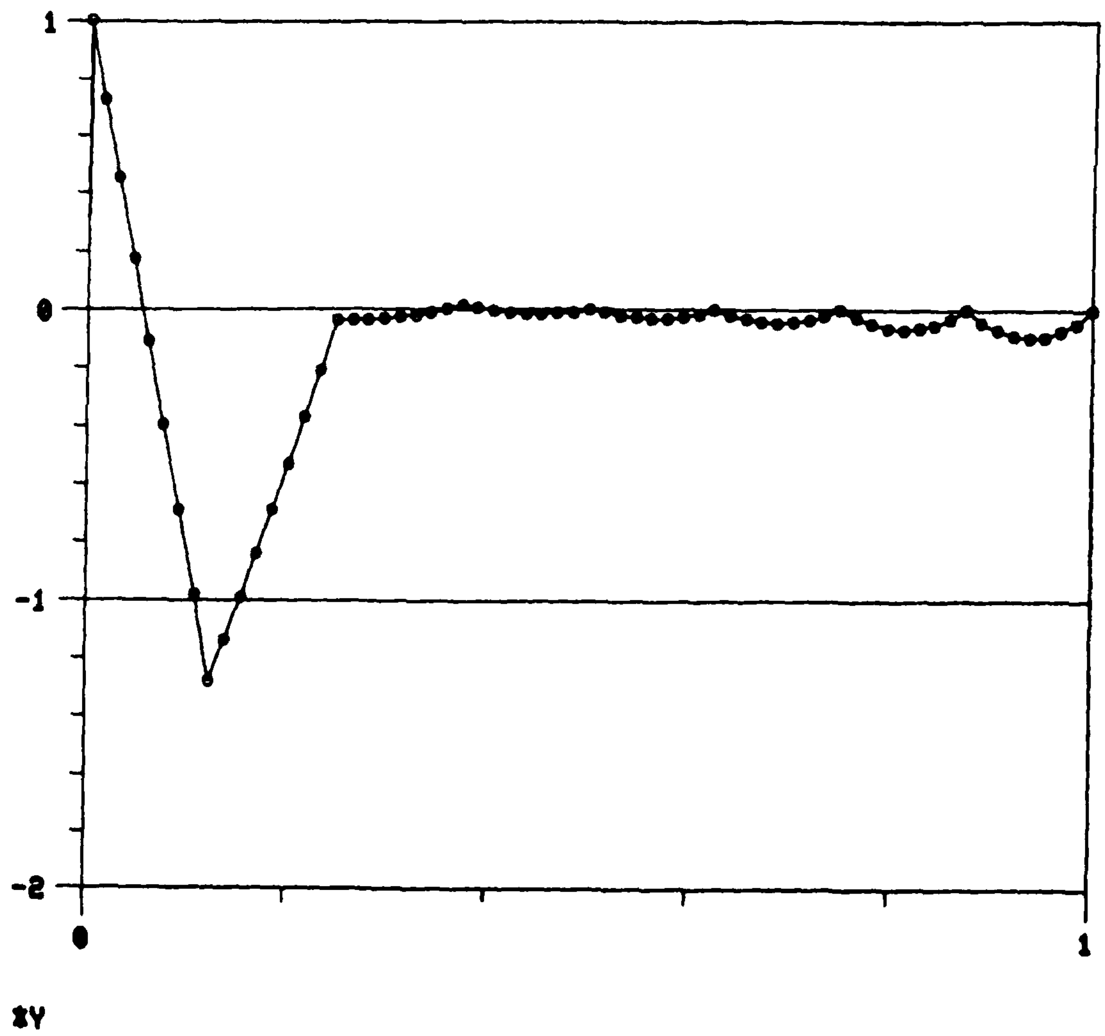


Figure 23. Plot No. 1, DAC program #1, Case #3.

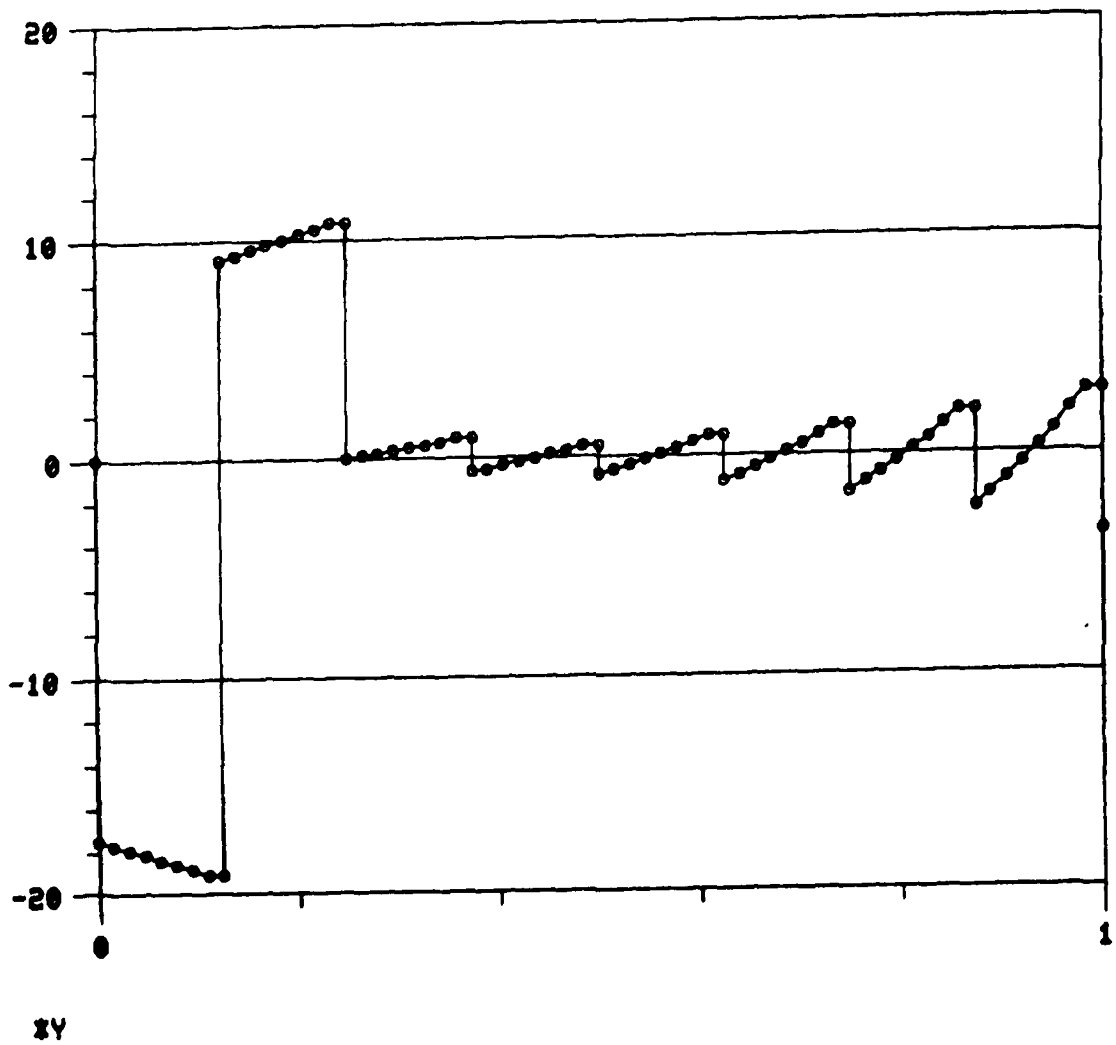


Figure 24. Plot No. 10, DAC program #1, Case #3.

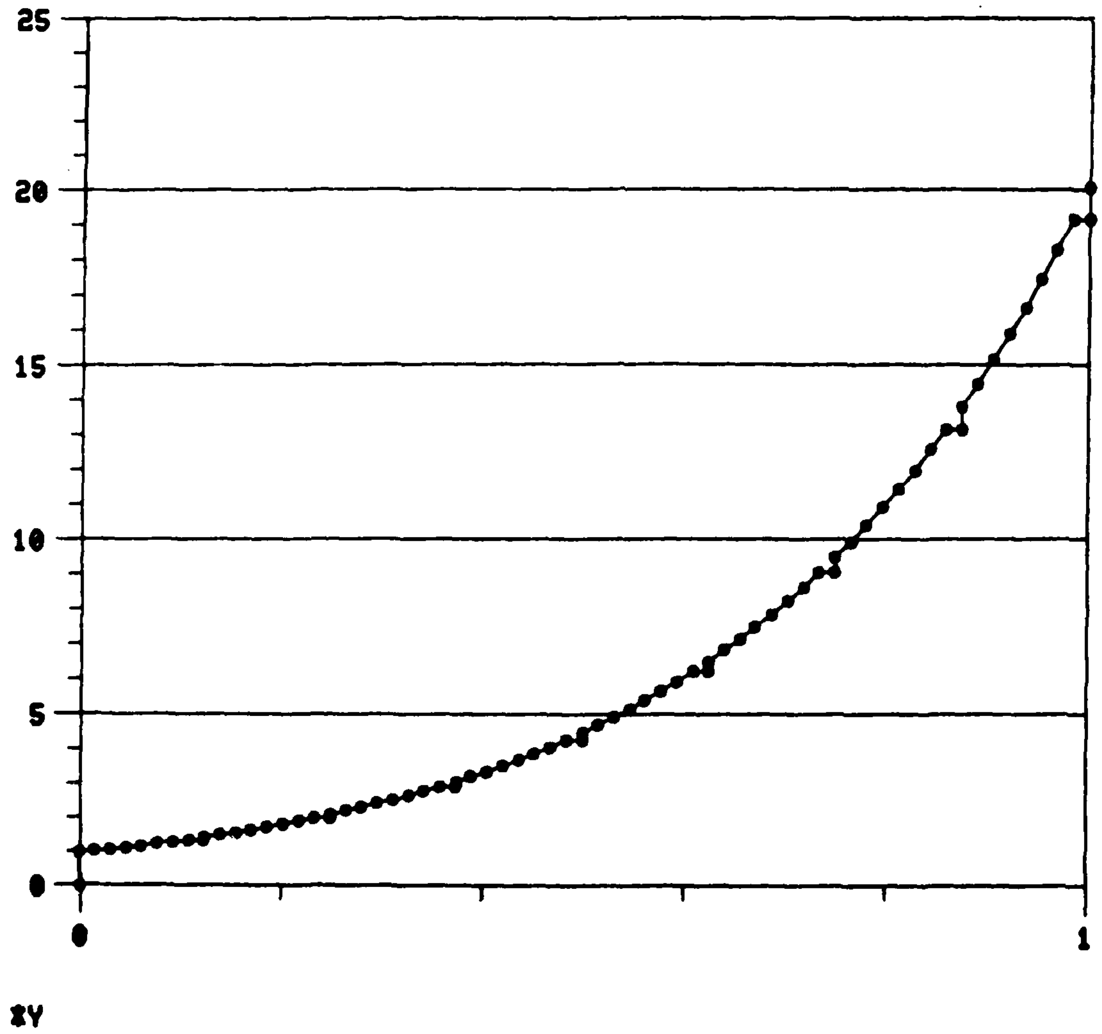


Figure 25. Plot No. 11, DAC program #1, Case #3.

```
DAC PROGRAM #1, CASE #4
INPUT XT = 1.0
FOR EXPONENTIAL DISTURBANCE(S):
INPUT CWT = 1.0
INPUT AWT = 10.0

DAC PROGRAM EXAMPLE NUMBER 1.
OUTPUT FORMAT:

   TIME             XDT              XT - YT          YNT
   UP               UD               UNT              TMP1
   XINPT            XINT             ZHNT             K                WT

 0.00000E+00     -0.32724E+02      0.10000E+01      0.10000E+01
-0.85104E+01     -0.26214E+02     -0.34724E+02     -0.13326E+02
 0.46514E+02      0.00000E+00      0.13326E+02     -0.85104E+01      0.10000E+01

 0.10000E+01     -0.18016E+05      0.38147E-04      0.38147E-04
-0.32465E-03     -0.40043E+05     -0.40043E+05     -0.50836E-03
 0.71051E+05      0.20357E+05      0.20357E+05     -0.85104E+01      0.22026E+05

CASE PARAMETERS:
INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER
INTEGRATION STEP SIZE: DT =  0.15625E-01
SAMPLE INTERVAL: ST =  0.12500E+00
DISTURBANCE: WT =  0.22026E+05
EQUATION FOR UNT: UNT = UP + UD
STEADY STATE OUTPUT: X(T) = -0.28150E+03
```

Figure 26. Output listing (condensed) of results for Case #4.

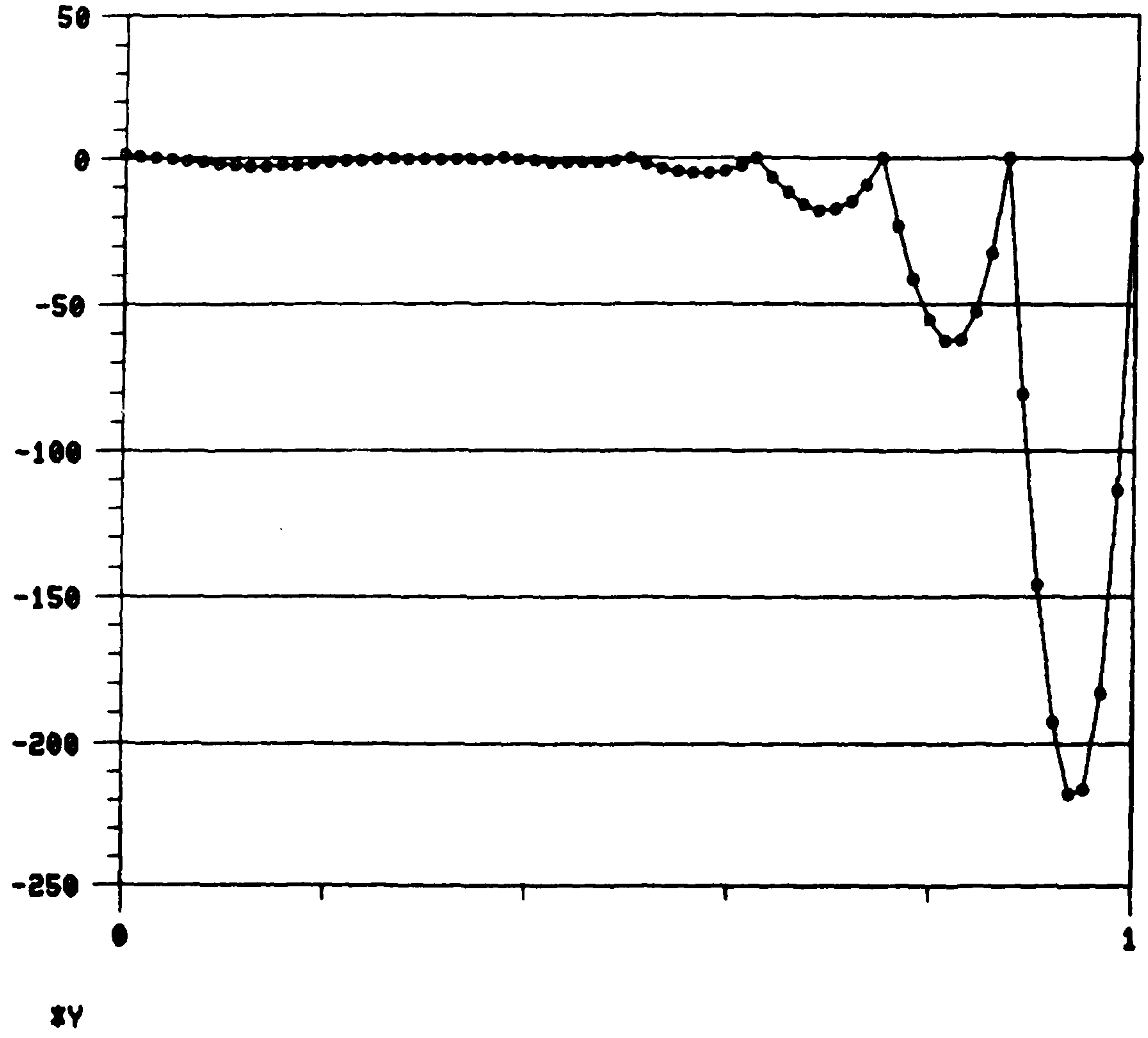


Figure 27. Plot No. 1, DAC program #1, Case #4.

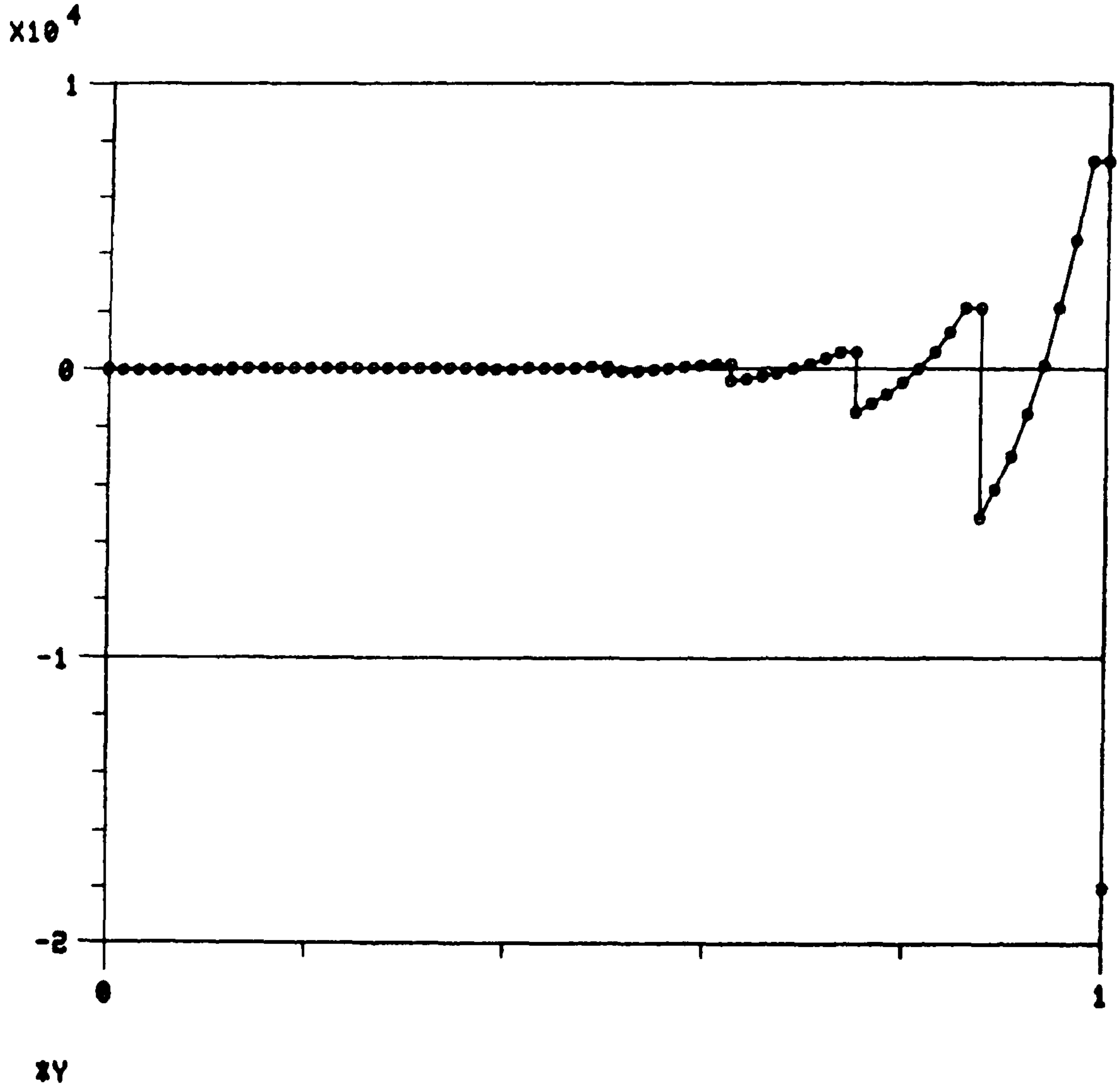


Figure 28. Plot No. 10, DAC program #1, Case #4.

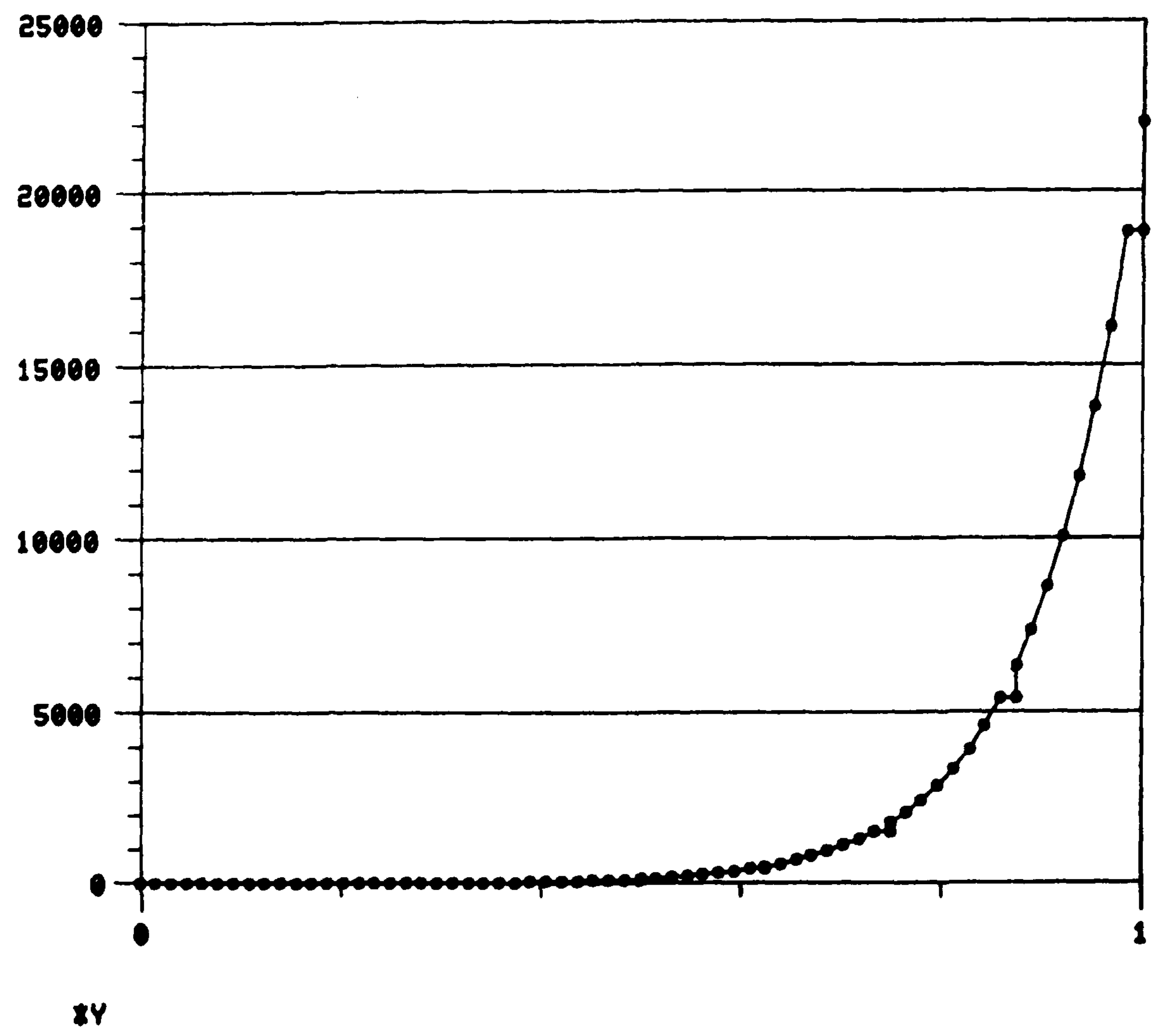


Figure 29. Plot No. 11, DAC program #1, Case #4.

```
RUN DACSPF

      DAC PROGRAM $1, CASE $10
      INPUT XT = 1.0
      FOR EXPONENTIAL DISTURBANCE(S):
      INPUT CWT = 1.0
      INPUT AWT = 0.0

      DAC PROGRAM EXAMPLE NUMBER 1.
      OUTPUT FORMAT:

    TIME           XDT            XT = YT        YNT
    UP             UD             UNT            TMP1
    XINPT          XINT           ZHNT           K              WT

  0.00000E+00   -0.13421E+02    0.10000E+01    0.10000E+01
 -0.85104E+01   -0.75104E+01   -0.16021E+02   -0.75104E+01    0.60002E+00
  0.75104E+01    0.00000E+00    0.75104E+01   -0.85104E+01    0.16000E+01

  0.62500E-01   -0.15918E+02    0.10295E+00    0.10000E+01
 -0.85104E+01   -0.75104E+01   -0.16021E+02   -0.75104E+01   -0.99990E+00
  0.75104E+01    0.00000E+00    0.75104E+01   -0.85104E+01    0.95367E-04

  0.12500E+00    0.57871E+01   -0.85863E+00   -0.85863E+00
  0.73073E+01   -0.10617E+01    0.62456E+01    0.64487E+01   -0.59983E+00
  0.10617E+01    0.75104E+01    0.10617E+01   -0.85104E+01    0.40017E+00

  0.18750E+00    0.65830E+01   -0.46278E+00   -0.85863E+00
  0.73073E+01   -0.10617E+01    0.62456E+01    0.64487E+01   -0.19975E+00
  0.10617E+01    0.75104E+01    0.10617E+01   -0.85104E+01    0.80025E+00

  0.25000E+00    0.85577E+00   -0.47746E-01   -0.47746E-01
  0.40634E+00   -0.70315E+00   -0.29681E+00    0.35859E+00    0.20032E+00
  0.70315E+00    0.10617E+01    0.70315E+00   -0.85104E+01    0.12003E+01

  0.31250E+00    0.13044E+01    0.85773E-03   -0.47746E-01
```

Figure 30. Output listing of results for Case #10.

0.40634E+00	-0.70315E+00	-0.29681E+00	0.35859E+00	0.60040E+00
0.70315E+00	0.10617E+01	0.70315E+00	-0.85104E+01	0.16004E+01
0.37500E+00	-0.13926E+01	0.45934E-01	0.45934E-01	
-0.39092E+00	-0.10481E+01	-0.14391E+01	-0.34498E+00	-0.99952E+00
0.10481E+01	0.70315E+00	0.10481E+01	-0.85104E+01	0.47731E-03
0.43750E+00	-0.10248E+01	0.13673E-01	0.45934E-01	
-0.39092E+00	-0.10481E+01	-0.14391E+01	-0.34498E+00	-0.59945E+00
0.10481E+01	0.70315E+00	0.10481E+01	-0.85104E+01	0.40055E+00
0.50000E+00	0.14763E+00	-0.26306E-01	-0.26306E-01	
0.22387E+00	-0.85057E+00	-0.62669E+00	0.19757E+00	-0.19937E+00
0.85057E+00	0.10481E+01	0.85057E+00	-0.85104E+01	0.80063E+00
0.56250E+00	0.55100E+00	-0.23009E-01	-0.26306E-01	
0.22387E+00	-0.85057E+00	-0.62669E+00	0.19757E+00	0.20071E+00
0.85057E+00	0.10481E+01	0.85057E+00	-0.85104E+01	0.12007E+01
0.62500E+00	0.65864E+00	0.60965E-02	0.60965E-02	
-0.51884E-01	-0.89635E+00	-0.94824E+00	-0.45787E-01	0.60078E+00
0.89635E+00	0.85057E+00	0.89635E+00	-0.85104E+01	0.16008E+01
0.68750E+00	-0.93752E+00	0.98540E-02	0.60965E-02	
-0.51884E-01	-0.89635E+00	-0.94824E+00	-0.45787E-01	-0.99914E+00
0.89635E+00	0.85057E+00	0.89635E+00	-0.85104E+01	0.85926E-03
0.75000E+00	-0.59623E+00	0.67111E-02	0.67111E-02	
-0.57114E-01	-0.94676E+00	-0.10039E+01	-0.50403E-01	-0.59906E+00
0.94676E+00	0.89635E+00	0.94676E+00	-0.85104E+01	0.40094E+00
0.81250E+00	-0.20871E+00	-0.58454E-02	0.67111E-02	
-0.57114E-01	-0.94676E+00	-0.10039E+01	-0.50403E-01	-0.19899E+00
0.94676E+00	0.89635E+00	0.94676E+00	-0.85164E+01	0.80101E+00
0.87500E+00	0.63506E+00	-0.25347E-01	-0.25347E-01	
0.21571E+00	-0.75639E+00	-0.54068E+00	0.19036E+00	0.20109E+00
0.75639E+00	0.94676E+00	0.75639E+00	-0.85104E+01	0.12011E+01

Figure 30. Output listing of results for Case #10 (continued).

```
 0.93750E+00     0.10696E+01     0.91363E-02    -0.25347E-01
 0.21571E+00    -0.75639E+00    -0.54068E+00     0.19036E+00     0.60116E+00
 0.75639E+00     0.94676E+00     0.75639E+00    -0.85104E+01     0.16012E+01

 0.10000E+01    -0.13438E+01     0.39188E-01     0.39188E-01
-0.33351E+00    -0.10507E+01    -0.13842E+01    -0.29432E+00    -0.99876E+00
 0.10507E+01     0.75639E+00     0.10507E+01    -0.85104E+01     0.12412E-02

      CASE PARAMETERS:
      INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER
      INTEGRATION STEP SIZE: DT =  0.15625E-01
      SAMPLE INTERVAL: ST =  0.12500E+00
      DISTURBANCE: WT =  0.12412E-02
      EQUATION FOR UNT: UNT = UP + UD
      STEADY STATE OUTPUT: X(T) =  0.18191E-01


DACSPF  --  STOP
```

Figure 30. Output listing of results for Case #10 (concluded).

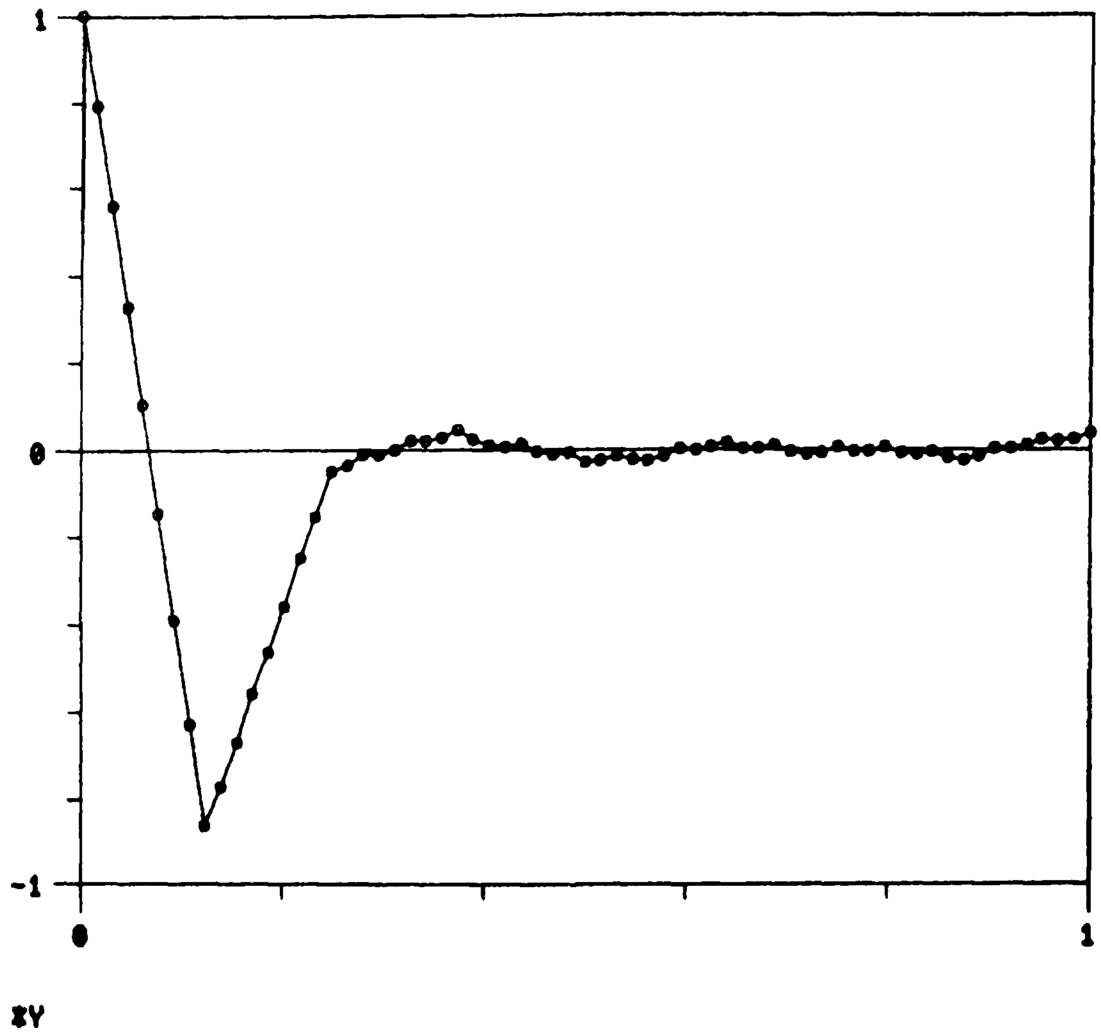


Figure 31. Plot No. 1, DAC program #1, Case #10.

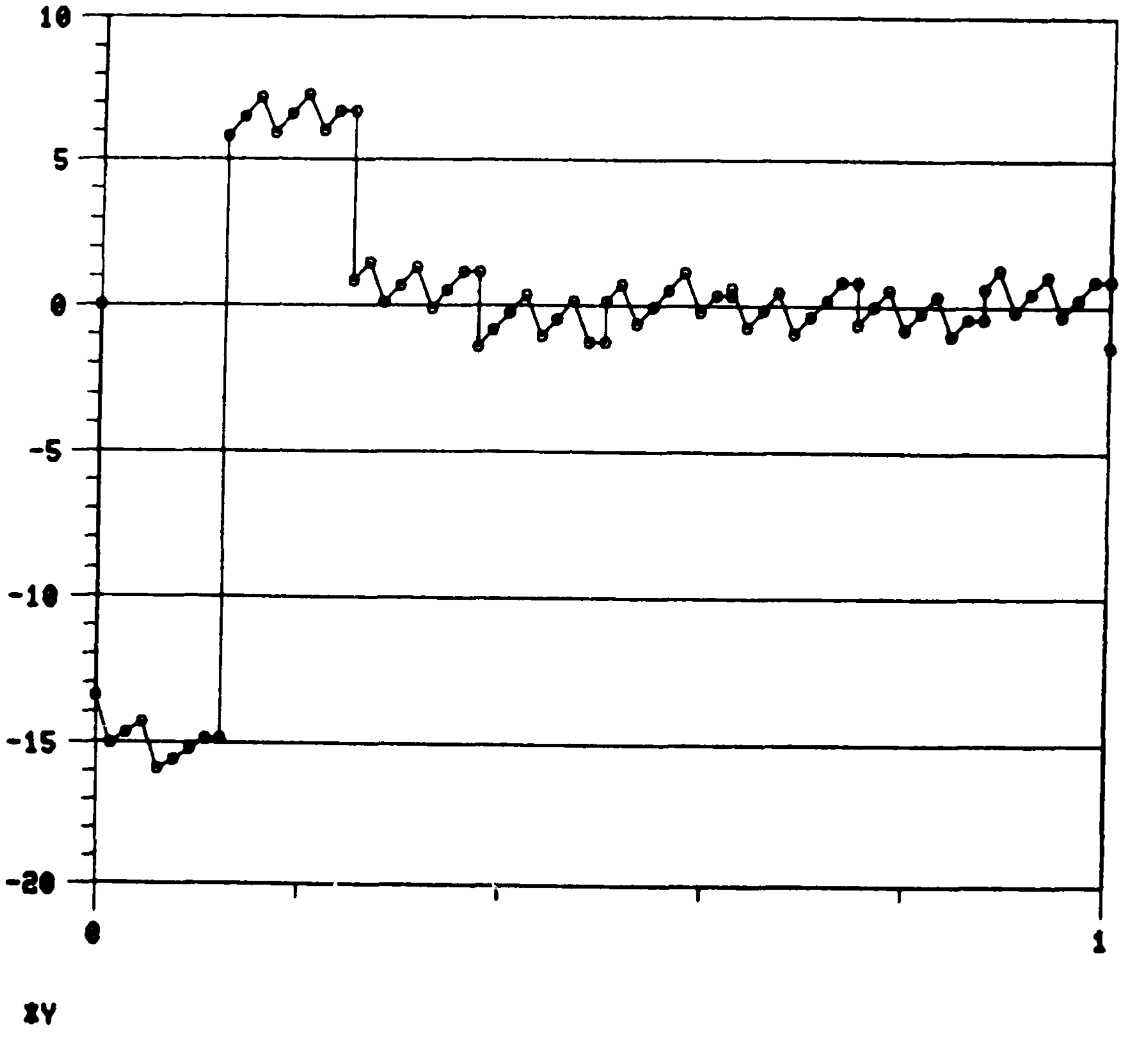


Figure 32. Plot No. 10, DAC program #1, Case #10.

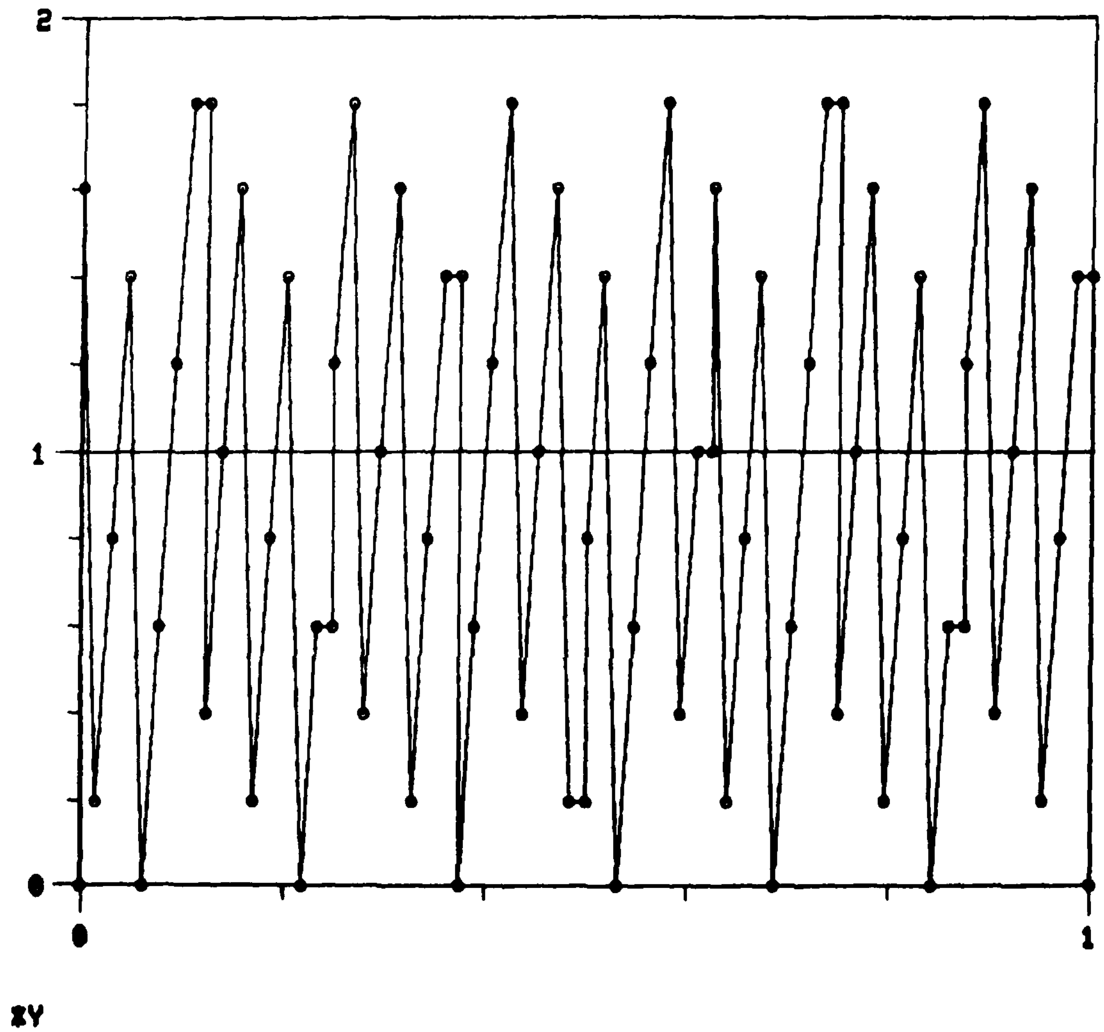


Figure 33. Plot No. 11, DAC program #1, Case #10.

```
RUN SDACP2

        DAC PROGRAM #1, CASE #20
        INPUT XT = 1.0

        DAC PROGRAM EXAMPLE NUMBER 1.
        OUTPUT FORMAT:

     TIME             XDT              XT - YT          YNT
     UP               UD               UNT              TMP1
     XINPT            XINT             ZHNT             E

   0.00000E+00     -0.14021E+02      0.10000E+01      0.10000E+01
  -0.85104E+01     -0.75104E+01     -0.16021E+02     -0.75104E+01
   0.75104E+01      0.00000E+00      0.75104E+01     -0.85104E+01      0.10000E+01

   0.62500E-01     -0.14918E+02      0.10294E+00      0.10000E+01
  -0.85104E+01     -0.75104E+01     -0.16021E+02     -0.75104E+01
   0.75104E+01      0.00000E+00      0.75104E+01     -0.85104E+01      0.10000E+01

   0.12500E+00      0.62799E+01     -0.85150E+00     -0.85150E+00
   0.72467E+01     -0.11153E+01      0.61314E+01      0.63951E+01
   0.11153E+01      0.75104E+01      0.11153E+01     -0.85104E+01      0.10000E+01

   0.18750E+00      0.66817E+01     -0.44972E+00     -0.85150E+00
   0.72467E+01     -0.11153E+01      0.61314E+01      0.63951E+01
   0.11153E+01      0.75104E+01      0.11153E+01     -0.85104E+01      0.10000E+01

   0.25000E+00      0.21853E+00     -0.22222E-01     -0.22222E-01
   0.18912E+00     -0.94837E+00     -0.75925E+00      0.16690E+00
   0.94837E+00      0.11153E+01      0.94837E+00     -0.85104E+01      0.10000E+01

   0.31250E+00     -0.57675E+01     -0.82408E-02     -0.22222E-01
   0.18912E+00     -0.94837E+00     -0.75925E+00      0.16690E+00
   0.94837E+00      0.11153E+01      0.94837E+00     -0.85104E+01     -0.50000E+01

   0.37500E+00     -0.28182E+00     -0.37725E+00     -0.37725E+00
   0.32105E+01      0.18849E+01      0.50954E+01      0.28333E+01
  -0.18849E+01      0.94837E+00     -0.18849E+01     -0.85104E+01     -0.50000E+01

   0.43750E+00     -0.29986E+00     -0.39528E+00     -0.37725E+00
   0.32105E+01      0.18849E+01      0.50954E+01      0.28333E+01
  -0.18849E+01      0.94837E+00     -0.18849E+01     -0.85104E+01     -0.50000E+01

   0.50000E+00      0.31105E+01     -0.41446E+00     -0.41446E+00
   0.35272E+01      0.49977E+01      0.85249E+01      0.31128E+01
  -0.49977E+01     -0.18849E+01     -0.49977E+01     -0.85104E+01     -0.50000E+01

   0.56250E+00      0.33095E+01     -0.21545E+00     -0.41446E+00
   0.35272E+01      0.49977E+01      0.85249E+01      0.31128E+01
  -0.49977E+01     -0.18849E+01     -0.49977E+01     -0.85104E+01     -0.50000E+01

   0.62500E+00      0.53461E-01     -0.37133E-02     -0.37133E-02
   0.31602E-01      0.50256E+01      0.50572E+01      0.27889E-01
  -0.50256E+01     -0.49977E+01     -0.50256E+01     -0.85104E+01     -0.50000E+01
```

Figure 34. Output listing of results for Case #20.

0.68750E+00	0.56881E-01	-0.29289E-03	-0.37133E-02	
0.31602E-01	0.50256E+01	0.50572E+01	0.27889E-01	
-0.50256E+01	-0.49977E+01	-0.50256E+01	-0.85104E+01	-0.50000E+01
0.75000E+00	0.13995E+01	0.24140E+00	0.24140E+00	
-0.20544E+01	0.32125E+01	0.11581E+01	-0.18130E+01	
-0.32125E+01	-0.50256E+01	-0.32125E+01	-0.85104E+01	0.00000E+00
0.81250E+00	0.14890E+01	0.33094E+00	0.24140E+00	
-0.20544E+01	0.32125E+01	0.11581E+01	-0.18130E+01	
-0.32125E+01	-0.50256E+01	-0.32125E+01	-0.85104E+01	0.00000E+00
0.87500E+00	-0.31895E+01	0.42621E+00	0.42621E+00	
-0.36272E+01	0.11506E-01	-0.36157E+01	-0.32010E+01	
-0.11506E-01	-0.32125E+01	-0.11506E-01	-0.85104E+01	0.00000E+00
0.93750E+00	-0.33936E+01	0.22215E+00	0.42621E+00	
-0.36272E+01	0.11506E-01	-0.36157E+01	-0.32010E+01	
-0.11506E-01	-0.32125E+01	-0.11506E-01	-0.85104E+01	0.00000E+00
0.10000E+01	0.99361E+01	0.50234E-02	0.50234E-02	
-0.42751E-01	-0.26222E-01	-0.68973E-01	-0.37728E-01	
0.26222E-01	-0.11506E-01	0.26222E-01	-0.85104E+01	0.10000E+02
0.10625E+01	0.10572E+02	0.64073E+00	0.50234E-02	
-0.42751E-01	-0.26222E-01	-0.68973E-01	-0.37728E-01	
0.26222E-01	-0.11506E-01	0.26222E-01	-0.85104E+01	0.10000E+02
0.11250E+01	-0.17463E+02	0.11609E+01	0.11609E+01	
-0.98795E+01	-0.87448E+01	-0.18624E+02	-0.87186E+01	
0.87448E+01	0.26222E-01	0.87448E+01	-0.85104E+01	0.00000E+00
0.11875E+01	-0.18581E+02	0.43555E-01	0.11609E+01	
-0.98795E+01	-0.87448E+01	-0.18624E+02	-0.87186E+01	
0.87448E+01	0.26222E-01	0.87448E+01	-0.85104E+01	0.00000E+00
0.12500E+01	0.84577E+01	-0.11452E+01	-0.11452E+01	
0.97465E+01	-0.14357E+00	0.96029E+01	0.86012E+01	
0.14357E+00	0.87448E+01	0.14357E+00	-0.85104E+01	0.00000E+00
0.13125E+01	0.89988E+01	-0.60412E+00	-0.11452E+01	
0.97465E+01	-0.14357E+00	0.96029E+01	0.86012E+01	
0.14357E+00	0.87448E+01	0.14357E+00	-0.85104E+01	0.00000E+00
0.13750E+01	0.28264E+00	-0.28374E-01	-0.28374E-01	
0.24148E+00	0.69533E-01	0.31101E+00	0.21310E+00	
-0.69533E-01	0.14357E+00	-0.69533E-01	-0.85104E+01	0.00000E+00
0.14375E+01	0.30072E+00	-0.10291E-01	-0.28374E-01	
0.24148E+00	0.69533E-01	0.31101E+00	0.21310E+00	
-0.69533E-01	0.14357E+00	-0.69533E-01	-0.85104E+01	0.00000E+00
0.15000E+01	-0.64885E-01	0.89488E-02	0.89488E-02	
-0.76158E-01	0.23236E-02	-0.73834E-01	-0.67209E-01	
-0.23236E-02	-0.69533E-01	-0.23236E-02	-0.85104E+01	0.00000E+00

Figure 34. Output listing of results for Case #20 (continued).

```
CASE PARAMETERS:
INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER
INTEGRATION STEP SIZE: DT =  0.15625E-01
SAMPLE INTERVAL: ST =  0.12500E+00
DISTURBANCE: WT =  0.00000E+00
EQUATION FOR UNT: UNT = UP + UD
STEADY STATE OUTPUT: X(T) =  0.79349E-02


SDACP2  --  STOP
```

Figure 34. Output listing of results for Case #20 (concluded).

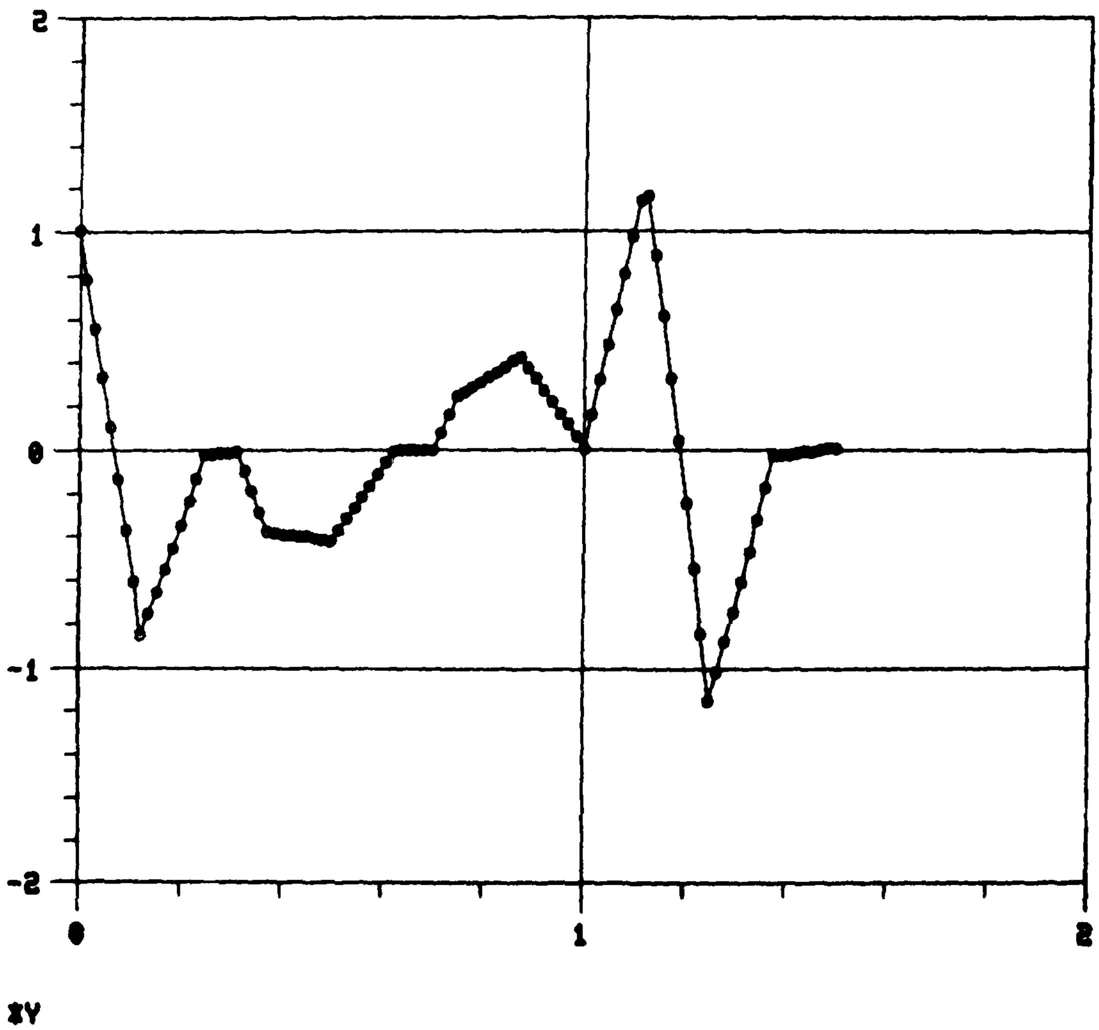


Figure 35. Plot No. 1, DAC program #1, Case #20.

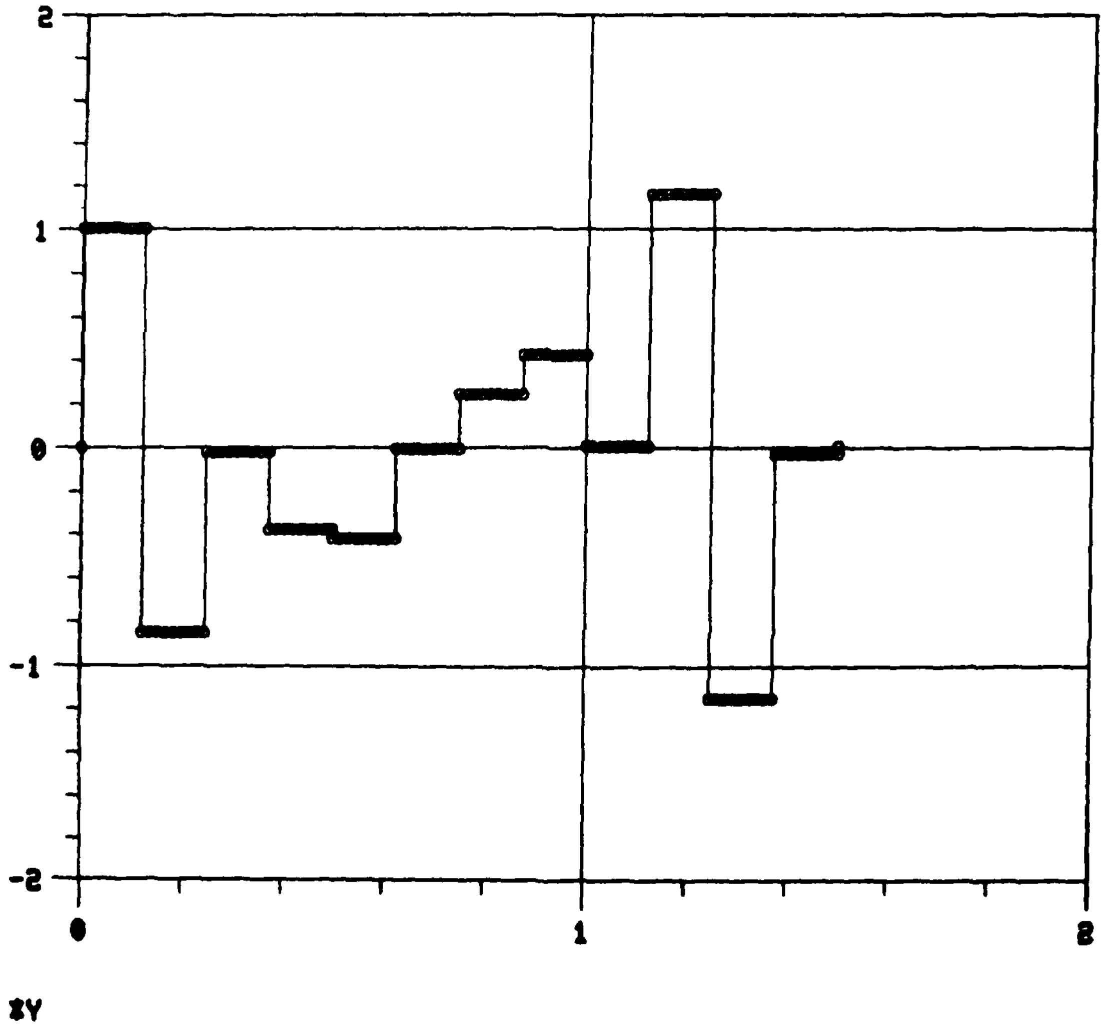


Figure 36. Plot No. 1, DAC program #1, Case #20.

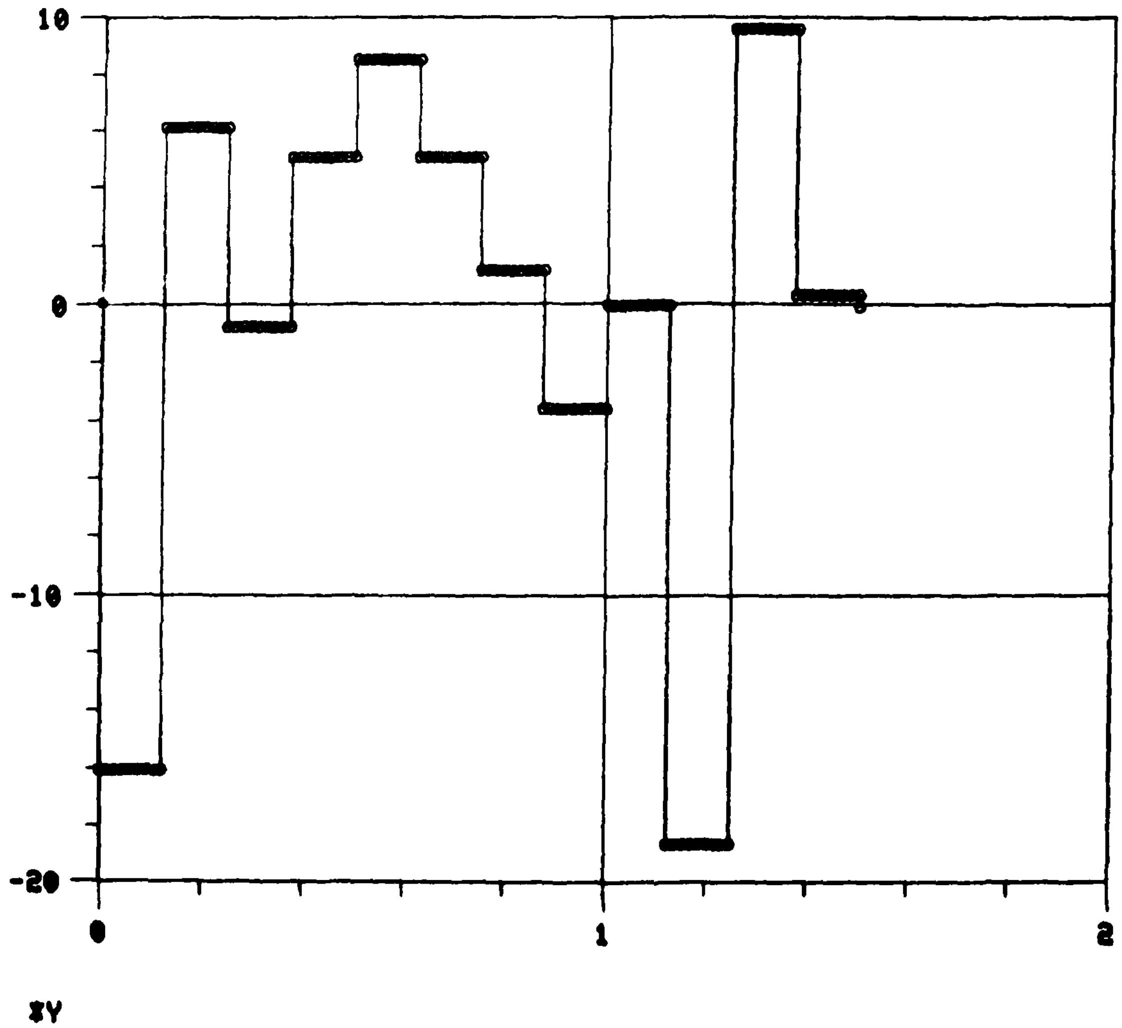


Figure 37. Plot No. 3, DAC program #1, Case #20.

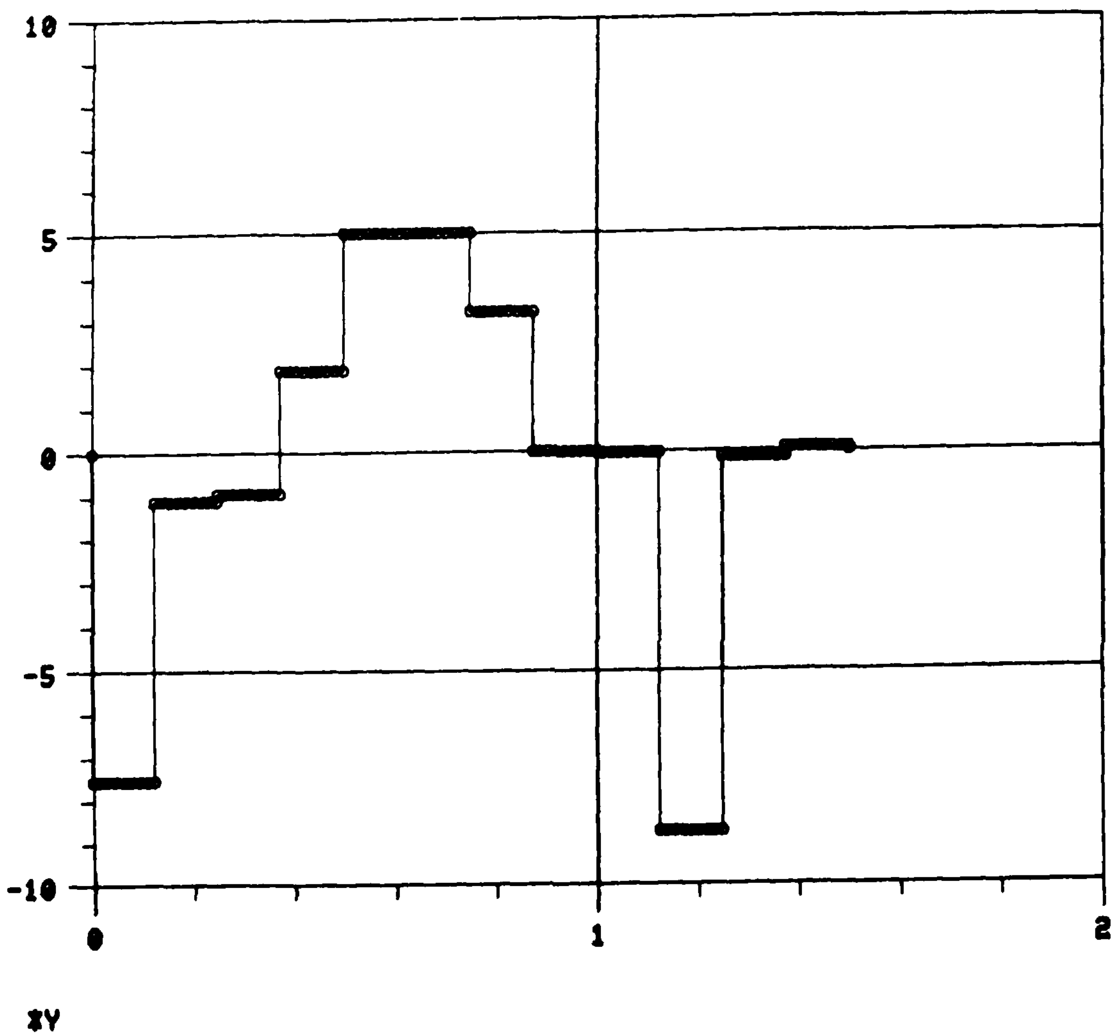


Figure 38. Plot No. 4, DAC program #1, Case #20.

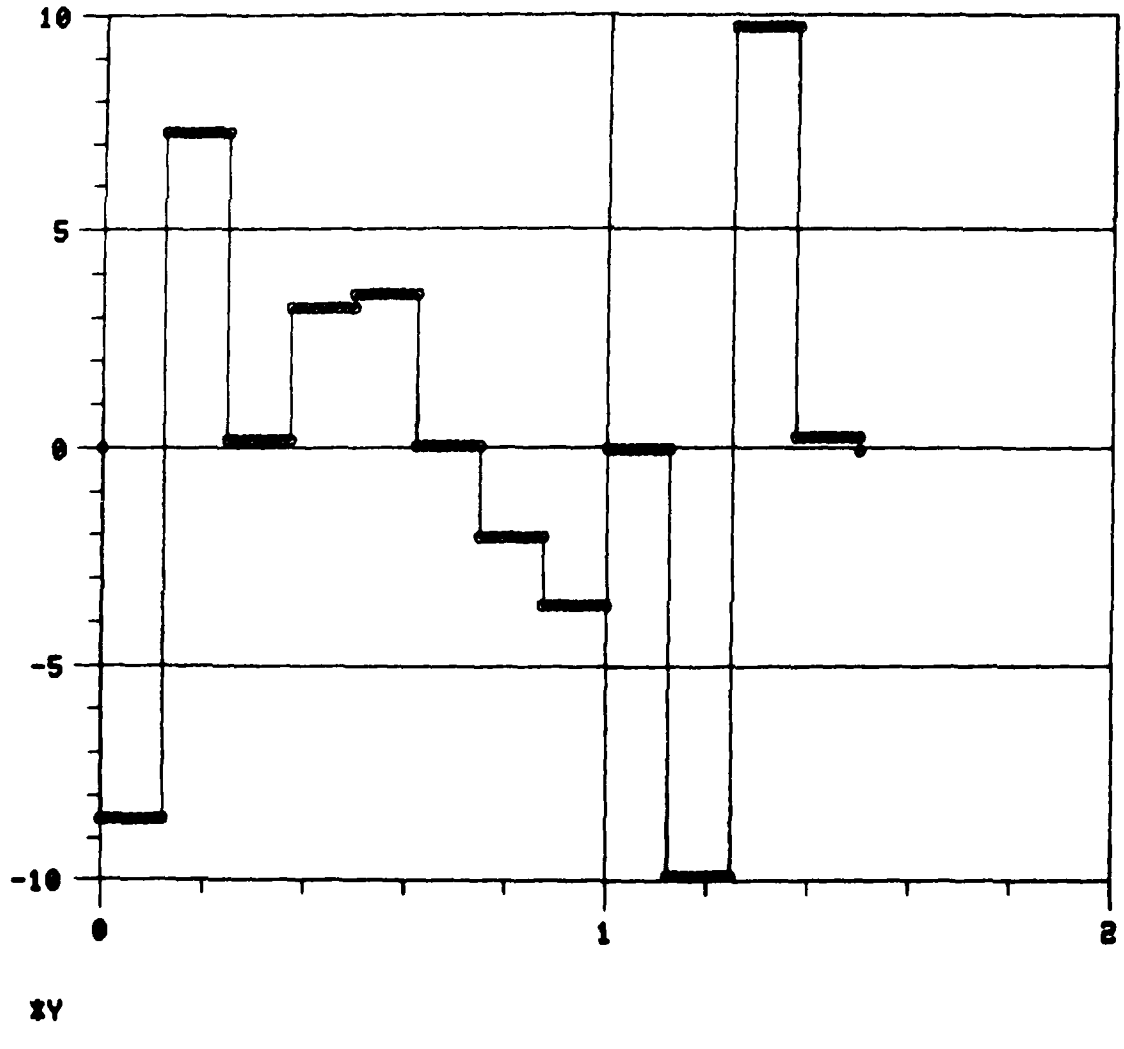


Figure 39. Plot No. 5, DAC program #1, Case #20.

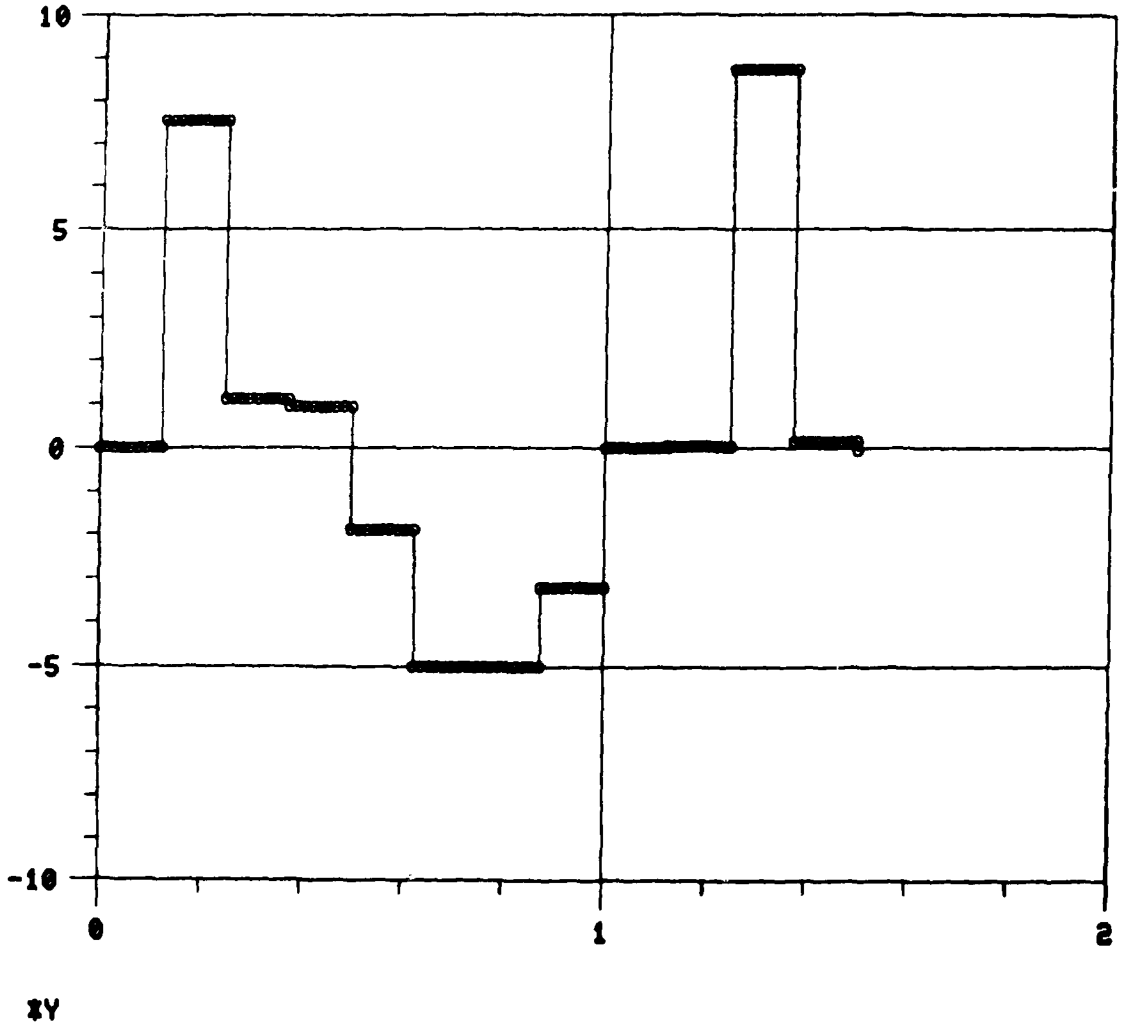


Figure 40. Plot No. 6, DAC program #1, Case #20.

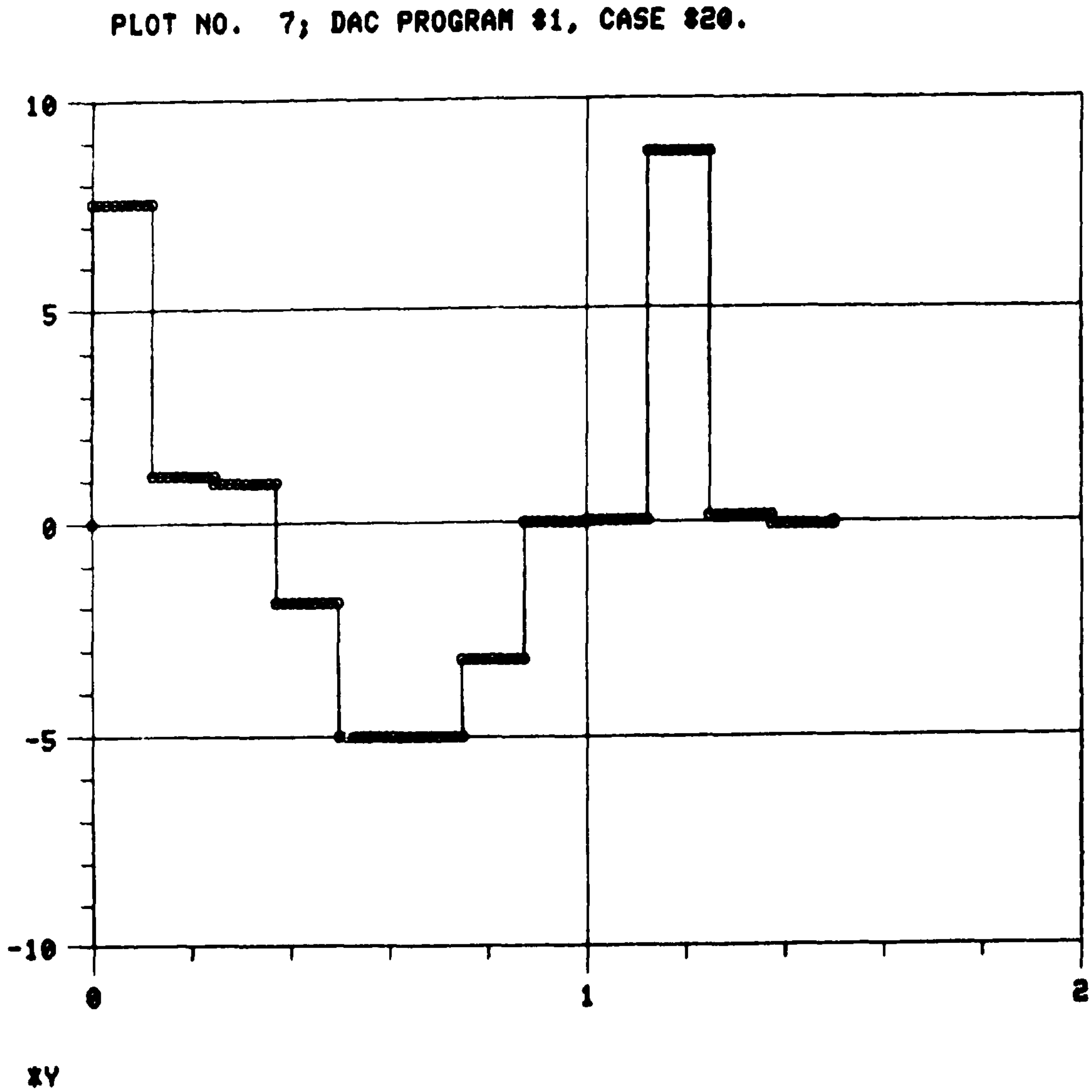


Figure 41. Plot No. 7, DAC program #1, Case #20.

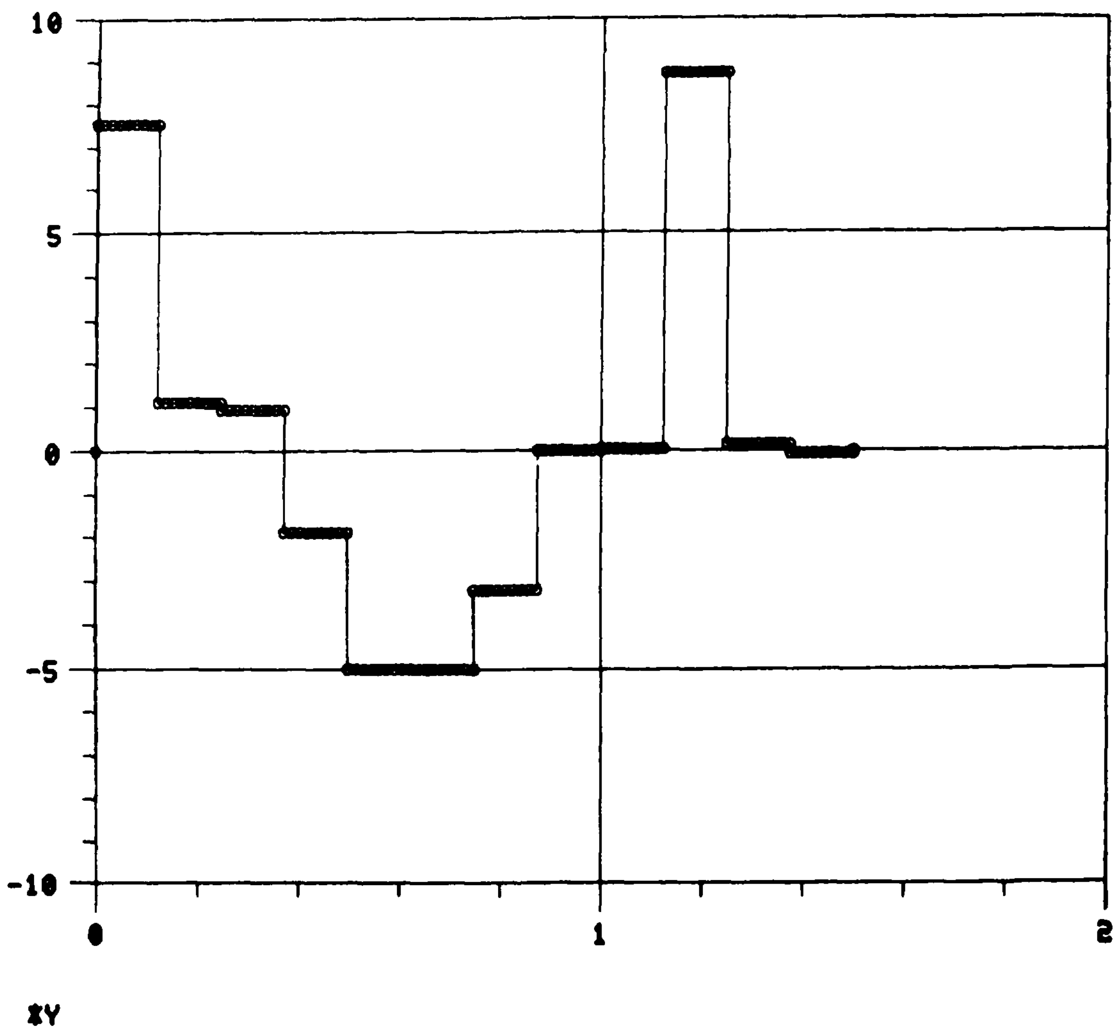


Figure 43. Plot No. 9, DAC program #1, Case #20.

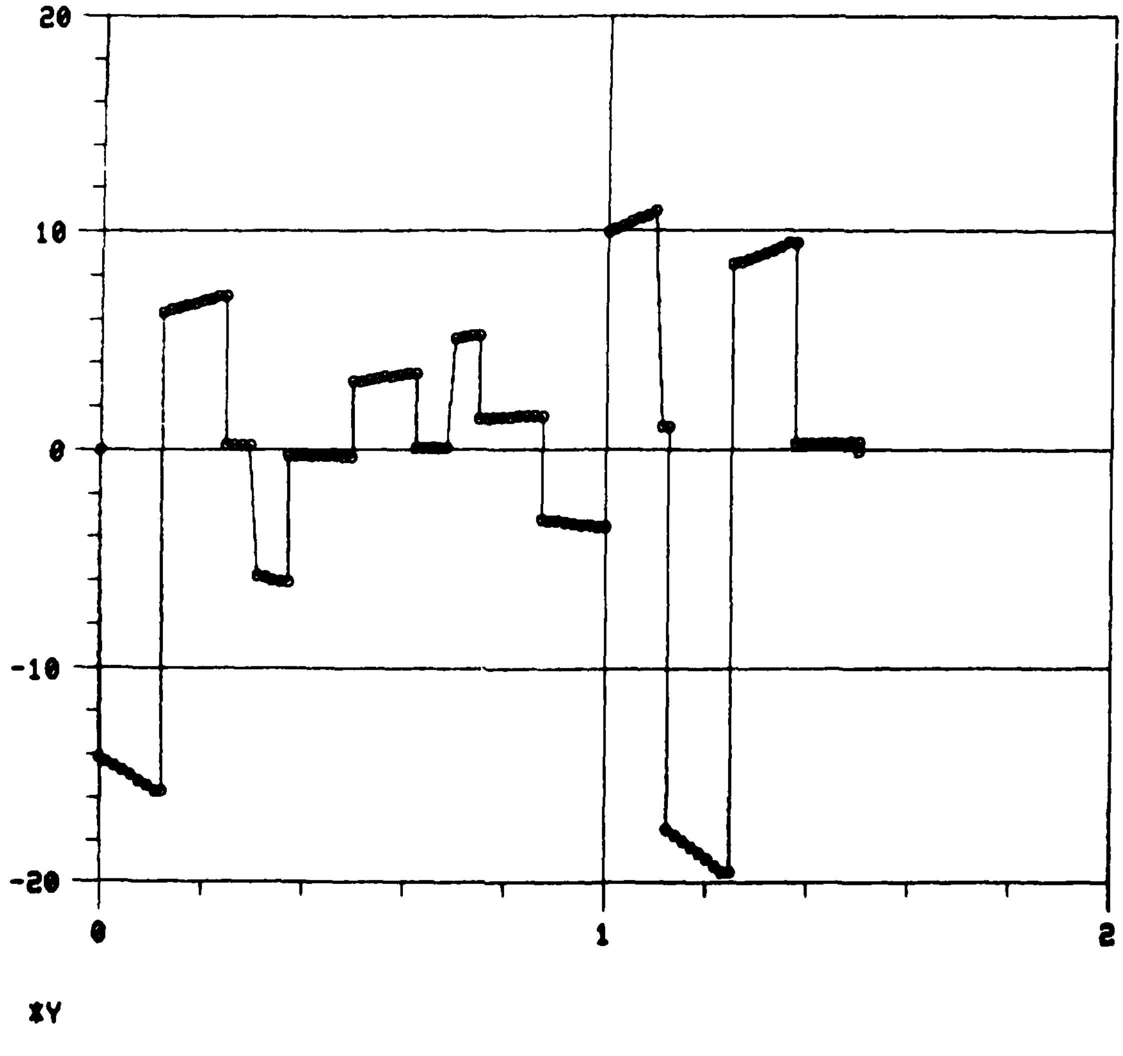


Figure 44. Plot No. 10, DAC program #1, Case #20.

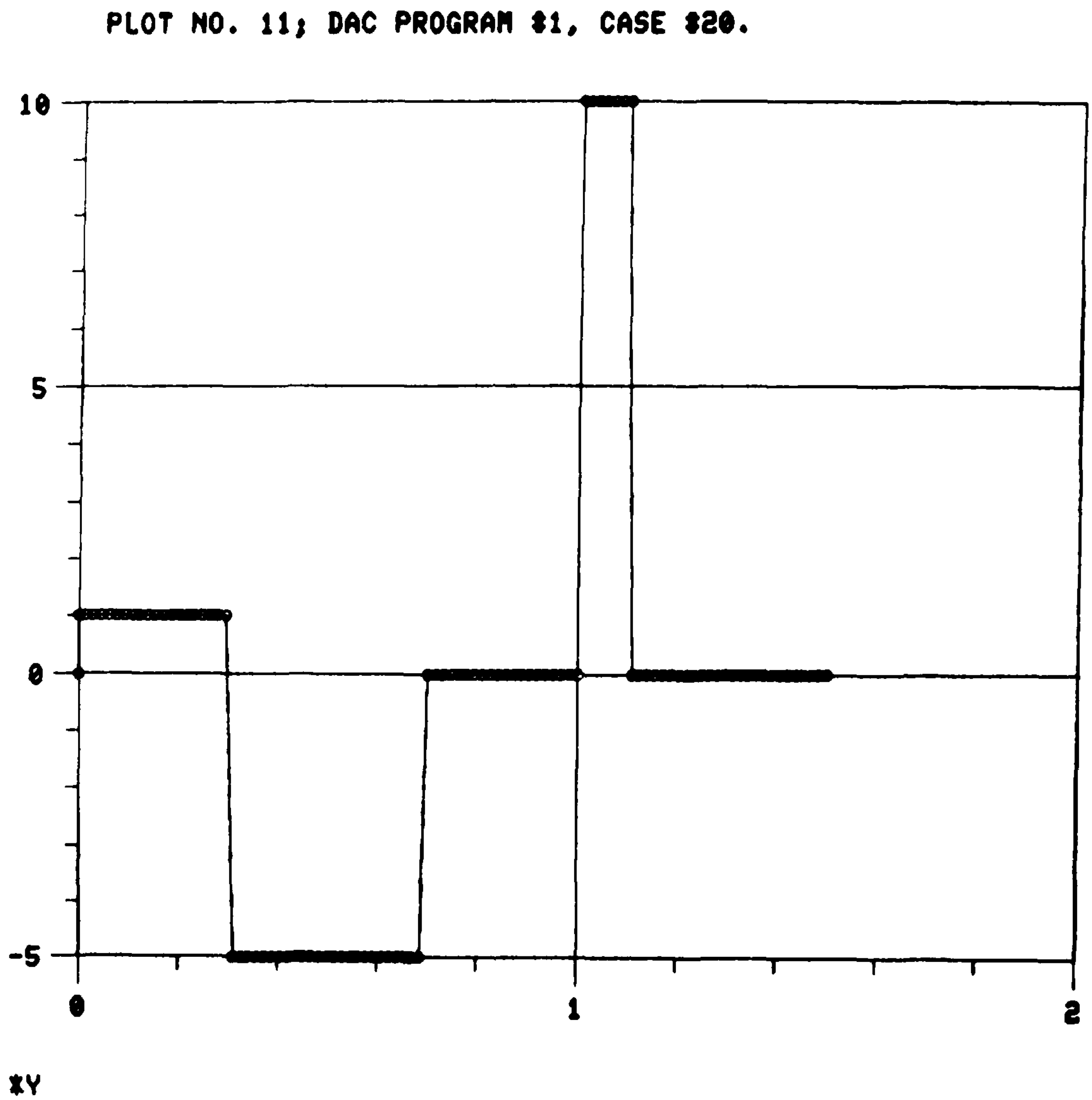


Figure 45. Plot No. 11, DAC program #1, Case #20.

```
DAC PROGRAM #1, CASE #29
INPUT XT = 0.0
FOR EXPONENTIAL DISTURBANCE(S):
INPUT CWT = 1.0
INPUT AWT = 0.0

DAC PROGRAM EXAMPLE NUMBER 1.
OUTPUT FORMAT:

   TIME               XDT               XT = YT           YNT
   UP                 UD                UNT               TMP1
   XINPT              XINT              ZHNT              K               WT

 0.00000E+00       0.10000E+01       0.00000E+00       0.00000E+00
 0.00000E+00       0.00000E+00       0.00000E+00       0.00000E+00
 0.00000E+00       0.00000E+00       0.00000E+00      -0.85104E+01      0.10000E+01

 0.10000E+01       0.11921E-06      -0.13970E-07      -0.13970E-07
 0.11889E-06      -0.10000E+01      -0.10000E+01       0.10492E-06
 0.10000E+01       0.10000E+01       0.10000E+01      -0.85104E+01      0.10000E+01

CASE PARAMETERS:
INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER
INTEGRATION STEP SIZE: DT =  0.15625E-01
SAMPLE INTERVAL: ST =  0.12500E+00
DISTURBANCE: WT =  0.10000E+01
EQUATION FOR UNT: UNT = UP + UD
STEADY STATE OUTPUT: X(T) = -0.12107E-07


TTO  --  STOP
```

Figure 46. Output listing (condensed) of results for Case #29.

PLOT NO. 1; DAC PROGRAM #1, CASE #29.

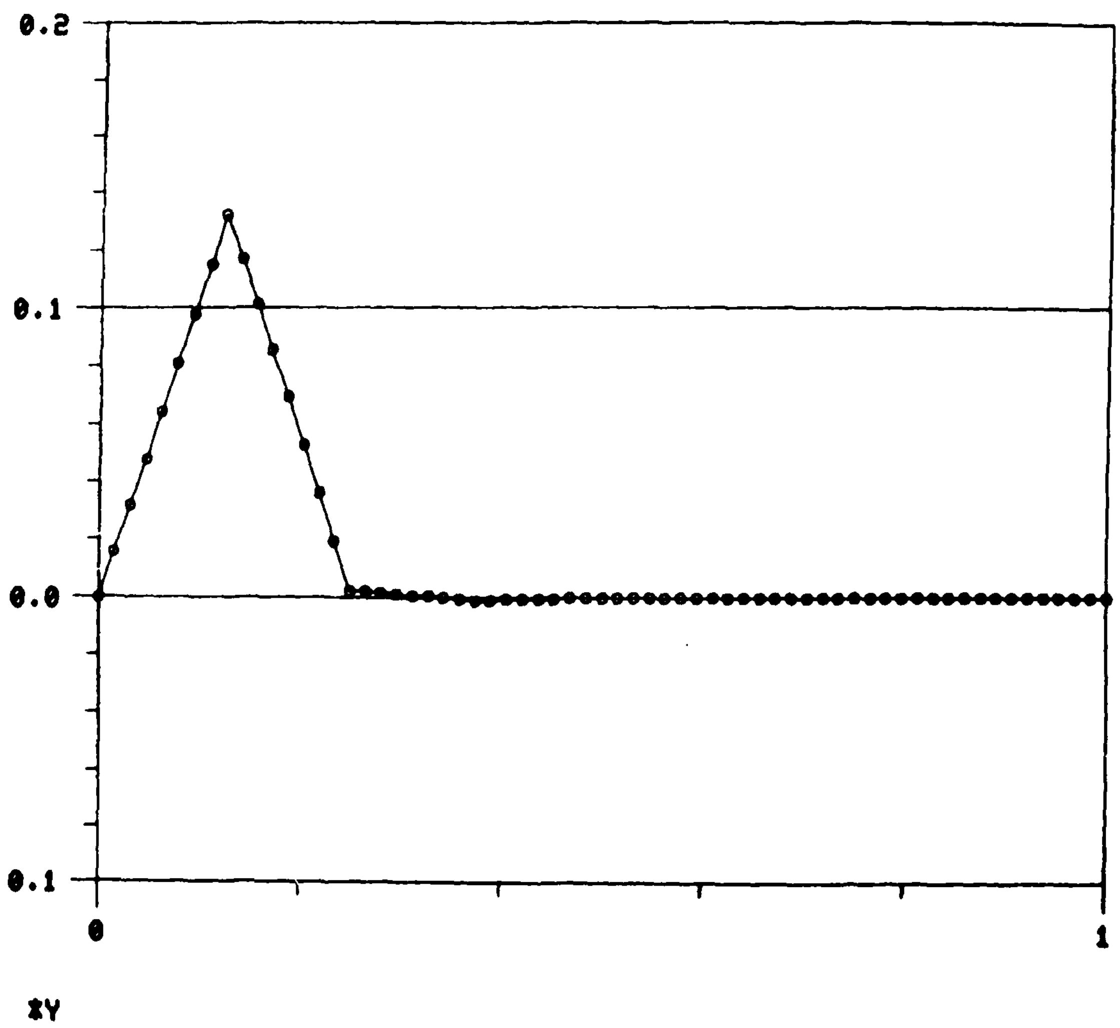


Figure 47. Plot No. 1, DAC program #1, Case #29.

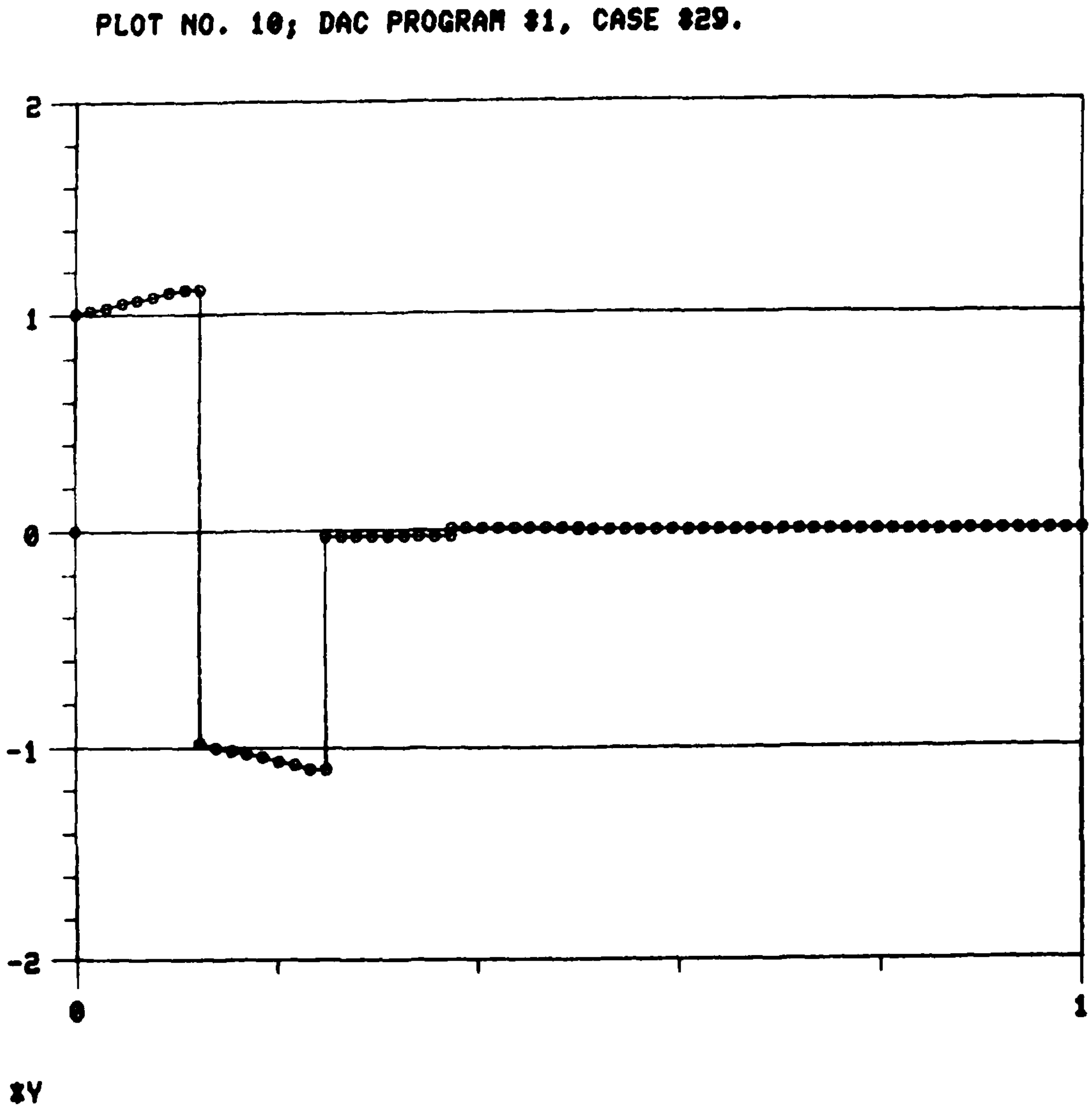


Figure 48. Plot No. 10, DAC program #1, Case #29.

```
DAC PROGRAM #1, CASE #31
INPUT XT = 1.0
FOR EXPONENTIAL DISTURBANCE(S):
INPUT CWT = 1.0
INPUT AWT = 0.0

DAC PROGRAM EXAMPLE NUMBER 1.
OUTPUT FORMAT:

   TIME              XDT               XT = YT           YNT
   UP                UD                UNT               TMP1
   XINPT             XINT              ZHNT              K                 WT

 0.00000E+00      -0.65104E+01       0.10000E+01       0.10000E+01
-0.85104E+01      -0.75104E+01      -0.85104E+01      -0.75104E+01
 0.00000E+00       0.00000E+00       0.75104E+01      -0.85104E+01       0.10000E+01

 0.10000E+01       0.00000E+00       0.93132E-09       0.93132E-09
-0.79259E-08      -0.10000E+01      -0.10000E+01      -0.69946E-08
 0.10000E+01       0.10000E+01       0.10000E+01      -0.85104E+01       0.10000E+01

CASE PARAMETERS:
INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER
INTEGRATION STEP SIZE: DT =  0.15625E-01
SAMPLE INTERVAL: ST =  0.12500E+00
DISTURBANCE: WT =  0.10000E+01
EQUATION FOR UNT: UNT = UP + UD
STEADY STATE OUTPUT: X(T) =  0.93132E-09
```

Figure 49. Output listing (condensed) of results for Case #31.

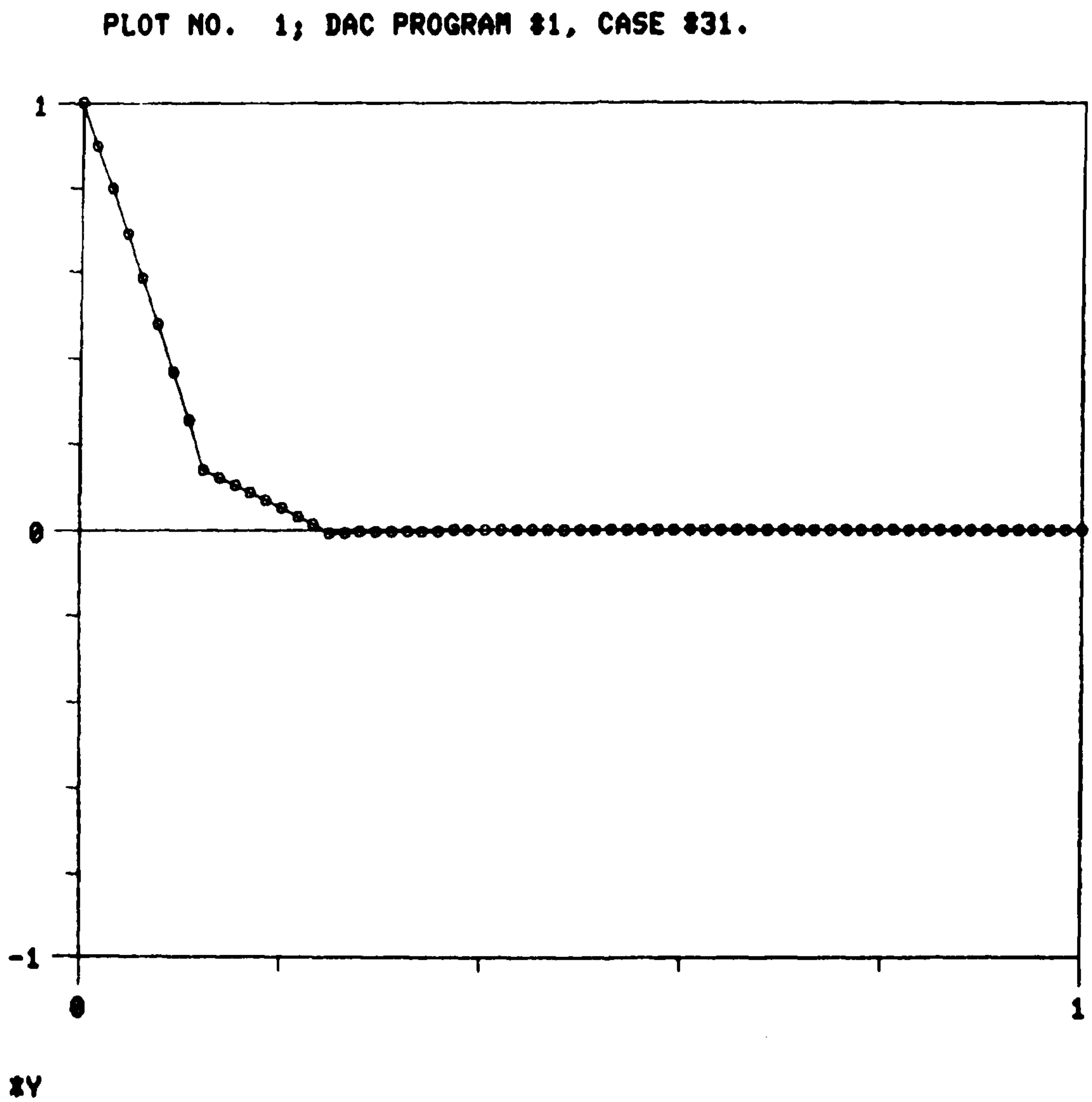


Figure 50. Plot No. 1, DAC program #1, Case #31.

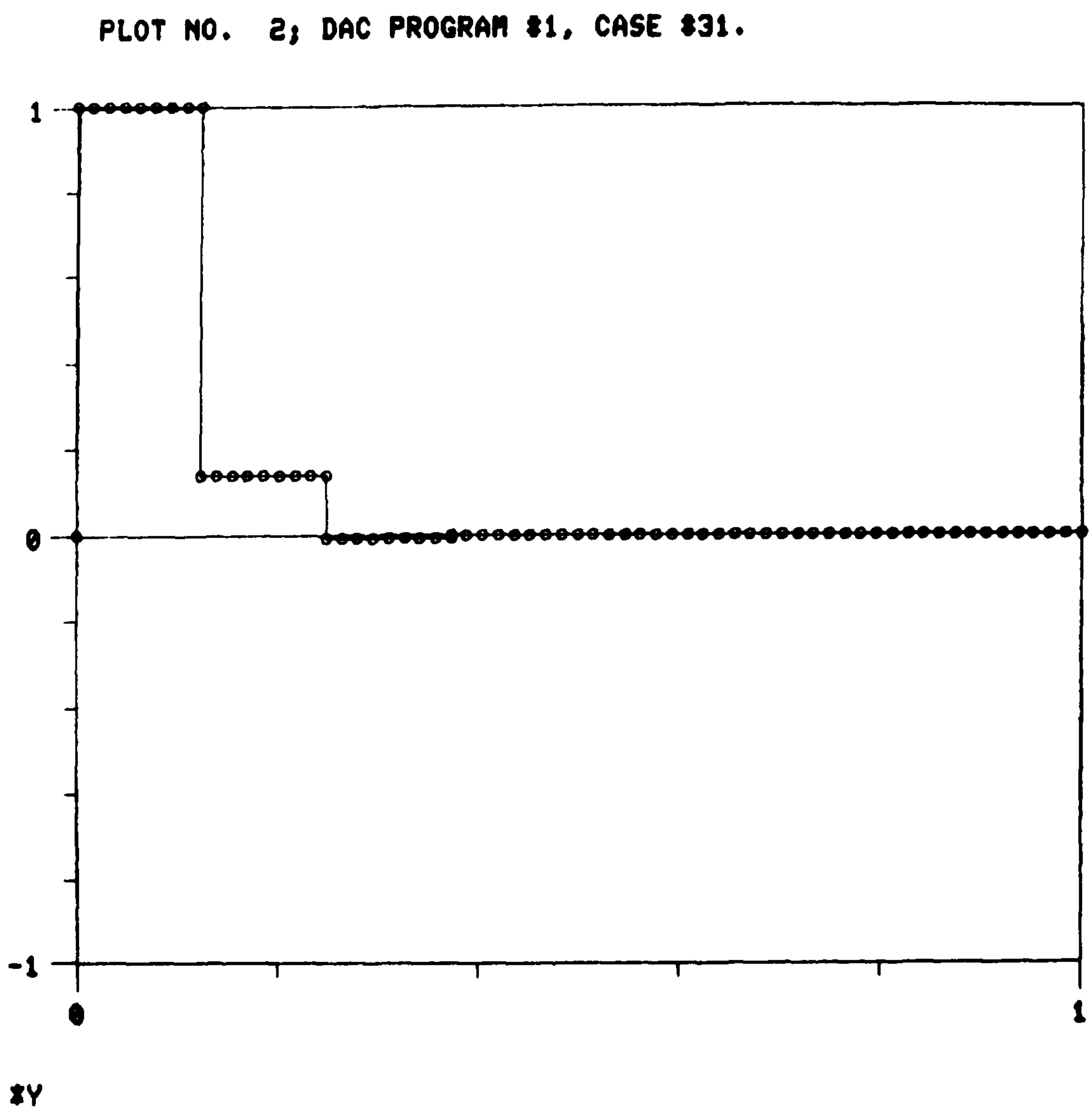


Figure 51. Plot No. 2, DAC program #1, Case #31.

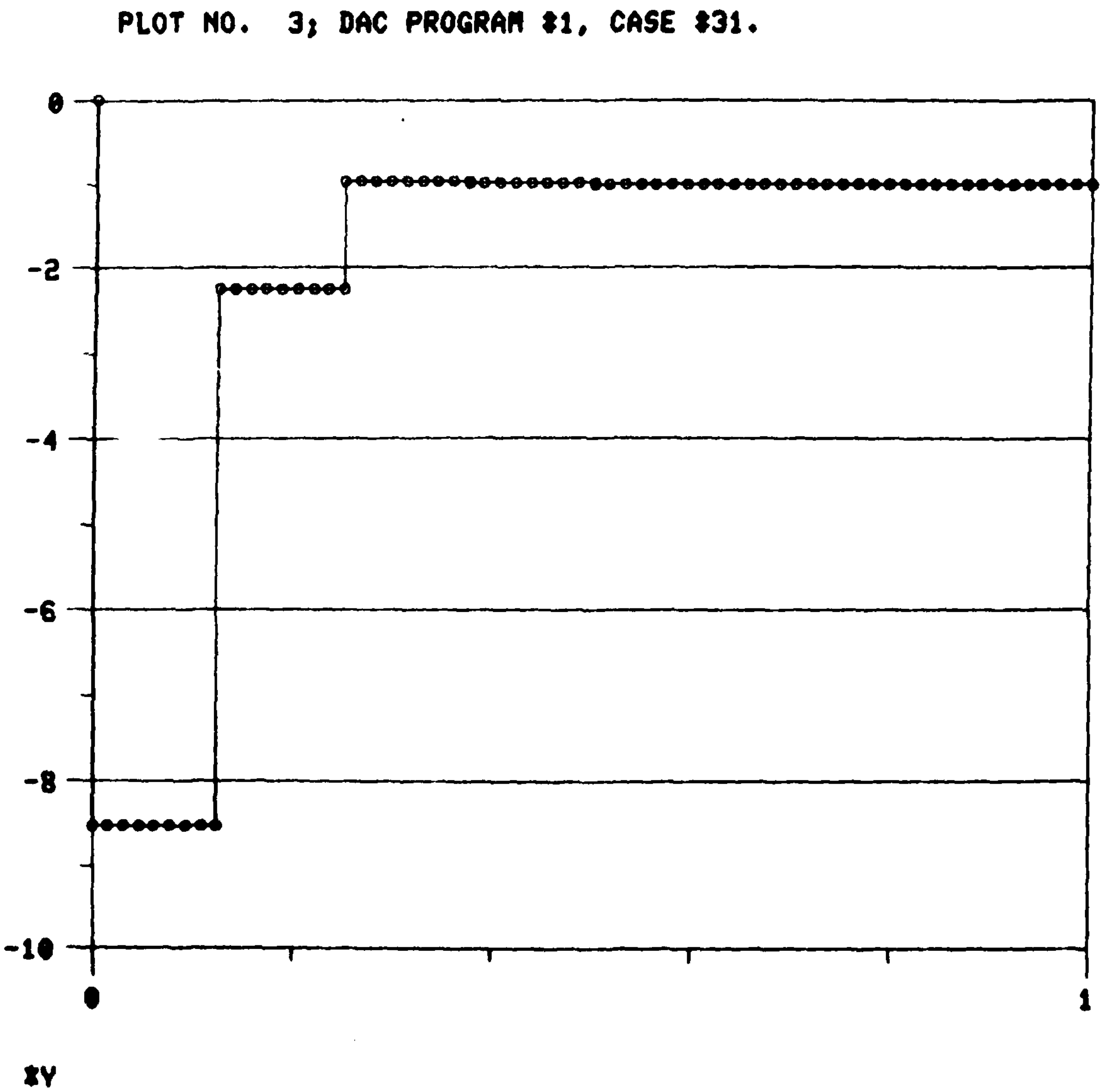


Figure 52. Plot No. 3, DAC program #1, Case #31.

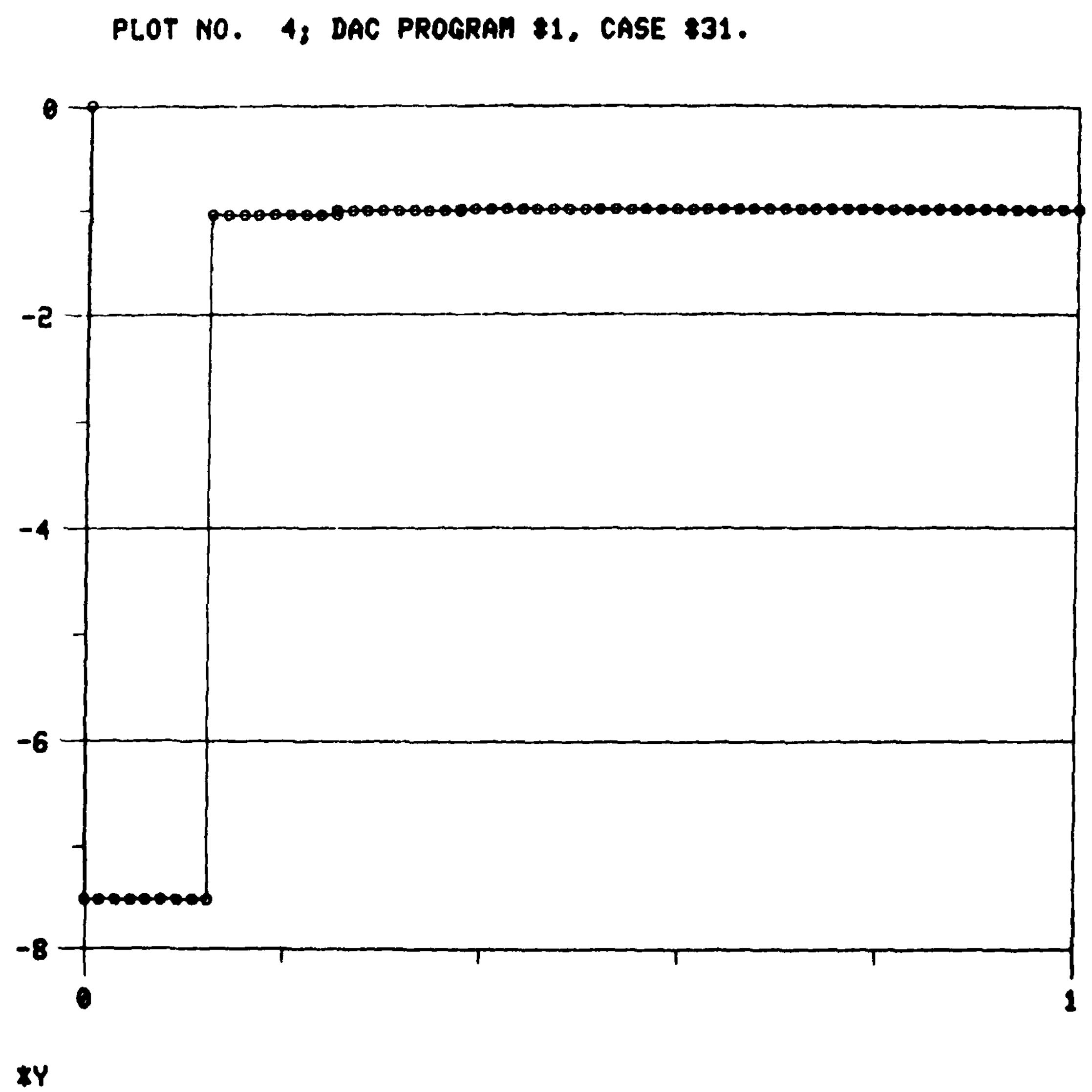


Figure 53. Plot No. 4, DAC program #1, Case #31.

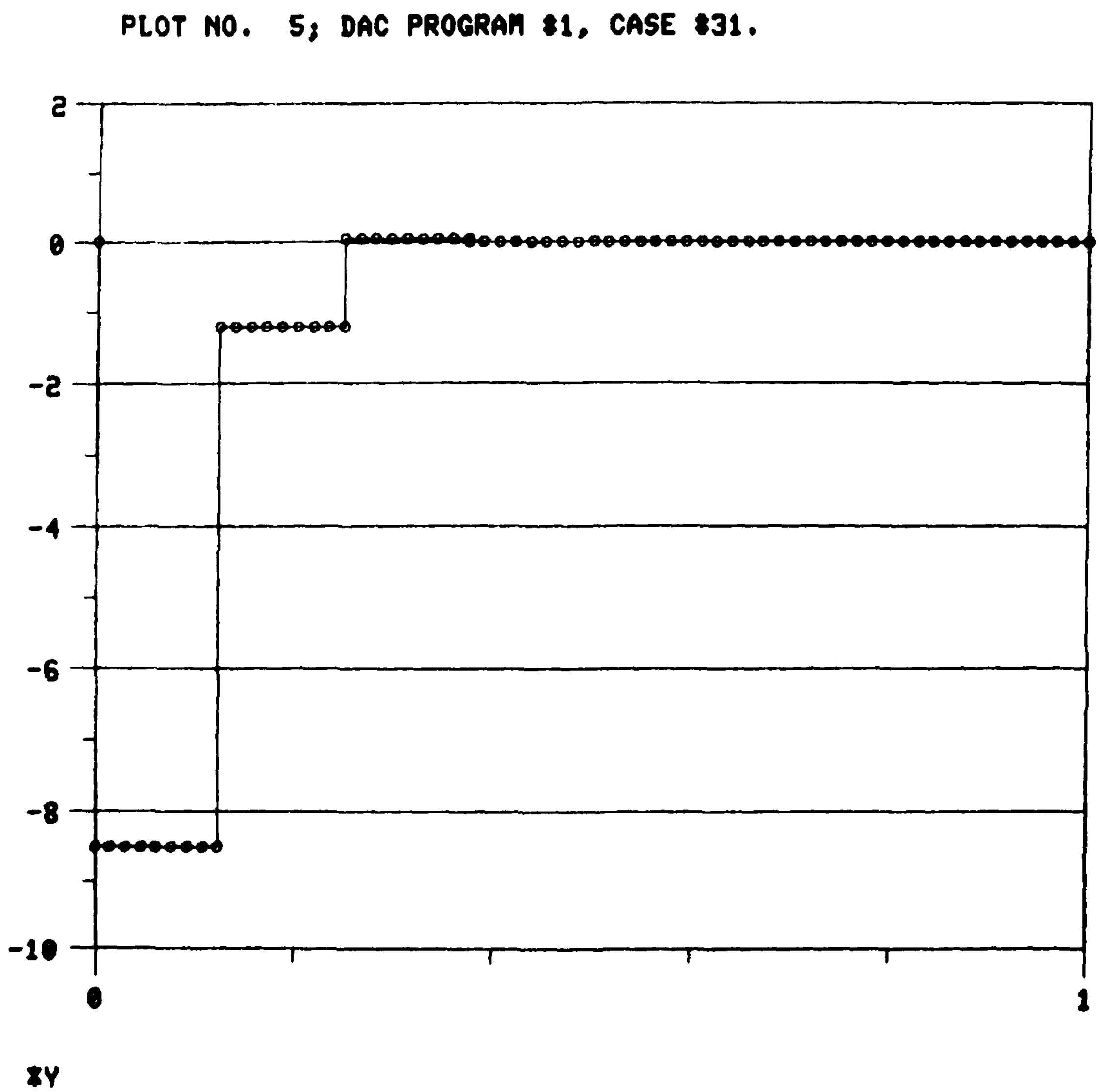


Figure 54. Plot No. 5, DAC program #1, Case #31.

PLOT NO. 6; DAC PROGRAM #1, CASE #31.

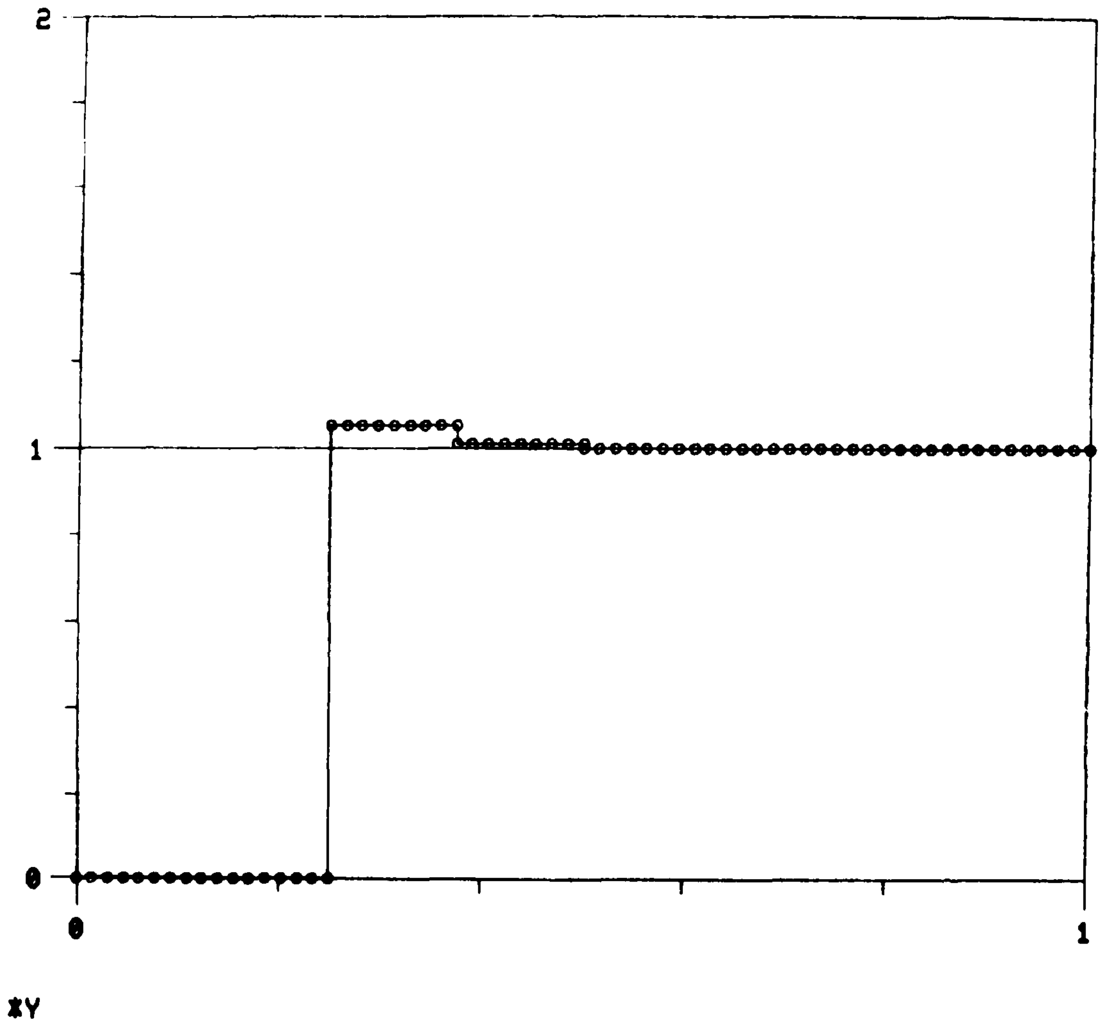


Figure 55. Plot No. 6, DAC program #1, Case #31.

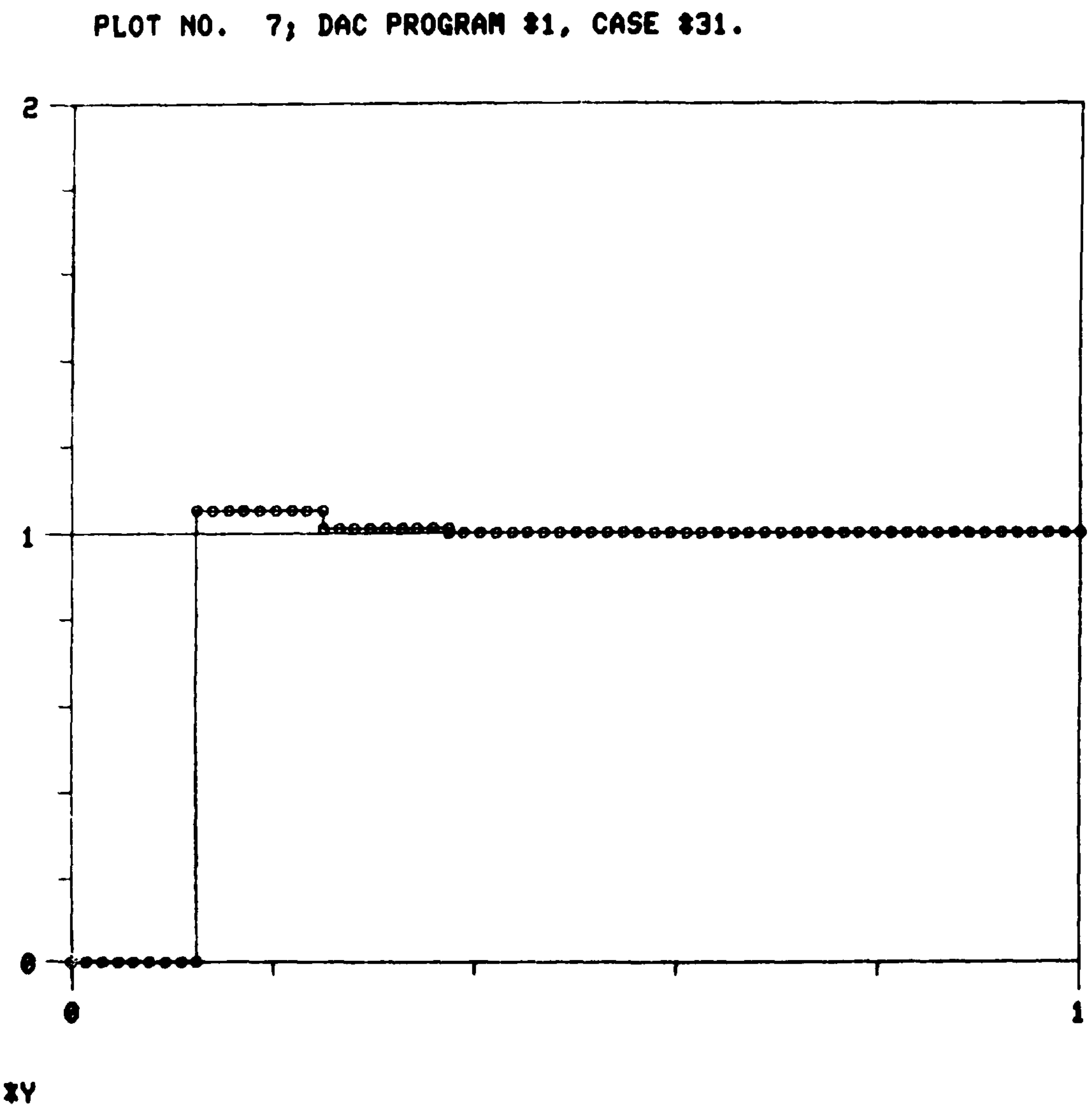


Figure 56. Plot No. 7, DAC program #1, Case #31.

PLOT NO. 8; DAC PROGRAM $1, CASE $31.

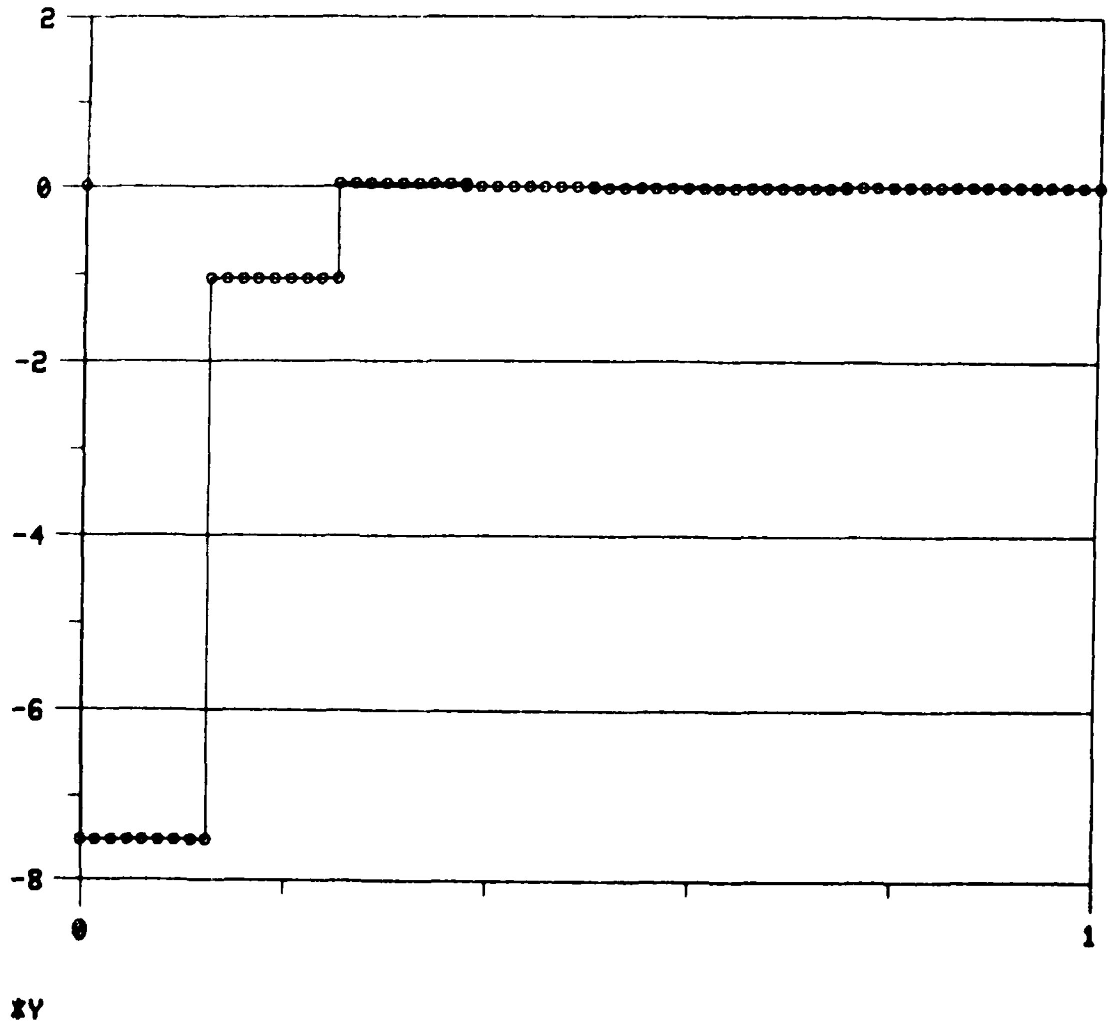


Figure 57. Plot No. 8, DAC program #1, Case #31.

PLOT NO. 9; DAC PROGRAM #1, CASE #31.

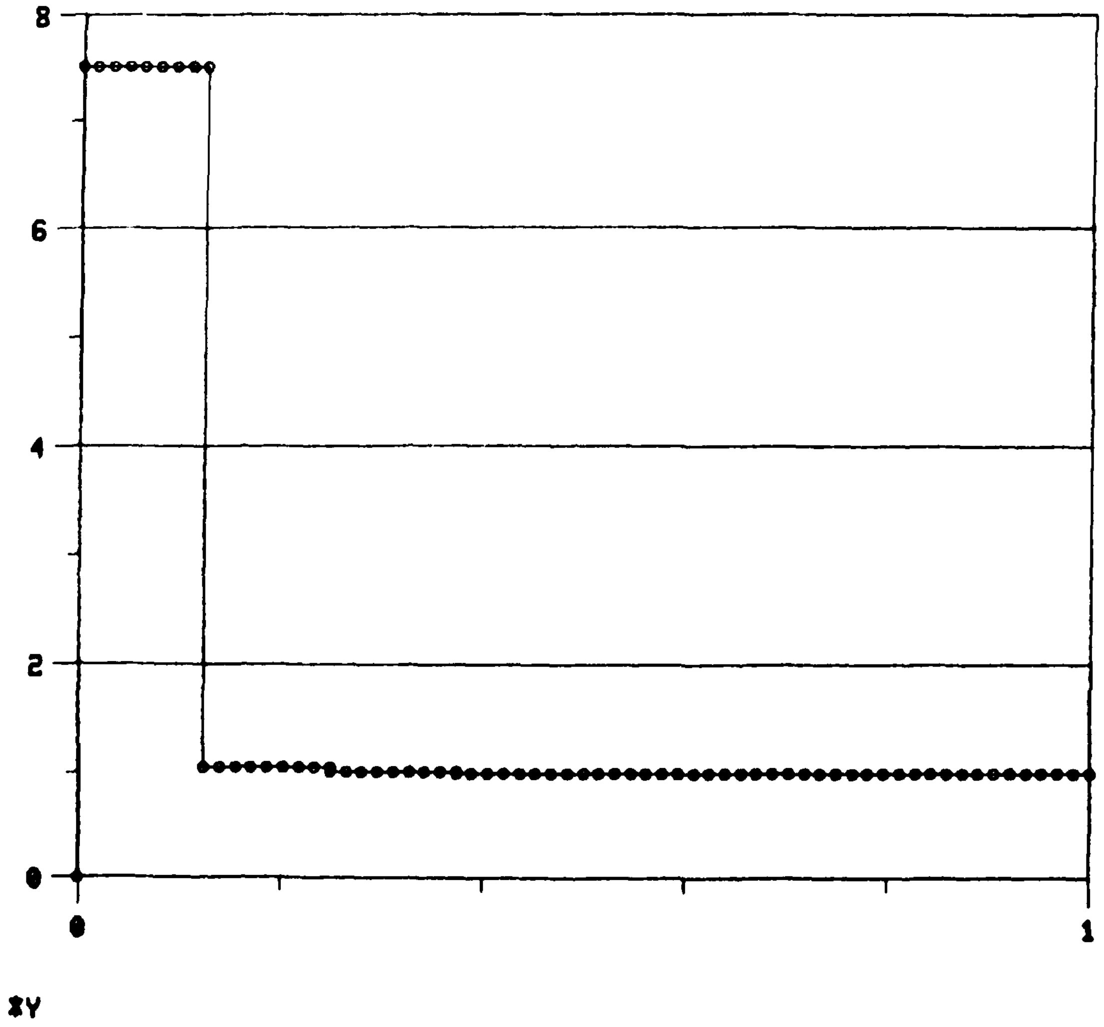


Figure 58. Plot No. 9, DAC program #1, Case #31.

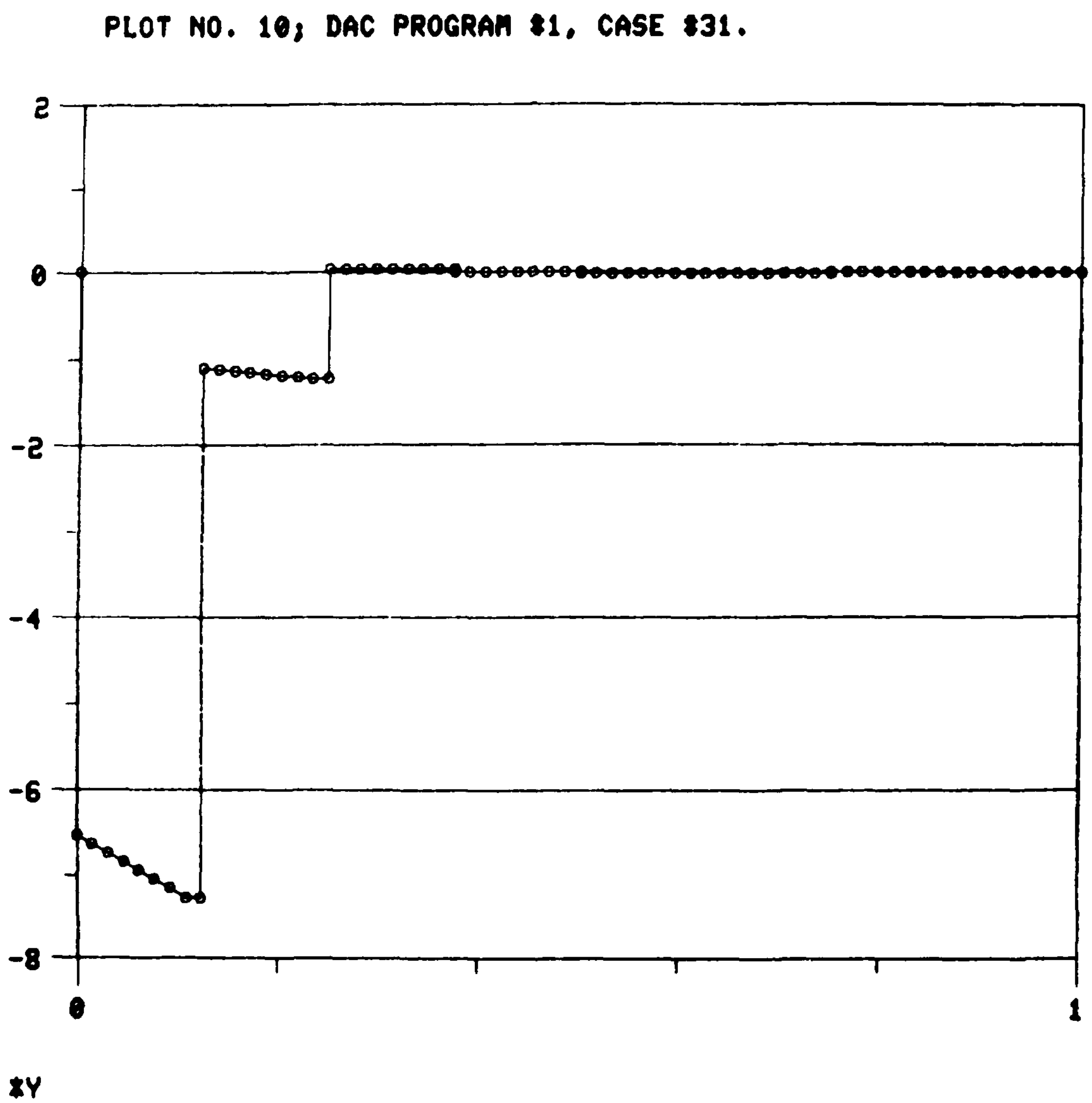


Figure 59. Plot No. 10, DAC program #1, Case #31.

```
        DAC PROGRAM $1, CASE $
>32
        INPUT XT = -1.0
        FOR EXPONENTIAL DISTURBANCE(S):
        INPUT CWT = -1.0
        INPUT AWT = 0.0


        DAC PROGRAM EXAMPLE NUMBER 1.
        OUTPUT FORMAT:

     TIME            XDT             XT = YT         YNT
     UP              UD              UNT             TMP1
     XINPT           XINT            ZHNT            K               WT

   0.00000E+00     0.65104E+01    -0.10000E+01    -0.10000E+01
   0.85104E+01     0.75104E+01     0.85104E+01     0.75104E+01
   0.00000E+00     0.00000E+00    -0.75104E+01    -0.85104E+01    -0.10000E+01

   0.10000E+01     0.00000E+00    -0.93132E-09    -0.93132E-09
   0.79259E-08     0.10000E+01     0.10000E+01     0.69946E-08
  -0.10000E+01    -0.10000E+01    -0.10000E+01    -0.85104E+01    -0.10000E+01


        CASE PARAMETERS:
        INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER
        INTEGRATION STEP SIZE: DT =  0.15625E-01
        SAMPLE INTERVAL: ST =  0.12500E+00
        DISTURBANCE: WT = -0.10000E+01
        EQUATION FOR UNT: UNT = UP + UD
        STEADY STATE OUTPUT: X(T) = -0.93132E-09


DACSP1  --  STOP
```

Figure 60. Output listing (condensed) of results of Case #32.

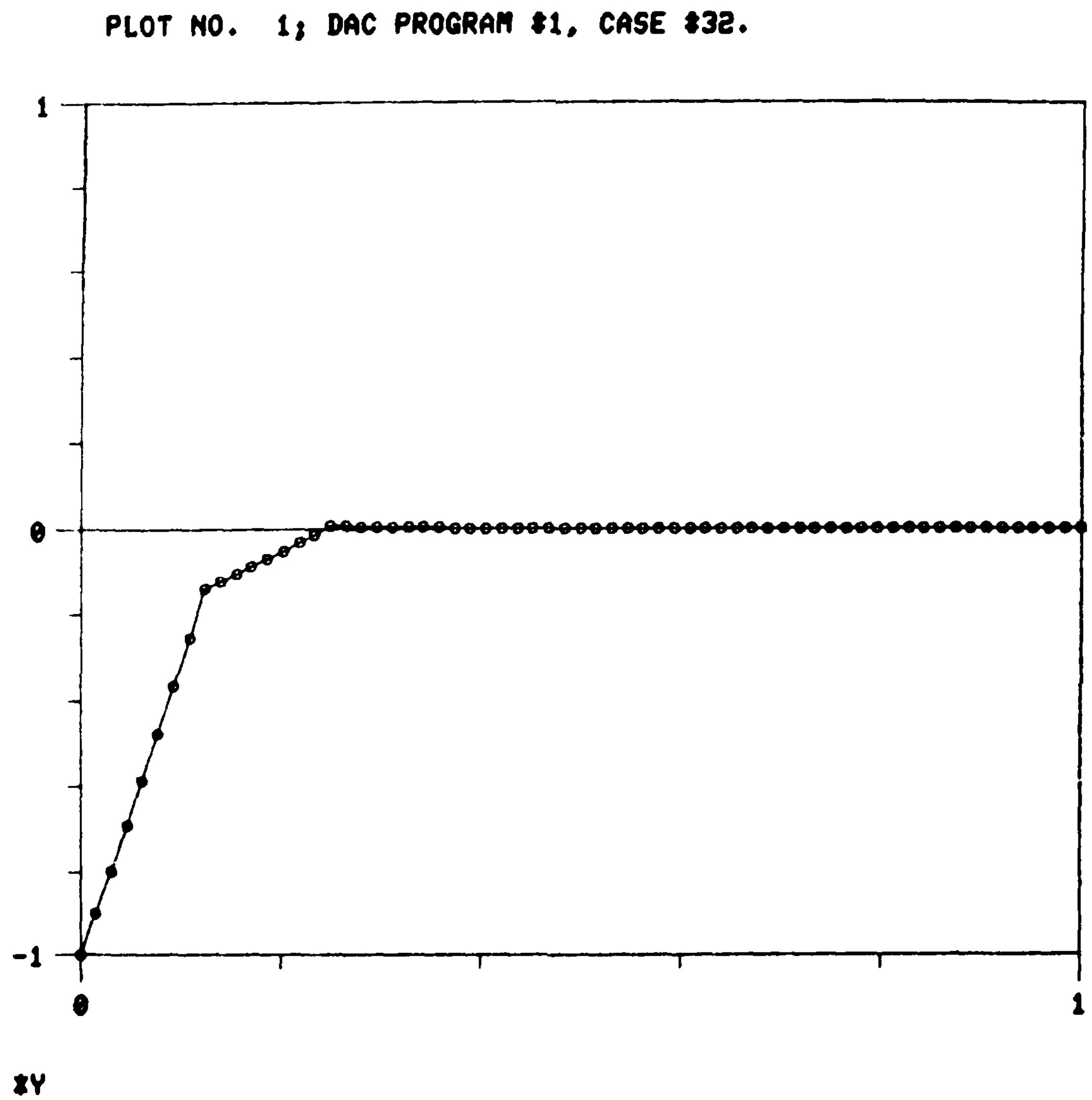


Figure 61. Plot No. 1, DAC program #1, Case #32.

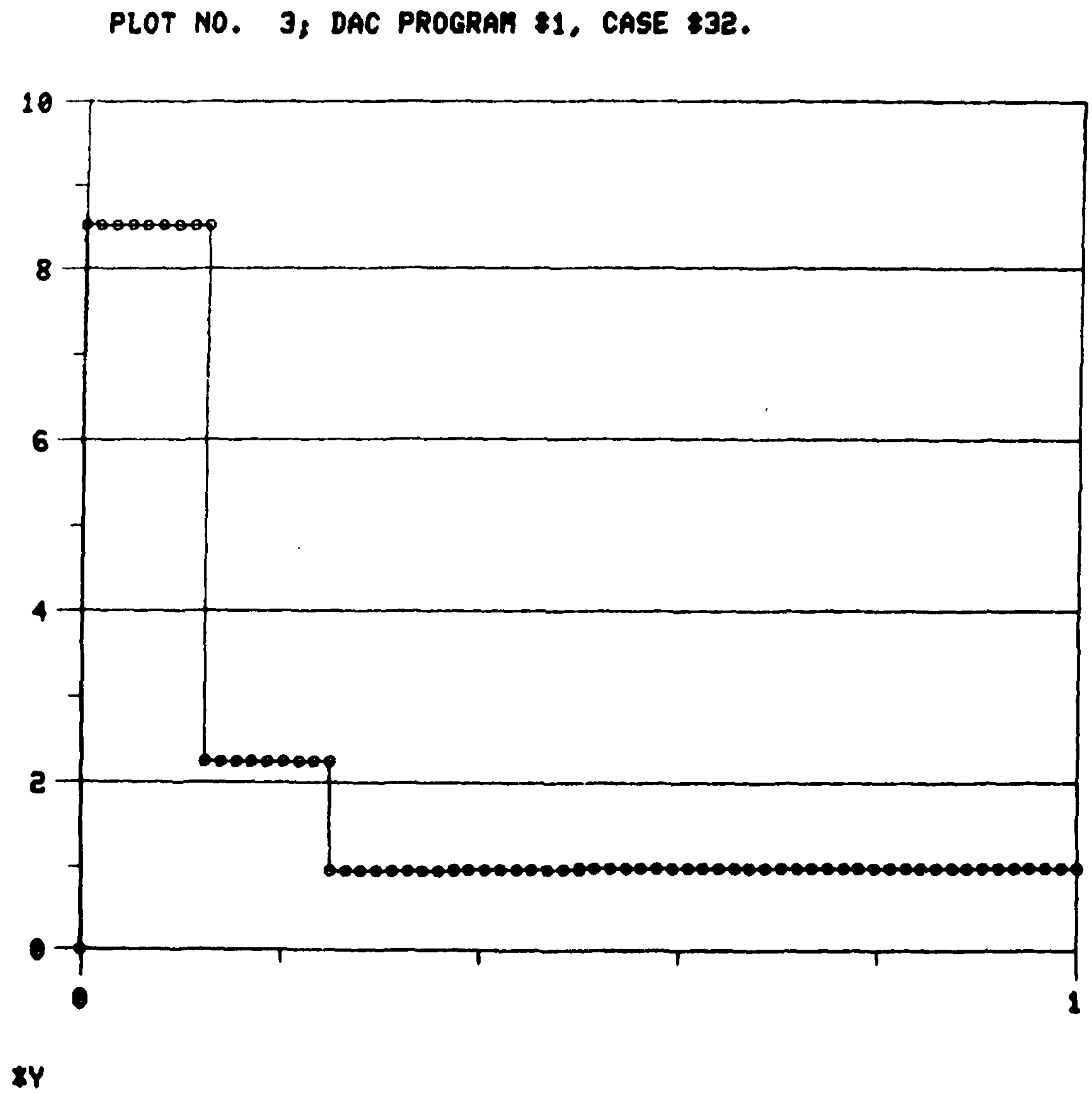


Figure 62. Plot No. 3, DAC program #1, Case #32.

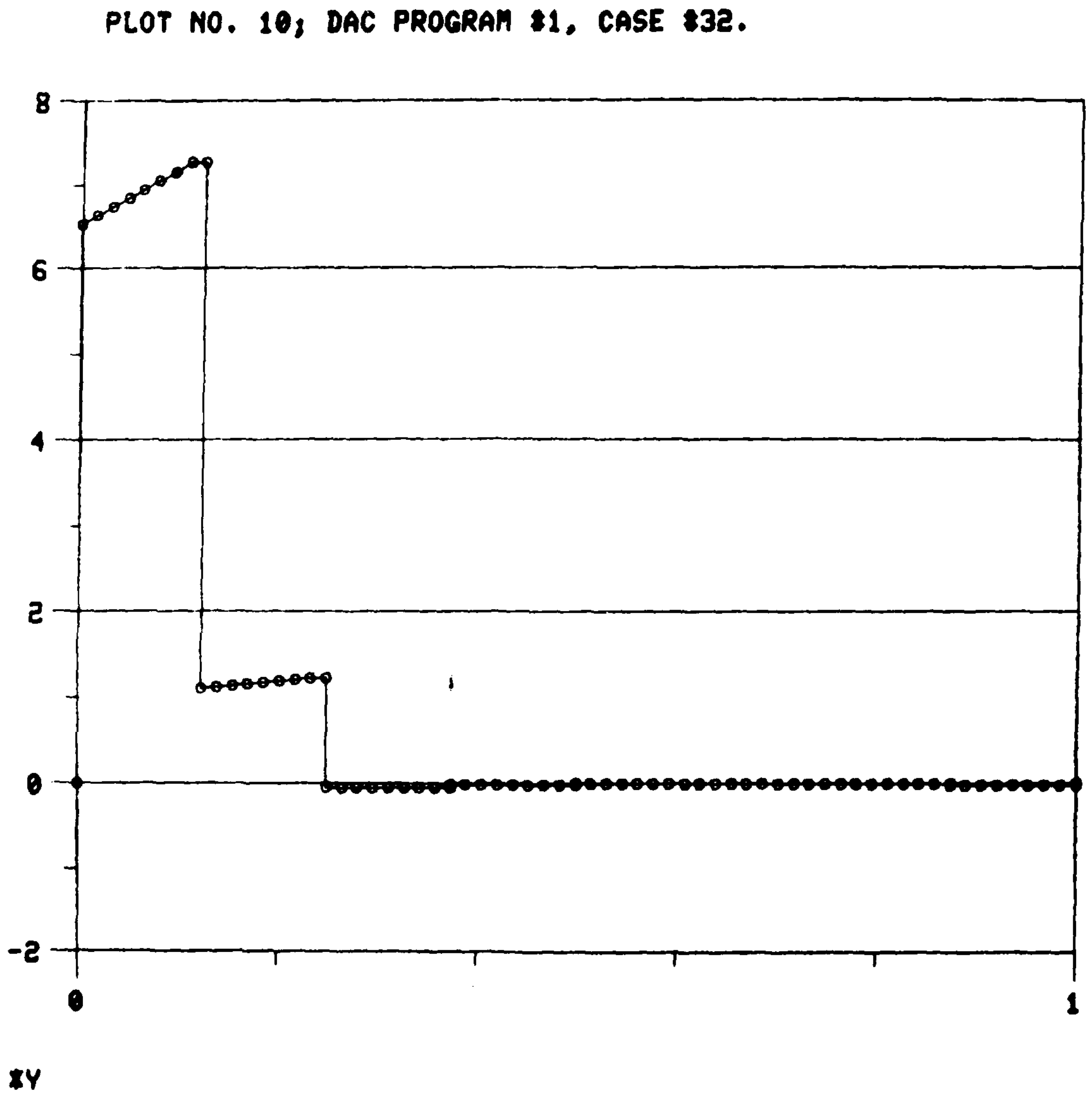


Figure 63. Plot No. 10, DAC program #1, Case #32.

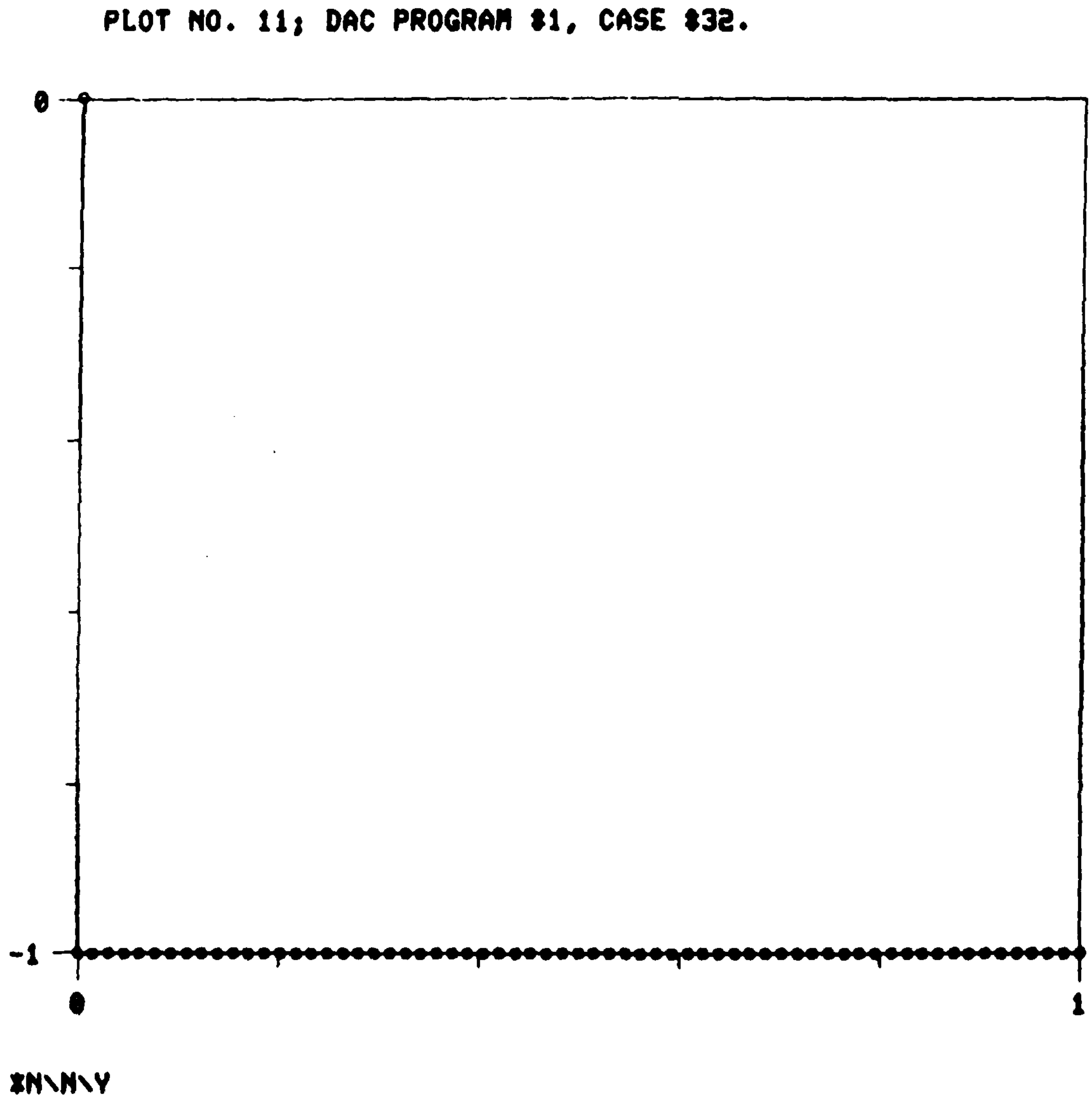


Figure 64. Plot No. 11, DAC program #1, Case #32.

```
DAC PROGRAM #1, CASE #46
INPUT XT = -1.0
FOR EXPONENTIAL DISTURBANCE(S):
INPUT CWT = -1.0
INPUT AWT = 0.0

DAC PROGRAM EXAMPLE NUMBER 1.
OUTPUT FORMAT:

     TIME            XDT             XT = YT          YNT
     UF              UD              UNT              TMP1
     XINPT           XINT            ZHNT             K               WT

  0.00000E+00     0.14021E+02    -0.10000E+01    -0.10000E+01
  0.85104E+01     0.75104E+01     0.16021E+02     0.75104E+01
 -0.75104E+01     0.00000E+00    -0.75104E+01    -0.85104E+01    -0.10000E+01

  0.62500E-01     0.14918E+02    -0.10294E+00    -0.10000E+01
  0.85104E+01     0.75104E+01     0.16021E+02     0.75104E+01
 -0.75104E+01     0.00000E+00    -0.75104E+01    -0.85104E+01    -0.10000E+01

  0.12500E+00    -0.62799E+01     0.85150E+00     0.85150E+00
 -0.72467E+01     0.11153E+01    -0.61314E+01    -0.63951E+01
 -0.11153E+01    -0.75104E+01    -0.11153E+01    -0.85104E+01    -0.10000E+01

  0.18750E+00    -0.66817E+01     0.44972E+00     0.85150E+00
 -0.72467E+01     0.11153E+01    -0.61314E+01    -0.63951E+01
 -0.11153E+01    -0.75104E+01    -0.11153E+01    -0.85104E+01    -0.10000E+01

  0.25000E+00    -0.21853E+00     0.22222E-01     0.22222E-01
 -0.18912E+00     0.94837E+00     0.75925E+00    -0.16690E+00
 -0.94837E+00    -0.11153E+01    -0.94837E+00    -0.85104E+01    -0.10000E+01

  0.31250E+00    -0.23251E+00     0.82408E-02     0.22222E-01
 -0.18912E+00     0.94837E+00     0.75925E+00    -0.16690E+00
 -0.94837E+00    -0.11153E+01    -0.94837E+00    -0.85104E+01    -0.10000E+01

  0.37500E+00     0.48036E-01    -0.66351E-02    -0.66351E-02
  0.56467E-01     0.99820E+00     0.10547E+01     0.49832E-01
 -0.99820E+00    -0.94837E+00    -0.99820E+00    -0.85104E+01    -0.10000E+01

  0.43750E+00     0.5 109E-01    -0.35618E-02    -0.66351E-02
  0.56467E-01     0.99820E+00     0.10547E+01     0.49832E-01
 -0.99820E+00    -0.94837E+00    -0.99820E+00    -0.85104E+01    -0.10000E+01

  0.50000E+00     0.25864E-02    -0.29179E-03    -0.29179E-03
  0.24832E-02     0.10004E+01     0.10029E+01     0.21914E-02
 -0.10004E+01    -0.99820E+00    -0.10004E+01    -0.85104E+01    -0.10000E+01

  0.56250E+00     0.27518E-02    -0.12631E-03    -0.29179E-03
  0.24832E-02     0.10004E+01     0.10029E+01     0.21914E-02
 -0.10004E+01    -0.99820E+00    -0.10004E+01    -0.85104E+01    -0.10000E+01
```

Figure 65. Output listing of results for Case #46.

```
  0.62500E+00   -0.35244E-03    0.49753E-04    0.49753E-04
 -0.42342E-03    0.10000E+01    0.99960E+00   -0.37366E-03
 -0.10000E+01   -0.10004E+01   -0.10000E+01   -0.85104E+01   -0.10000E+01

  0.68750E+00   -0.37503E-03    0.27202E-04    0.49753E-04
 -0.42342E-03    0.10000E+01    0.99960E+00   -0.37366E-03
 -0.10000E+01   -0.10004E+01   -0.10000E+01   -0.85104E+01   -0.10000E+01

  0.75000E+00   -0.26941E-04    0.32079E-05    0.32079E-05
 -0.27301E-04    0.10000E+01    0.99997E+00   -0.24093E-04
 -0.10000E+01   -0.10000E+01   -0.10000E+01   -0.85104E+01   -0.10000F+01

  0.81250E+00   -0.28670E-04    0.14841E-05    0.32079E-05
 -0.27301E-04    0.10000E+01    0.99997E+00   -0.24093E-04
 -0.10000E+01   -0.10000E+01   -0.10000E+01   -0.85104E+01   -0.10000E+01

  0.87500E+00    0.23842E-05   -0.35064E-06   -0.35064E-06
  0.29841E-05    0.10000E+01    0.10000E+01    0.26335E-05
 -0.10000E+01   -0.10000E+01   -0.10000E+01   -0.85104E+01   -0.10000E+01

  0.93750E+00    0.25034E-05   -0.19791E-06   -0.35064E-06
  0.29841E-05    0.10000E+01    0.10000E+01    0.26335E-05
 -0.10000E+01   -0.10000E+01   -0.10000E+01   -0.85104E+01   -0.10000E+01

  0.10000E+01    0.35763E-06   -0.35856E-07   -0.35856E-07
  0.30515E-06    0.10000E+01    0.10000E+01    0.26929E-06
 -0.10000E+01   -0.10000E+01   -0.10000E+01   -0.85104E+01   -0.10000E+01

        CASE PARAMETERS:
        INTEGRATION SCHEME: RUNGA-KUTTA 4TH ORDER
        INTEGRATION STEP SIZE: DT =  0.15625E-01
        SAMPLE INTERVAL: ST =  0.12500E+00
        DISTURBANCE: WT = -0.10000E+01
        EQUATION FOR UNT: UNT = UP + UD
        STEADY STATE OUTPUT: X(T) = -0.30268E-07

TTO  --  STOP
```

Figure 65. Output listing of results for Case #46 (concluded).

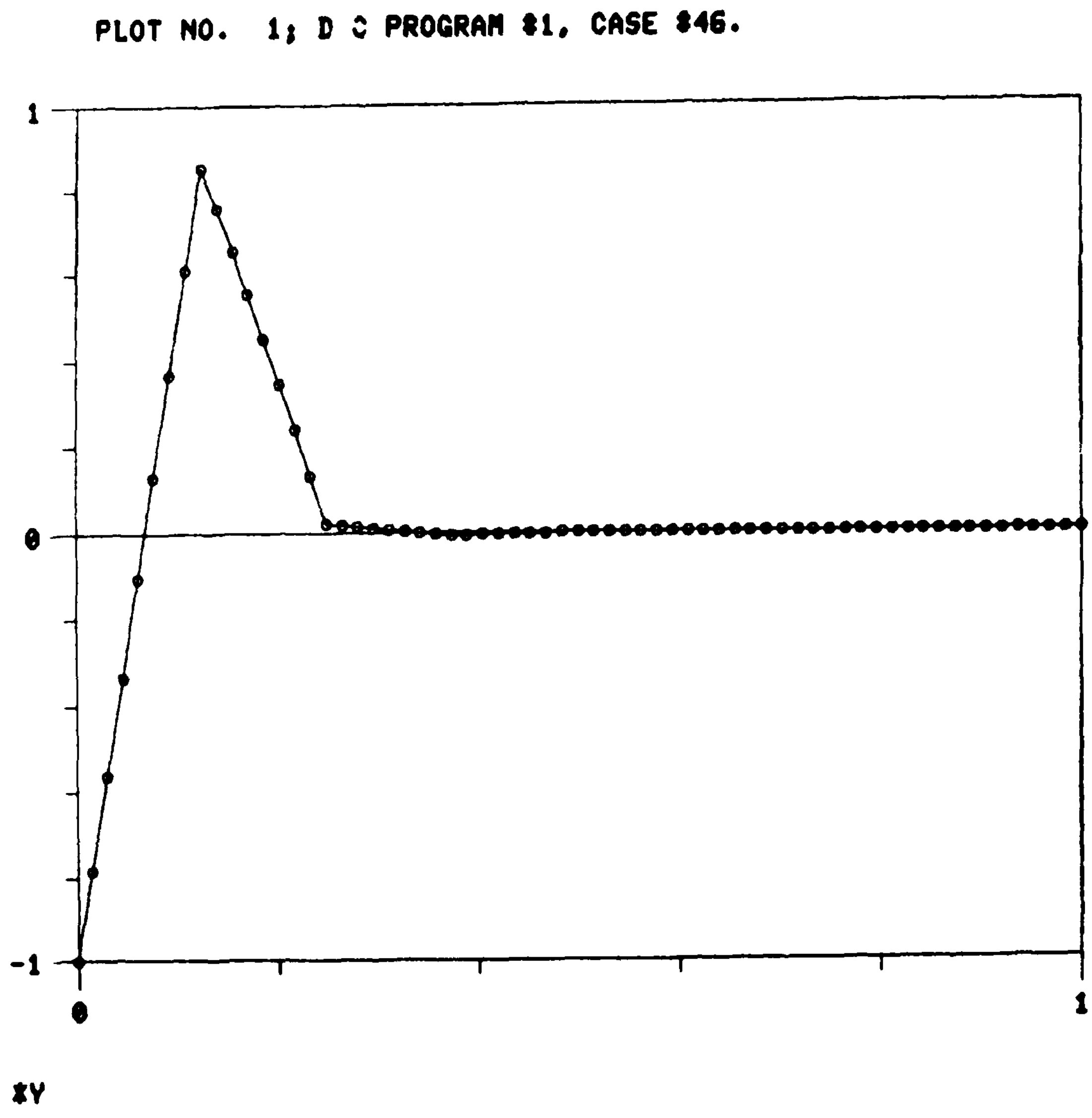


Figure 66. Plot No. 1, DAC program #1, Case #46.

PLOT NO. 3; DAC PROGRAM #1, CASE #46.

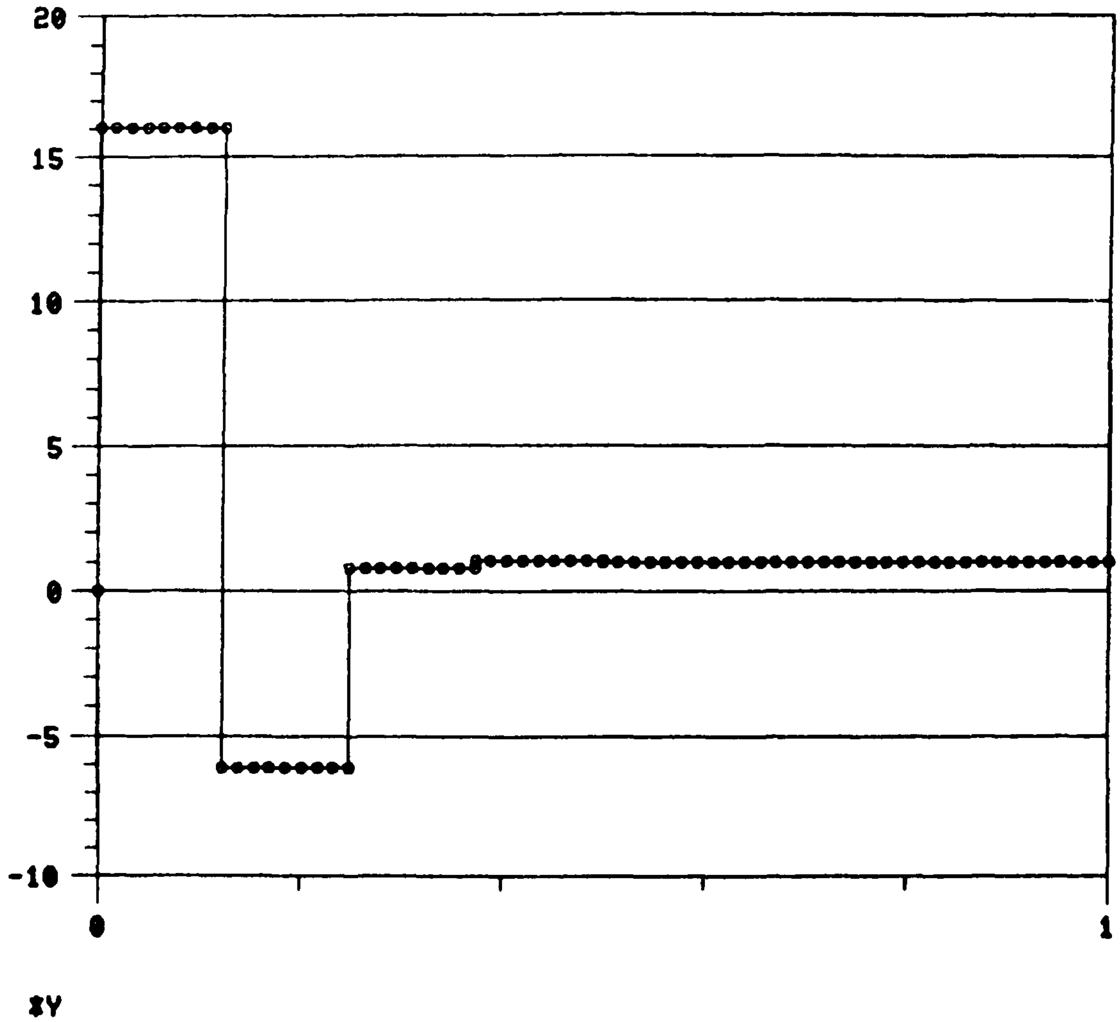


Figure 67. Plot No. 3, DAC program #1, Case #46.

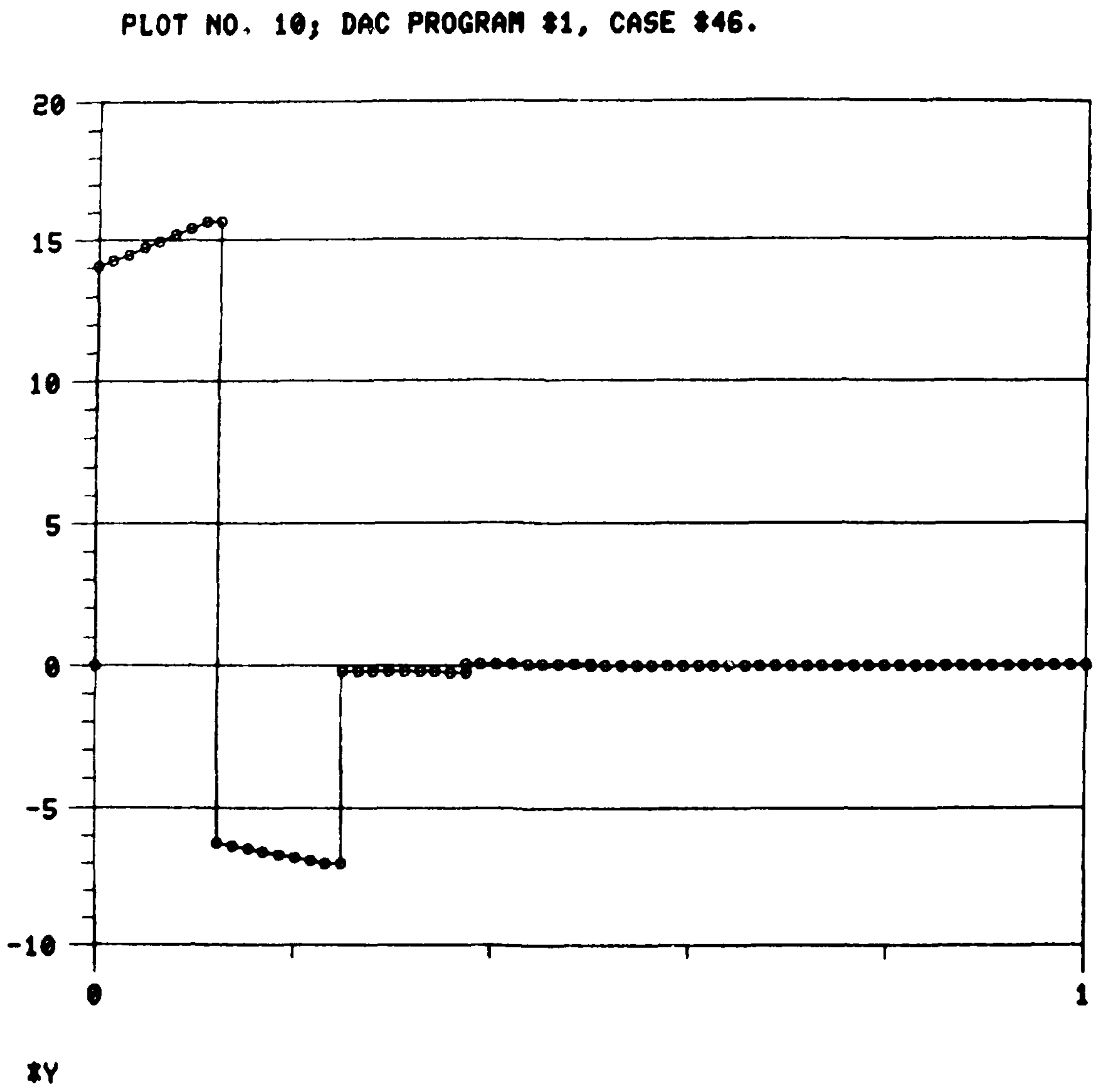


Figure 68. Plot No. 10, DAC program #1, Case #46.

AD-A105 802 ARMY MISSILE COMMAND REDSTONE ARSENAL AL GUIDANCE A--ETC F/G 19/2
DIGITAL COMPUTER IMPLEMENTATION OF A DISCRETE-TIME DISTURBANCE---ETC(U)
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PLOT NO. 11; DAC PROGRAM #1, CASE #46.

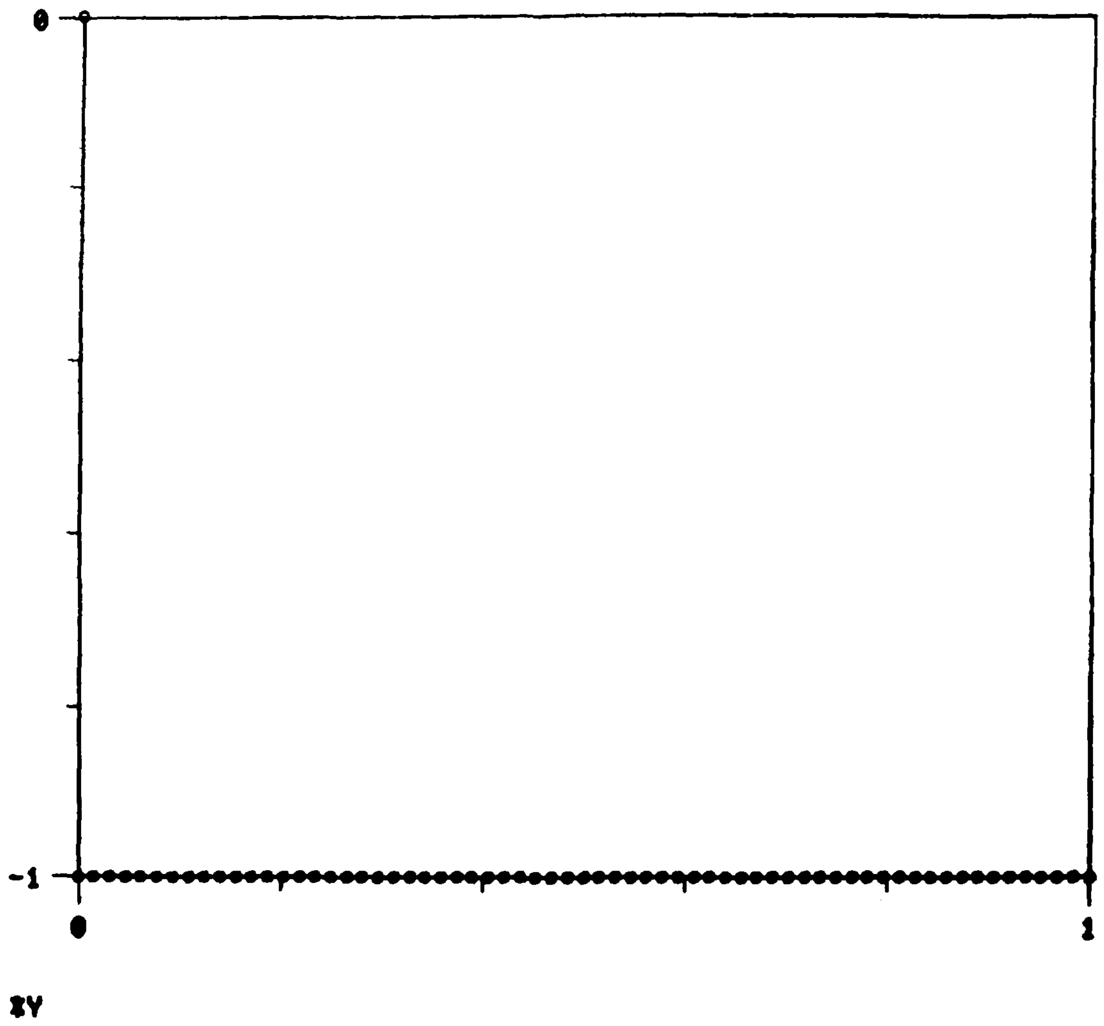

Figure 69. Plot No. 11, DAC program #1, Case #46.

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