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Microprocessor-Controlled, Programmable Ramp Voltage Generator

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MICROPROCESSOR-CONTROLLED, PROGRAMMABLE RAMP VOLTAGE GENERATOR

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ABSTRACT

A special-purpose voltage generator has been developed for driving the quadrupole mass filter of a residual gas analyzer. The generator is microprocessor-controlled with desired ramping parameters programmed by setting front-panel digital thumb switches. The start voltage, stop voltage, and time of each excursion are selectable. A maximum of five start-stop levels may be pre-selected for each program. The ramp voltage is 0 to 10 volts with sweep times from 0.1 to 999.99 seconds.

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MICROPROCESSOR-CONTROLLED, PROGRAMMABLE RAMP VOLTAGE GENERATOR

Introduction

The Extranuclear Laboratories Quadrupole Mass Spectrometer employs quadrupole rod assemblies with combined rf and dc electric fields to obtain ion separation for gas analyses. For a given field potential, only ions of a specific mass-to-charge ratio follow stable trajectories along the length of the rod array and ultimately reach a detector. In this way the quadrupole assembly serves as a mass filter. By ramping the voltage in a saw-toothed fashion from low to high potential, ions of increasing mass number are swept through the filter.

Since the actual voltages applied to the rods can be on the order of kilovolts, a programmable, high-voltage supply is utilized to avoid problems associated with large ramp voltages. To drive the high-voltage supply of the quadrupole residual gas analyzer at Sandia Laboratories, Livermore, a 0-10-V ramp voltage generator has been developed. It is the purpose of this report to describe the design of this microprocessor-controlled, programmable generator.

General Description

The generator produces two output voltages: Output 1, the quadrupole ramp voltage (or sweep voltage), and Output 2, called the scope ramp voltage (or scope sweep voltage), which is used to drive the horizontal axis of a recording device (oscilloscope or chart recorder). Both of these are controlled by a resident microprocessor program.

The desired ramping form of Output 1--initial and final voltages (10 V maximum) and ramping time--is selected by means of front-panel digital thumb switches. Output 2 always rises from 0 to 10 V, with a ramping time identical to that of Output 1. Activation of a store switch causes the program to read and store the digital weight of each switch, perform the necessary

calculations to determine the voltage amplitude-ramp time slope, and then store that information. A complex (but constant slope) ramp of up to five different steps is possible (see Figure 1).

Activation of a start switch causes the program to fetch and distribute stored data to appropriate registers, initiate ramp-voltage generation, and monitor the ramping process. Other front-panel controls permit repetitive or single ramping, baseline shifts, in-process angle modification, and an indefinite hold at any voltage in a pattern.

It is not necessary to use the generator for programmed ramping. When AUTO/MANUAL is set to MANUAL, and there is no program in the memory, Output 1 will be equal to the start voltage setting.

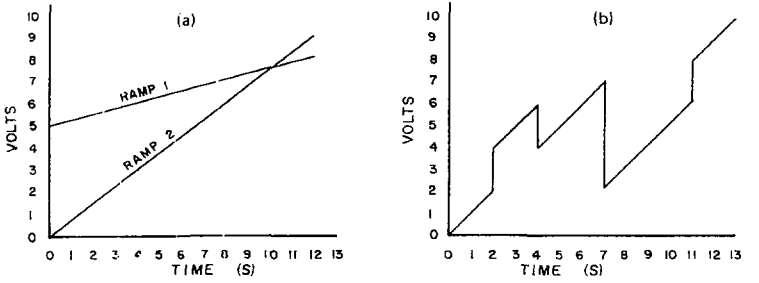


Figure 1. Ramp Program. (a) Two illustrative ramp outputs, showing that the starting voltage and ramp slope are arbitrary (within certain special limitations). (b) Example of a five-step pattern that can be programmed into the ramp voltage generator.

Front-Panel Operating Controls

Figure 2 shows a photograph of the front panel of the programmable ramp generator. The control functions, ranges, and limitations are as follows.

Reset

Places all logic in the zero state. Must be actuated prior to any programming if there is already a pattern in the RAM. Turning the generator power on is equivalent to the reset operation.

Start Voltage

The voltage level from which the ramp will start. Continuously variable from 0.00 to 10.0 V. A maximum of five voltage steps may be programmed.

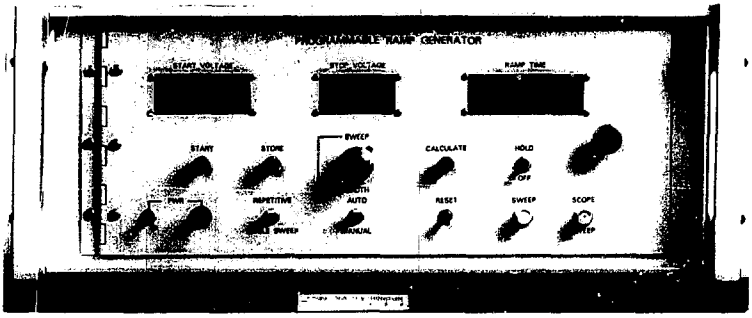


Figure 2. Front Panel of the Programmable Ramp Voltage Generator

Stop Voltage

The voltage level at which the ramp will end. Variable in 10 mV increments from 0.00 to 9.99 V (but see Ramp Time description for limitations).

Ramp Time

The total time the generator will take to reach the stop voltage level from the start voltage level. Continuously variable from 0.1 to 999.99 seconds, with the following limitations:

Ramp Time	Max Stop Voltage
0.1 sec	5.00 V
0.2 sec	6.00 V

Ramp times of 0.01 to 0.09 sec are not possible; the program will treat these times as 1.0 to 9.0 sec if there is an attempt to produce them.

If multiple steps are programmed, the ramp angle is calculated from the initial time. No additional time settings are necessary or possible.

Store

Causes the program to read all front-panel thumb switches, store voltage levels, and calculate the ramp angle. Five start-stop voltage levels can be programmed. The ramp angle is calculated from the initial setting and remains constant throughout program execution. RESET should be used prior to STORE to clear the logic.

Start

Initiates voltage ramp (sweep) generation. Will not function unless a ramp angle is programmed (see Store).

Sweep Width

Permits a ± 5% change in the programmed ramp time. Continuously variable as the setting is changed from 0.00 to 9.99. When set at 5.00, the sweep time will be the programmed (or dialed) ramp time (see Auto/Manual below).

Calculate

A nonfunctional switch (its functions were taken over by STORE during program development).

Hold/Off

When switched to the HOLD position, the program is stopped and the voltage stays constant at the level it reached. The program will continue when the switch is returned to the OFF position.

Repetitive/Single Sweep

Repetitive Mode--The program is repeated continuously (see Figure 3a).

Single Sweep Mode--The program is executed once for each activation of the START switch. When AUTO is selected, the sweep voltage will remain constant once it reaches the stop voltage level. When MANUAL is chosen, the sweep voltage will return to the start voltage level as soon as it reaches the stop voltage (see Figure 3b).

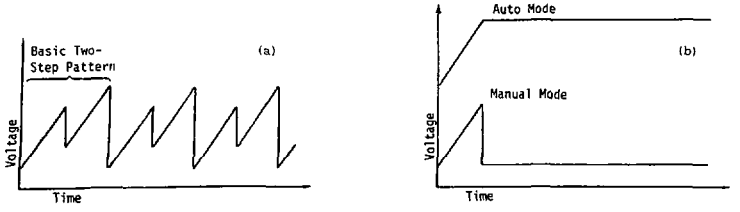


Figure 3. Ramp Generator Output for Repetitive/Single Sweep Modes. (a) Two-step pattern in the repetitive mode. (b) Single sweep mode. The top trace shows a single, one-step ramp in the auto mode. The bottom trace shows the same ramp, but in the manual mode.

Auto/Manual

Auto Mode--The sweep voltage follows the program without modification, repeating the programmed pattern when Repetitive is chosen and remaining constant if Single Sweep if selected.

Manual Mode--If no pattern has been programmed, the sweep output will follow the indicated start voltage. If a pattern has been programmed, the sweep voltage follows the programmed pattern, repeating the programmed pattern if Repetitive is chosen and returning to the start voltage level as soon as it reaches the stop voltage when Single Sweep is selected. If the start voltage is changed (but the change is not stored), the baseline will shift accordingly. For example, if the original start and stop voltages were 1 and 6 V, respectively, and the start voltage is changed to 3 V, then the generator will ramp from 3 to 8 V. Thus, the sum of the start and stop voltages can never exceed 10 V (see Figure 4). Changes (other than programmed changes) in stop voltage or ramp time do not affect the ramp pattern.

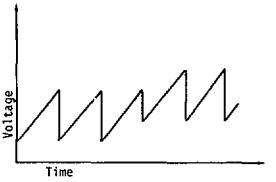


Figure 4. Ramp Generator Output for One-Step Pattern. In the Repetitive Mode with AUTO/MANUAL set to MANUAL. During the third sweep the start voltage was increased, causing baseline to shift to new start voltage.

Int/Ext

A switch located inside the generator (see Figure 5), accessed by opening the front panel (use knob on the right-hand side of the front panel). In the INT position the ramp voltage is controlled by the program. In the EXT position the ramp voltage can be controlled by a 0-10-V analog signal supplied through a rear-panel BNC.

Pushing START will now initiate ramp generation. If SINGLE SWEEP has been set, the generator will produce the above pattern once each time START is pushed.

NOTE: The SCOPE SWEEP output always ramps from 0 to 10 V (or whatever the gain setting happens to be) in the ramp time programmed at the first step. Thus, when a voltage excursion in any step after Step 1 is greater than the initial voltage excursion, the scope output will ramp up to 10 V before the quad ramp is finished, return to 0 V, and begin ramping again. If a voltage step following the first is smaller, the scope ramp will terminate before it has reached 10 V and begin a new excursion at the beginning of the next quad step output (a desirable condition).

Program Description

There are three major program branches, called Manual, Store, and Start. The following is a brief description of each branch. By referring to the flow chart (Figure 6) and the program manuscript in Appendix A, detailed operation will be apparent.

Program Branches

Manual--The program initially enters a loop and sense routine, waiting for a front-panel switch activation. If manual operation is commanded, the positions of each of the start voltage switches are read and the data are immediately deposited in the start level register, A6, causing the dc output voltage to the quadrupole tube to follow the commanded voltage. Start-switch sensing and register depositing are continuous as long as the manual mode switch is activated.

Store--When the store switch is activated, the program reads the front-panel start voltage, stop voltage, and ramp time switches and stores the data in the on-board random-access memory (RAM). The location in the RAM is determined by the number of store-switch operations. RAM data locations are shown on the RAM register maps, Figures 7a and 7b. After storing all switch data, the Floating Point Arithmetric unit (FPAR) calculates ΔV by subtracting the stop level from the start level and stores the results in RAM. The FPAR then calculates the cotangent by dividing the ramp time by ΔV, and this result is also stored in the RAM. (An outline description of how the FPAR works is given at the end of this section.)

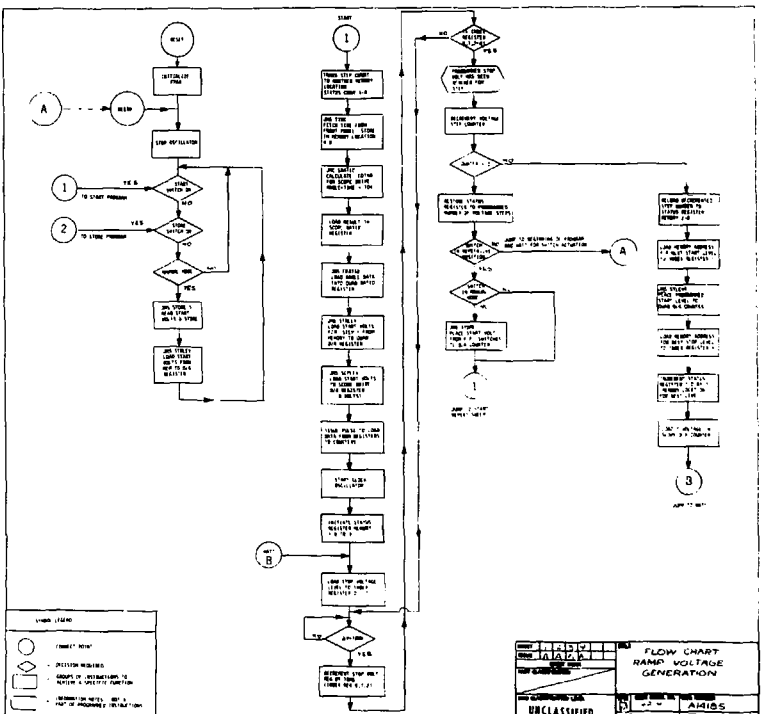


Figure 6. Flow Chart for Programmable Ramp Generator

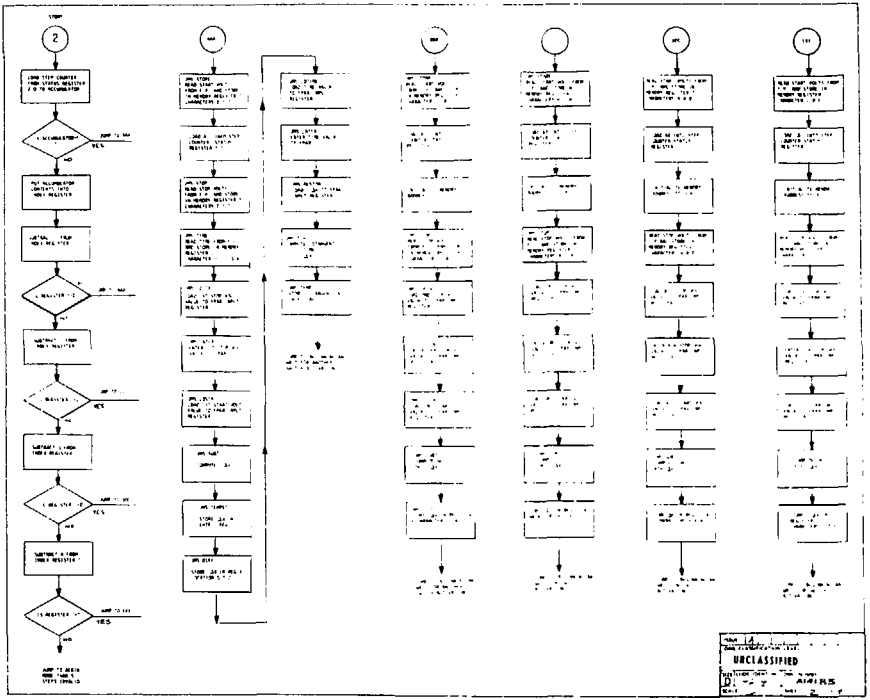


Figure 6 (cont.)

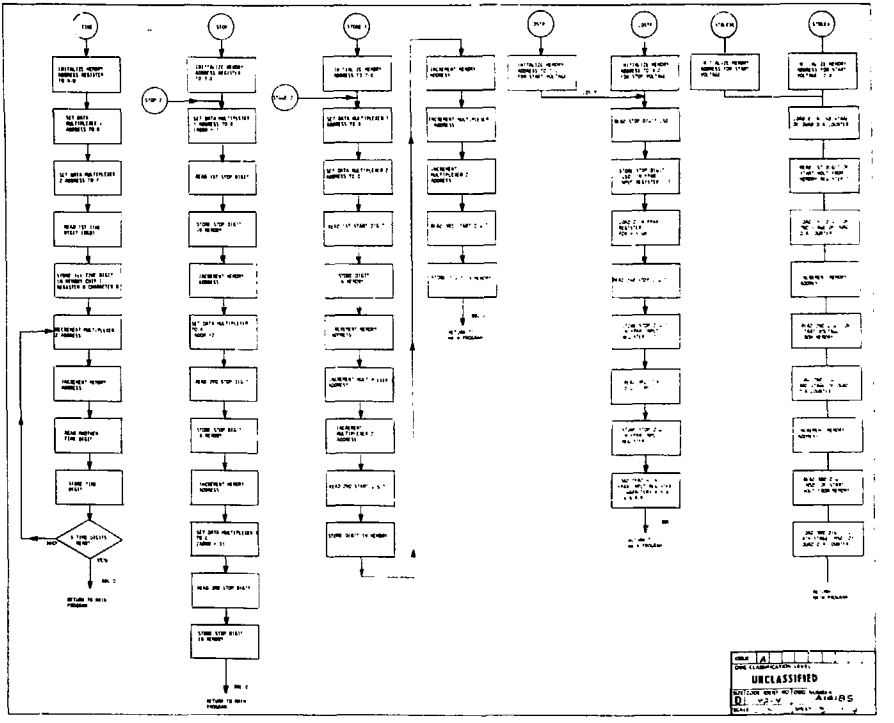


Figure 6 (cont.)

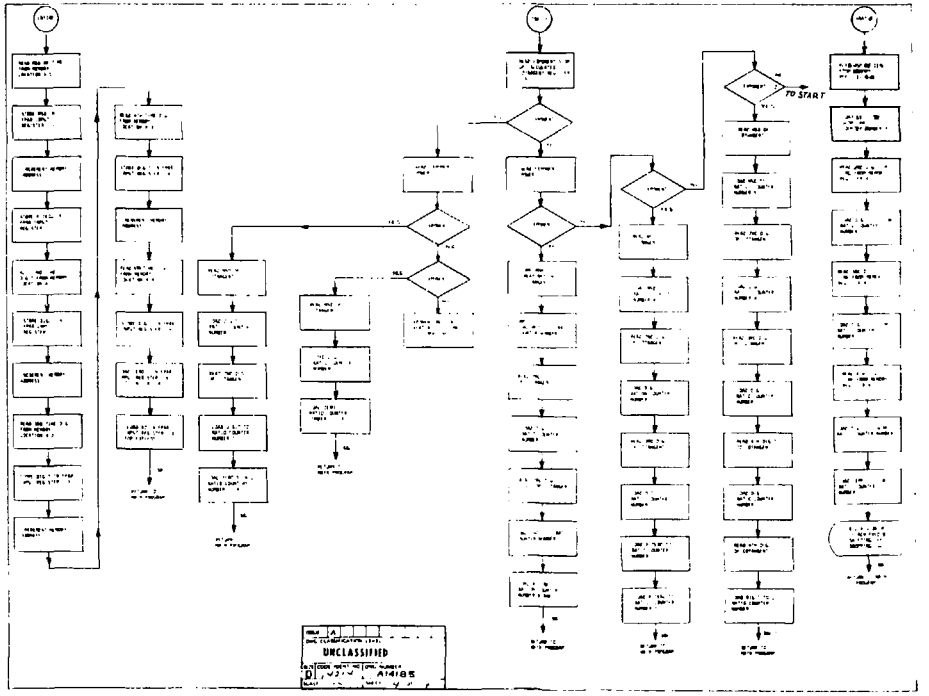
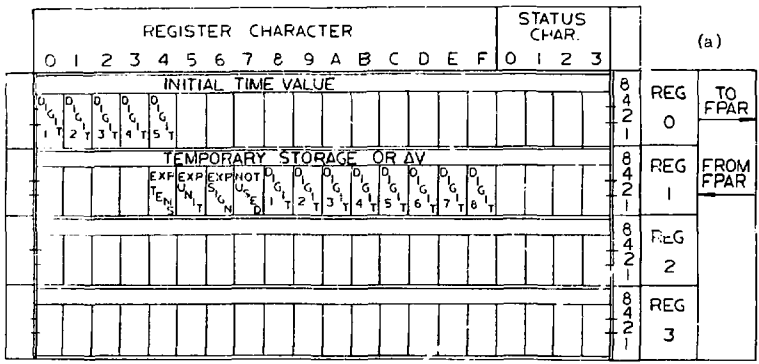
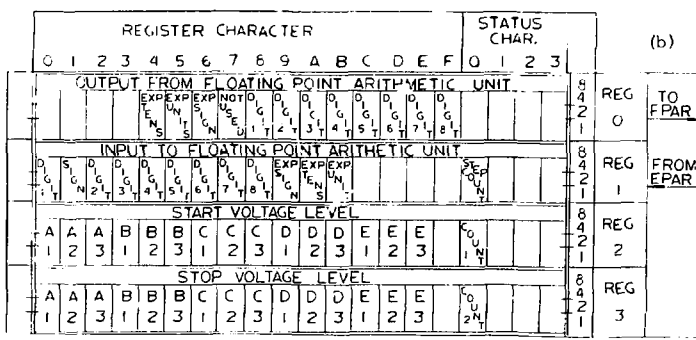


Figure 6 (cont.)



INTEL 4002-1 RAM REGISTER MAP #1



INTEL 4002-1 RAM REGISTER MAP #2

Figure 7. RAM Register Maps for Programmable Ramp Generator

Angle information for driving the quadrupole tube at the desired ramp angle is now stored. The program then returns to the loop and sense routine, awaiting further commands. If the STORE switch is again activated, the preceding will be repeated but the RAM locations will be different.

Start--*When the START switch is activated, the program first calculates* the angle cotangent for the scope ramp output. The FPAR does this by dividing the ramp time (read from the RAM) by the GAIN setting (nominally 10 V), the maximum amplitude of the scope output. The result is placed in scope ramp register, A8, which the program accomplishes by placing a data digit at Outport 2 and then activating the appropriate load line (L10-L14). A load line is activated by placement of the correct number at Outport 3, which causes the corresponding line from the load line selector, A4, to be energized. The same technique is used for loading all other registers.

Next, the quad ratio register, A5, is loaded with the cotangent previously stored in the RAM. The quad start voltage level is subsequently extracted from the RAM and deposited in the start level register, A6. Finally, the start level for the scope ramp is placed in A9. With all registers loaded, a pulse is issued which dumps the register contents of A5 and A8 into mating counters, the clock is turned on, and ramping commences. During the ramping, the program counts each 10-mV increment in output voltage. For a one-step ramp, when the stop voltage has been reached and the REPETITIVE/SINGLE switch is in the single mode, the clock is turned off and the loop and sense routine is again entered. However, if a multiple-step ramp is programmed, *the next start level is fetched from RAM and is* properly deposited and the ramp output continues from the new level until the second stop level is reached. This process is continuous until the program is completed, after which the REPETITIVE/SINGLE switch is interrogated. If it is in the single mode, the clock is turned off and the program awaits further commands; if it is in the repetitive mode, the entire program is repeated.

FPAR--The FPAR operates broadly as follows:* Upon ac power turn-on or manual reset, the program enters a subroutine CALRDY which initializes the FPAR by first manipulating the hold line and then waiting for certain timing relationships between RDYI and RDYO signals. A series of three commands subsequently enters, a master clear code followed by an error clear and a code which specifies that the FPAR work with data in scientific notation. Eight digits, sign, exponent, and exponent signs must be presented to the FPAR fixed format (Figure 7a, Register 0). The RAM Register 0 is always used as input to the FPAR. Prior to an entry function or arithmetic operation, the 12 digits are first arranged in a correct format under program format control. After an operation, the result is removed by an

*For complete details see D. C. Macmillan, "A Floating Point Arithmetic Unit for Pro-Log Based Control Systems," Sandia Laboratories, SAND77-8041, January 1978.

output subroutine and placed in RAM Register 2 in the format and location shown on the RAM register map (Figure 7a); however, the number in the FPAR is retained. Because of the FPAR timing constraints, the number is placed as the FPAR offers it in RAM Register 3. Other subroutines then unscramble Register 3 contents and move them to other registers.

Circuit Description

The programmable RAM generator block diagram shown in Figure 8 contains ten plug-in printed wiring boards, A1 through A13 (three boards required two spaces each). The circuits are a hybrid design of CMOS and TTL integrated-circuit packages. The following is a description of each board.

A1--The Program Logic System (Prolog Model PLS-441)--Contains the Intel 4040 microprocessor, the Intel 1702 programmable read-only memories for program storage (1280 words by 8 bits), the Intel P4001 RAMs (80 words x 4 bits), and the input/output ports (four each). Figure 9 illustrates the microprocessor port assignments.

A2--Floating Point Arithmetric Unit--Contains the National Semiconductor Model No. 57109 FPAR and associated control logic and performs all calculations.

A3--Clock and Switch Control--All front-panel switch controls are interfaced through this board for debouncing before connecting to the microprocessor. The 100-kHz system clock is also designed into this board. The square-wave output from the clock is formed by interconnecting three CMOS gates. In order to allow a slight modification of the analog output ramp angle, a front-panel ten-turn digital potentiometer provides $\pm$ 5% change in clock frequency. Control lines are wired to the microprocessor Outport 0 to control the on/off time of the clock.

A4--Load Line Selector--Contains the 4- to 16-line decoder. Decodes four BCD inputs from the microprocessor Outport 3 to 1 of 16 mutually exclusive outputs. Each output line is connected to a load input on a data register. There is a common data line to all registers, with the program selecting what register receives which data. The program thus acts primarily as a data distributor and controller, sequentially removing data from the RAM or front-panel switches, placing it in a particular storage register, and then turning on the 100-kHz oscillator.

A5--Quadrupole Ramp Cotangent Register and Counter--A five-stage register and counter. The register is loaded initially with the calculated ratio of the time and the start/stop voltage difference. Under program control, the register is loaded into the five-stage counter, which then counts

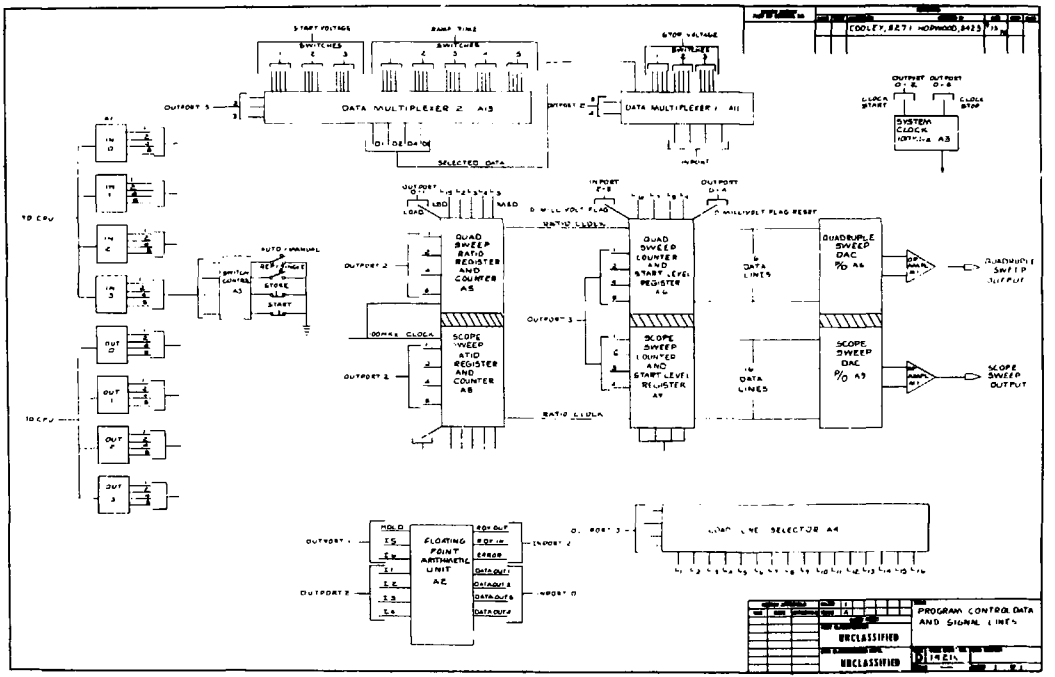


Figure 8. Block Diagram for Programmable Ramp Generator

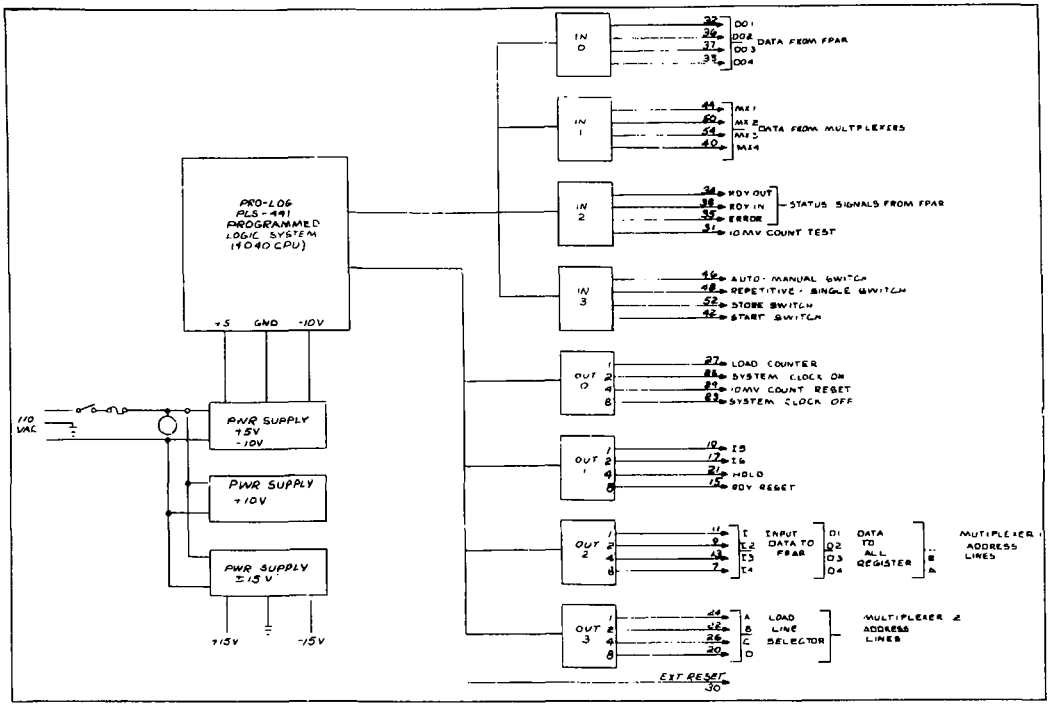


Figure 9. Microprocessor Port Assignments

down to 0 at a 100-kHz rate. On reaching 0 count a pulse is produced by a mono-stable multivibrator located on A5, which is connected to other circuits and eventually increments the analog ramp output voltage by 10 mV. In addition, the pulse causes the counter to be reloaded with the cotangent stored in the register. This process is continuous until the program stop voltage is reached.

A6--Quadrupole Ramp Counter and Start Level Register--A combined four-stage register, counter, and digital-to-analog converter. The 16 BCD output lines from the counter are connected to the inputs of a four-digit D/A converter. A counter state of zero results in 0 V, whereas the maximum counter state of 9999 results in -9.99 V from the D/A converter. Prior to the counting action, the initial start voltage is loaded from RAM under program control, resulting in an instantaneous change in the analog output voltage. The clock input for the counter is from the pulse produced from the cotangent counter previously described. Each clock input produces an output voltage change of 10 mV. Thus, for example, if an excursion of 10 V in 400.00 seconds is programmed, then the cotangent register contains the number 5000,

$$500.00 \text{ (sec)}/10 \text{ (V)} = 50.00 \ ,$$

but 50.00 is read as 5000 by the register. The total time needed to empty the register for each 10-mV pulse is then (the clock period being 10 microseconds)

$$(5000)(10) = 50,000 \text{ microseconds} \ .$$

10,000 counts are required to the D/A converter for a 10-V output. The microprocessor reads and records each 10-mV increment and stops the 100-kHz clock when the stop voltage has been reached.

A7--An unused connector slot.

A8--Scope Sweep Cotangent Register and Counter--Operates identically to A6.

A9--Scope Ramp Counter and Start Level Register--Operates identically to A6, except that all load lines of the counter are common. Separate load lines are unnecessary since the start voltage is always zero.

A10--An unused connector slot.

A11--Data Multiplexer Number One and Output Amplifier--Consists of a 16-line to 4-line data selecter. Data are selected by two address lines from the microprocessor Outport 2. Input data to the multiplexer are from the panel stop voltage switch and data from Multiplexer 2. The two output

buffer amplifiers are connected in an inverting configuration to supply a ramp voltage of + 10 V (nominal maximum) to the quadrupole tube of an oscilloscope horizontal axis. A gain adjustment located behind the front panel and accessible by the operator permits a change of ± 50% in scope-drive output voltage.

A12--Data Multiplexer Number 2--This circuit utilizes four each, 8-line to 1-line data selecters, forming a 32-line to 4-line selector. Data are selected by three address lines of the microprocessor Outport 3. Data input to the multiplexer is from the front-panel start voltage switches and ramp time switches. The output is connected directly to the microprocessor Inport 1.

The detailed schematic, wiring list, and chassis mechanical drawings are included in Appendix B.

APPENDIX A

PROGRAM FOR THE RAMP GENERATOR

```
 2 001000                NOP
 3 001001        INIT:   JMS     CALRDY
 4 001003        BEGIN:  FIM     0,0,0
 5 001005                SRC     0,
 6 001006                LDM     8,
 7 001007                WRR
 8 001010                CLB
 9 001011                WRR
10 01012                 FIM     3,3,0
11 01014                   SRC     3
12 01015                   RDR
13 01016                   RAL
14 01017                   JCN     C0,ST
15 01021                   JUN     START
16 01023        ST:        RAL
17 01024                   JCN     C0,MANU
18 01026                JUN     DEBOUC
19 01030        MANU:   RDR
20 01031                RAR
21 01032                JCN     C1,BEGIN
22 01034                JMS     STORE1
23 01036                JMS     STRLEV
24 01040                JUN     BEGIN
25 01042        DEBOUC: CLB
26 01043                RDR
27 01044                RAL
28 01045                RAL
29 01046                JCN     C1,DEBOUC
30 01050                JUN     STORE
31 01052        START:     FIM     2,2,0       /SAVE ORIGINAL STATUS COUNTER%
32 01054                   FIM     3,3,0
33 01056                   SRC     2
34 01057                   RD0
35 01060                   SRC     3
36 01061                   WR0
37 01062                   JMS     TIME        /FETCH THE FINAL TIME SWITCH SETTI
38 01064                   JMS     SRATIO      /LOAD THE SCOPE RATIO INTO COUNTER
39 01066                   JMS     TRATIO      /LOAD RATIO INTO QUAD COUNTER%
40 01070                   JMS     STRLEV      /LOAD START LEVEL
41 01072                   JMS     SCPLEV      /LOAD 0 IN SCOPE D/A COUNTER
42 01074                   FIM     0,0,0
43 01076                   SRC     0
44 01077                   LDM     1
45 01100                   WRR
46 01101                   CLB
47 01102                   WRR                 /INITIAL LOAD PULSE FOR RATIO COUN
48 01103                   LDM     2
49 01104                   WRR
50 01105                   CLB
51 01106                   WRR                 /START CLOCK OSCILLATOR
52 01107                FIM     1,1,0    /INITIALIZE STEP STATUS REG
53 01111                LDM     3
54 01112                SRC     1
55 01113                WR0
56 01114                   FIM     2,3,0
57 01116        MATT:      FIM     0,0,0       /REGISTER 0,1,2 WILL HOLD STOP VOL
58 01120                   FIM     1,0,0
59 01122                   FIM     3,0,0
60 01124                   SRC     2
61 01125                   RDM
62 01126                   XCH     2
63 01127                   INC     5
64 01130                   SRC     2
65 01131                   RDM
```

```
66 01132                XCH     1
67 01133                INC     5
68 01134                SRC     2
69 01135                RDM
70 01136                XCH     0
71 01137              FIM     2,2,0
72 01141      COUN1:    SRC     2           ;WAIT FOR COUNTER FLIP-FLOP
73 01142                RDR
74 01143                RAL
75 01144                JCN     C0,COUNT
76 01146      GO1       SRC     3
77 01147                LDM     4
78 01150                WRR                 ;RESET COUNT FLIP-FLOP
79 01151                CLB
80 01152                WRR
81 01153              SRC     2
82 01154              RDR
83 01155              RAL
84 01156              JCN     C1,GO   ;WAIT UNTIL CHANGE
85 01160                LD      0
86 01161                JCN     A1,RED
87 01163                LDM     9.          ;REG2 IS 0  LSD<
88 01164                XCH     0           ;PUT A 9 IN REG 2
89 01165                LD      1
90 01166                JCN     A1,REDA
91 01170                LDM     9.
92 01171                XCH     1
93 01172                LD      2
94 01173                JCN     A1,REDB
95 01175                JUN     OE          ;ALL ZEROS HAVE BEEN REACHED
96 01177      RED:      DAC
97 01200                XCH     0
98 01201                JUN     COUNT
99 01203      REDA:     DAC
100 1204                XCH     1
101 1205                JUN     COUNT
102 1207      REDB:     DAC
103 1210                XCH     2
104 1211                JUN     COUNT
105 1213      OE:       FIM     2,2,0       ;STOP VOLTAGE HAS BEEN REACHED
106 1215                SRC     2
107 1216                RD0
108 1217              DAC
109 1220                JCN     A1,HOP
110 1222              JUN     DONE
111 1224      HOP:          WR0
112 1225              FIM     0,2,0
113 1227              FIM     1,1,0
114 1231              SRC     1
115 1232              RD0
116 1233              XCH     1
117 1234              JMS     STLEVA
118 1236              FIM     2,3,0
119 1240              FIM     1,1,0
120 1242              SRC     1
121 1243              RD0
122 1244              XCH     5
123 1245              RD0
124 1246              IAC
125 1247              IAC
126 1250              IAC
127 1251              WR0
128 1252              JMS     SCPLEV
129 1254              JUN     MAIN
130 1256      DONE:     FIM     2,2,0
131 1260                FIM     3,3,0
132 1262                SRC     3
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```
133 1263                RDO
134 1264                SRC     2
135 1265                WRO                     ;RESTORE STATUS REGISTER BEFORE LE
136 1266                FIM     3,3,0           ;CHECK TO SEE POSITION OF REP-SING
137 1270                SRC     3
138 1271                CLB
139 1272                RDM
140 1273                RAR
141 1274                RAR
142 1275                JCN     C0,DEB
143 1277              FIM     0,3,0   ;CHECK FOR MANUAL OPER.
144 1301              SRC     0
145 1302              RDR
146 1303              RAR
147 1304              JCN     C0,MANUAL
148 1306              JUN     START
149 1310        MANUAL: JMS     STORE1
150 1312                JUN     START   ;SWITCH IS IN REP POSITION
151 1314        DEB:    JUN     BEGIN   ;SWITCH IS IN SINGLE POSITION%
152 1316        LOSTP:  FIM     2,2,8.    ;LOAD STOP VALUE IN FPAR REGISTER
153 1320                FIM     0,3,0   ;STOP ADDRESS IN RAM
154 1322                FIM     1,1,3
155 1324        LOSTR1: SRC     0
156 1325                ROM
157 1326                SRC     1
158 1327                WRM
159 1330              FIM     1,1,1
160 1332                CLB
161 1333                SRC     1
162 1334                WRM                     ;SIGN IS PLUS
163 1335                INC     1
164 1336                INC     3
165 1337                SRC     0
166 1340                RDM
167 1341                SRC     1
168 1342                WRM
169 1343                INC     1
170 1344              FIM     1,1,0
171 1346                SRC     0
172 1347                ROM
173 1350                SRC     1
174 1351                WRM
175 1352              FIM     1,1,3
176 1354        ZERO:   INC     3
177 1355                CLB
178 1356                SRC     1
179 1357                WRM
180 1360                ISZ     5,ZERO  ;LOAD 8 ZEROS
181 1362                BBL     0
182 1363        LOSTR:  FIM     2,2,8.    ;LOAD FIRST STAKT VALUE IN FPAR RE
183 1365                FIM     0,2,0
184 1367                FIM     1,1,3
185 1371                JMS     LOSTR1
186 1373                BBL     0
187 1374        TEMPST: FIM     0,0,4   ;OUTPUT FROM FPAR ADDRESS
188 1376                FIM     1,5,4
189 1400                FIM     2,0,4
190 1402        TRANS:  SRC     0
191 1403                RDM
192 1404                SRC     1
193 1405                WRM
194 1406                INC     1
195 1407                INC     3
196 1410                ISZ     5,TRANS
197 1412                BBL     0
198 1413        RESTOR: FIM     0,1,0
199 1415                FIM     1,5,8.
```

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200 1417                FIM     0,9.
201 1421                SRC     .
202 1422                RDM
203 1423                SRC     0
204 1424                WRM
205 1425                INC     1
206 1426                CLB
207 1427                SRC     0
208 1430                WRM                     /* SIGN
209 1431        ZEROB:  INC     1
210 1432                INC     3
211 1433                SRC     1
212 1434                RDM
213 1435                SRC     0
214 1436                WRM
215 1437                ISZ     5,ZEROB         /TRANSFER 7 DIGITS
216 1441                FIM     1,5,6
217 1443                SRC     1
218 1444                RDM
219 1445                RAR
220 1446                JCN     C1,MINUS
221 1450                FIM     0,1,9.
222 1452                CLB
223 1453                SRC     0
224 1454                WRM                     /5 # 0
225 1455                JUN     PLU
226 1457        MINUS:  FIM     0,1,9.
227 1461                LDM     F
228 1462                SRC     1
229 1463                WRM                     /MINUS # F
230 1464        PLU:    FIM     1,5,4
231 1466                INC     1
232 1467                SRC     1
233 1470                RDM
234 1471                SRC     0
235 1472                WRM                     /WRITE TENS EXPONENT
236 1473                INC     1
237 1474                INC     3
238 1475                SRC     1
239 1476                RDM
240 1477                SRC     0
241 1500                WRM
242 1501                BBL     0               /TRANSFER COMPLETE
243 1502        STHLEV: FIM     0,2,0           /RAM ADDRESS
244 1504        STLEVA: FIM     1,1,0
245 1506                FIM     2,2,0
246 1510                FIM     3,3,0
247 1512                CLB
248 1513                SRC     2
249 1514                WRM
250 1515                LDM     5
251 1516                JMS     FILL            /LOAD LSD IN LEVEL COUNTER
252 1520                SRC     2
253 1521                RDM                     /READ MSD OF START VOLTAGE
254 1522                SRC     2
255 1523                WRM                     /PUT TO PORT 2
256 1524                LDM     6
257 1525                JMS     FILL            /LOAD LSD OF START VOLTAGE
258 1527                INC     1
259 1530                SRC     0
260 1531                RDM
261 1532                SRC     2
262 1533                WRM
263 1534                LDM     7
264 1535                JMS     FILL            /LOAD SECOND DIGIT
265 1537                INC     1
266 1540                SRC     0
```

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267 1541                RDM
268 1542                SRC     2
269 1543                WRR
270 1544                LDM     8,
271 1545                JMS     FILL        /LOAD THIRD DIGIT
272 1547                BBL     0
273 1550        STORE1: CLB
274 1551                FIM     0,2,0
275 1553                SRC     0
276 1554                RD0                 /LOAD STATUS REGISTER
277 1555                JCN     A1,AA
278 1557                JUN     AAA
279 1561        AA1     XCH     1
280 1562                LDM     1
281 1563                SUB     1
282 1564                JCN     A1,BB
283 1566                JUN     BBB
284 1570        BB1     LDM     2
285 1571                SUB     1
286 1572                JCN     A1,CC
287 1574                JUN     CCC
288 1576        CC1     LDM     3
289 1577                SUB     1
290 1600                JCN     A1,DD
291 1602                JUN     DDD
292 1604        DD1     LDM     4
293 1605                SUB     1
294 1606                JCN     A1,EE
295 1610                JUN     EEE
296 1612        EE1     JUN     BEGIN
297 1614        AAA1    JMS     STORE1
298 1616                FIM     0,2,0
299 1620                LDM     1
300 1621                SRC     0
301 1622                WR0                 /PUT A L INTO STATUS REG
302 1623                JMS     STOP        /FETCH AND STORE STOP VALUE
303 1625                JMS     TIME        /FETCH AND STORE TIME VALUE
304 1627                JMS     LDSTP       /LOAD STOP VALUE IN FPAR REG
305 1631                JMS     ENTER
306 1633                JMS     LDSTR       /LOAD START VALUE IN FPAR REG1
307 1635                JMS     SUBT
308 1637                JMS     TEMPST      /TEMPORARILY STORE DIFF
309 1641                FIM     3,3,0
310 1643                JMS     DIFF        /RELOAD DIFFERENCE INTO CHIP 3,3,0
311 1645                JMS     LDTIME      /LOAD TIME INTO FPAR
312 1647                JMS     ENTER
313 1651                JMS     RESTOR      /LOAD DIFFERENCE INTO FPAR
314 1653                JMS     DIV
315 1655                JMS     TEMPST      /STORE Q RATIO IN 1 REG 2
316 1657                JUN     BEGIN
317 1661        BBB1    FIM     2,2,3
318 1663                JMS     STORE2
319 1665                FIM     0,2,0
320 1667                LDM     2
321 1670                SRC     0
322 1671                WR0
323 1672                FIM     3,3,3
324 1674                JMS     STOP2       /FETCH AND STORE SECOND STOP VALUE
325 1676                FIM     2,2,8,
326 1700                FIM     0,3,3       /STOP ADDRESS IN RAM
327 1702                JMS     CYCC
328 1704                FIM     0,2,3
329 1706                FIM     1,1,3
330 1710                JMS     LDSTR1      /LOAD SECOND START VALUE IN FPAR
331 1712                JMS     SUBT
332 1714                FIM     3,3,3
```

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333 1716                JMS     DIFF        /STORE DIFFERENCE IN RAM 0,3,4,5
334 1720                JUN     BEGIN
335 1722    CCC1        FIM     2,2,6
336 1724                JMS     STORE2
337 1726                FIM     0,2,0
338 1730                LDM     3
339 1731                SRC     0
340 1732                WR0                 /STORE A 3 IN STATUS REGISTER%
341 1733                FIM     3,3,6
342 1735                JMS     STOP2       /STORE THIRD STOP VALUE
343 1737                FIM     2,2,8.
344 1741                FIM     0,3,6
345 1743              JMS     CVCC
346 1745                FIM     0,2,6
347 1747                FIM     1,1,3
348 1751                JMS     LDSTR1
349 1753                JMS     SUBT
350 1755                FIM     3,3,6
351 1757                JMS     DIFF
352 1761                JUN     BEGIN
353 1763    DDD1        FIM     2,2,9.
354 1765                JMS     STORE2      /STORE FOURTH STOP VALUE
355 1767                FIM     0,2,0
356 1771                LDM     4
357 1772                SRC     0
358 1773                WR0
359 1774                FIM     3,3,9.
360 1776                JMS     STOP2
361 2000                FIM     2,2,8.
362 2002                FIM     0,3,9.
363 2004              JMS     CVCC
364 2006                FIM     0,2,9.
365 2010                FIM     1,1,3
366 2012                JMS     LDSTR1
367 2014                JMS     SUBT
368 2016                FIM     3,3,9.
369 2020                JMS     DIFF
370 2022                JUN     BEGIN
371 2024    EEE1    FIM     2,2,C
372 2026                JMS     STORE2      /STORE FIFTH STOP VALUE
373 2030                FIM     0,2,0
374 2032                LDM     5
375 2033                SRC     0
376 2034                WR0                 /LOAD A 5 IN STATUS REGISTER
377 2035                FIM     3,3,C
378 2037                JMS     STOP2
379 2041                FIM     2,2,8.
380 2043                FIM     0,3,C
381 2045              JMS     CVCC
382 2047                FIM     0,2,C
383 2051                FIM     1,1,3
384 2053                JMS     LDSTR1
385 2055                JMS     SUBT
386 2057                FIM     3,3,C
387 2061                JMS     DIFF
388 2063                JUN     BEGIN       /ALL DIFFERENCE CALCULATED AND STO
389 2065    CVCC1   FIM     1,1,3
390 2067                JMS     LDSTR1
391 2071                JMS     ENTER
392 2073                FIM     2,2,8.
393 2075                BBL     0
394 2076    STOP1       FIM     3,3,0       /REGISTER 1 # MPX1 ADDRESS
395 2100    STOP21      FIM     2,2,0
396 2102                FIM     1,1,0
397 2104              LDM     8.
398 2105                SRC     2
399 2106                WRM                 /MPX1 # 1%
400 2107                SRL     1
```

```
401 2110                RDM
402 2111                SRC     3
403 2112                WRM             ;STORE FIRST DIGIT OF STP-1 IN
404 2113                INC     7       ;CHIP 0 REGISTER 3 CHRO
405 2114              LDM     4
406 2115                SRC     2
407 2116                WRR             ;MPX1 # 2X
408 2117                SRC     1
409 2120                RDR
410 2121                SRC     3
411 2122                WRM             ;STORE STP=2
412 2123                INC     7
413 2124              LDM     C
414 2125                SRC     2
415 2126                WRR
416 2127                SRC     1
417 2130                RDR
418 2131                SRC     3
419 2132                WRM             ;STORE STP=3
420 2133                BBL     0
421 2134    TIME1     FIM     3,3,7   ;STORE TIME VALUE
422 2136                FIM     0,4,0   ;RAM ADDRESS
423 2140                FIM     1,1,0
424 2142                FIM     2,2,C
425 2144                CLB
426 2145                SRC     2
427 2146                WRR             ;MPX1 ADDRESS # 0
428 2147                LD      7
429 2150                SRC     3
430 2151                WRR             ;MPX2 ADDRESS # 3
431 2152                SRC     1
432 2153                RDM             ;READ FIRST DIGIT
433 2154                SRC     0
434 2155                WRM             ;STORE FIRST TIME DIGIT,MSC
435 2156    TIMEA1    XCH     7
436 2157                DAC
437 2160                XCH     7
438 2161                LD      7
439 2162                INC     1
440 2163                SRC     3
441 2164                WRR             ;MPX2 ADDRESS # 4
442 2165                SRC     1
443 2166                RDM
444 2167                SRC     0
445 2170                WRM             ;STORE SECOND TIME DIGIT
446 2171                ISZ     5,TIMEA ;STORE FIFTH DIGIT
447 2173                BBL     0
448 2174    STORE1:   FIM     2,2,0   ;MPX1 ADDRESS
449 2176    STORE2:     FIM     1,1,0   ;MPX2 ADDRESS,
450 2200                FIM     0,0,0   ;RAM ADDRESS
451 2202                FIM     3,3,0
452 2204                LD      1
453 2205                SRC     2
454 2206                WRR             ;MPX1    ;RESS # 0
455 2207                LD      3
456 2210                SRC     3
457 2211                WRR             ;MPX2 ADDRESS # 0
458 2212                SRC     1
459 2213                RDM             ;READ STR=1
460 2214                SRC     2
461 2215                WRM             ;STORE STR=1 IN CHIP 0 REG 2 CHAR
462 2216                INC     5
463 2217                INC     3
464 2220                LD      3
465 2221                SRC     3
466 2222                WRR             ;MPX2 ADDRESS # 1
467 2223                SRC     1
```

```
468 0224                RD5
469 0225                SRC     2
470 0226                WRM                     ;STORE STR=2
471 0227                INC     5
472 0230                INC     3
473 0231                LD      3
474 0232                SRC     3
475 0233                WRM                     ;MPX=2 ADDRESS # 2
476 0234                SRC     1
477 0235                RDR                     ;READ STR=3
478 0236                SRC     2
479 0237                WRM                     ;STORE STR=2
480 0240                BBL     0
481 0241    LDTIME1     FIM     0,1,0
482 0243                FIM     1,4,0
483 0245                FIM     2,0,B
484 0247                SRC     1
485 0250                ROM
486 0251                SRC     0
487 0252                WRM
488 0253                INC     1
489 0254                CLB
490 0255                SRC     0
491 0256                WRM                     ;E
492 0257                INC     1
493 0260                INC     3
494 0261                SRC     1
495 0262                ROM                     ;D2
496 0263                SRC     0
497 0264                WRM
498 0265                INC     1
499 0266                INC     3
500 0267                SRC     1
501 0270                ROM                     ;D3
502 0271                SRC     0
503 0272                WRM
504 0273                INC     1
505 0274                INC     3
506 0275                SRC     1
507 0276                ROM                     ;D4
508 0277                SRC     0
509 0300                WRM
510 0301                INC     1
511 0302                INC     3
512 0303                SRC     1
513 0304                ROM
514 0305                SRC     0
515 0306                WRM                     ;D5
516 0307    ZERO2:      INC     1
517 0310                CLB
518 0311                SRC     0
519 0312                WRM
520 0313                ISZ     5,ZERO2
521 0315                INC     1
522 0316                COM     2
523 0317                SRC     0
524 0320                WRM                     ;LOAD 2 IN 1#3 EXPONENT
525 0321                BBL     0
526 0322    SCPLEV1     FIM     7,2,0           ;LOAD ZEROS IN SCOPE D/A FOR START
527 0324                FIM     3,3,0
528 0326                SRC     7
529 0327                CLB
530 0330                WRM
531 0331                LDM     4
532 0332                JMS     FILL            ;LOAD SECOND STAGE
533 0334                BBL     0
534 0335    DIFF1       FIM     0,0,5
```

```
535 2337                    SRC     0
536 2340                    RDM                     ;READ FIRST EXPONENT
537 2341                    JCN     A0,NOEXP
538 2343                    JUN     SHIFT
539 2345    NOEXP:          FIM     0,0,8,
540 2347                SRC     0
541 2350                    RDM
542 2351                    SRC     3               ;DIFFERENCE RAM ADDRESS
543 2352                    WRM
544 2353                    INC     7               ;INCREMENT RAM DIFF ADDRESS
545 2354                    INC     1
546 2355                    SRC     0
547 2356                    RDM
548 2357                    SRC     3
549 2360                    WRM                     ;STORE SECOND DIGIT OF DIFF
550 2361                    INC     7
551 2362                    INC     1
552 2363                    SRC     0
553 2364                    RDM
554 2365                    SRC     3
555 2366                    WRM                     ;STORE THIRD DIGIT OF DIFF
556 2367                    BBL     0
557 2370    SHIFT:  RAR
558 2371                JCN     A0,ONEEXP
559 2373                JUN     SHIFT2
560 2375    ONEEXP:         FIM     0,0,8,
561 2377                    CLB
562 2400                    SRC     3
563 2401                    WRM                     ;PUT 0 IN FIRST DIGIT
564 2402                    INC     7               ;INC RAM DIFF ADDRESS
565 2403                    SRC     0
566 2404                    RDM                     ;READ 01
567 2405                    SRC     3
568 2406                    WRM                     ;WRITE SECOND DIGIT OF DIFF
569 2407                    INC     7
570 2410                    INC     1
571 2411                    SRC     0
572 2412                    RDM
573 2413                    SRC     3
574 2414                    WRM                     ;WHITE THIRD DIGIT OF DIFF
575 2415                    BBL     0
576 2416    SHIFT2:         FIM     0,0,8,
577 2420                    CLB
578 2421                    SRC     3
579 2422                    WRM                     ;PUT 0 IN FIRST DIFF DIGIT
580 2423                    INC     7
581 2424                    SRC     3
582 2425                    WRM                     ;PUT 0 IN SECOND DIFF DIGIT
583 2426                    INC     7
584 2427                    SRC     0
585 2430                    RDM                     ;READ 01 FROM FPAR
586 2431                    SRC     3
587 2432                    WRM                     ;WRITE THIRD DIFF DIGIT
588 2433                    BBL     0
589 2434    THATIO:         FIM     0,5,6           ;LOAD RATIO INTO COUNTER
590 2436                    FIM     2,2,0
591 2440                    FIM     3,3,0
592 2442                    SRC     0
593 2443                    RDM                     ;READ SIGN OF EXPONENT
594 2444                    RAR
595 2445                    JCN     C0,PLSEXP
596 2447                    CLB
597 2450                    JUN     MINEXP
598 2452    PLSEXP:         FIM     0,5,5
599 2454                    SRC     0
600 2455                    RDM                     ;READ ONE'S EXPONENT
601 2456                    JCN     A0,PZER
```

```
602 2460                RAR
603 2461                JCN     A0,PONE
604 2463                  JUN     PTWO
605 2465        PZERO:    FIM     0,5,7
606 2467                  JMS     RDM         ;READ MSBX
607 2471                  LDM     2
608 2472                  JMS     FILL
609 2474                  JMS     RDM         ;READ SECOND DIGIT
610 2476                  LDM     1
611 2477                  JMS     FILL
612 2501                  JMS     RDM
613 2503                  LDM     E
614 2504                  JMS     FILL
615 2506                  CLB
616 2507                  SRC     2
617 2510                  WRR
618 2511                  JMS     FILLC       ;PUT 0 IN LC,LD
619 2513                  BBL     0
620 2514        PTWO:     FIM     0,5,8,
621 2516                  JMS     PTW
622 2520                  FIM     0,5,7
623 2522                  JMS     RDM
624 2524                  LDM     4
625 2525                  JMS     FILL
626 2527                  BBL     0
627 2530        PONE:     FIM     0,5,7       ;EXP = +01, CANOT BE GREATER
628 2532        PTW:            JMS     RDM
629 2534                  LDM     3
630 2535                  JMS     FILL
631 2537                  JMS     RDM         ;READ SECOND DIGIT
632 2541                  LDM     2
633 2542                  JMS     FILL
634 2544                  JMS     RDM
635 2546                  LDM     1
636 2547                  JMS     FILL
637 2551                  CLB
638 2552                  SRC     2
639 2553                  WRR
640 2554                  LDM     4
641 2555                  JMS     FILL
642 2557                  LDM     E
643 2560                  JMS     FILL
644 2562                  BBL     0
645 2563        MINEXP:   FIM     0,5,5       ;MINUS EXPONENT
646 2565                  SRC     0
647 2566                  RDM
648 2567                  RAR
649 2570                  JCN     A0,MONE
650 2572                RAR
651 2573                JCN     A1,MONE ;EXP=-3, ILLEGAL,TREAT AS EXP=-1
652 2575                JUN     MTWO
653 2577        MONE:     FIM     0,5,7       ;EXP = -01
654 2601                  JMS     RDM
655 2603                  LDM     1
656 2604                  JMS     FILL
657 2606                  JMS     RDM
658 2610                  LDM     E
659 2611                  JMS     FILL
660 2613                  CLB
661 2614                  SRC     2
662 2615                  WRR
663 2616                  JMS     FILL8
664 2620                  BBL     0
665 2621        MTWO:     FIM     0,5,7       ;EXP = -02
666 2623                  JMS     RDM
667 2625                  LDM     E
668 2626                  JMS     FILL
```

```
669 2630                CLB
670 2631                SRC     2
671 2632                WRR
672 2633    FILLA:      LDM     1
673 2634                JMS     FILL
674 2636    FILLB:      LDM     2
675 2637                JMS     FILL
676 2641    FILLC:      LDM     3
677 2642                JMS     FILL
678 2644    FILLD:      LDM     4
679 2645                JMS     FILL
680 2647                BBL     0
681 2650    FILL:       SRC     3           ;STROBE DATA INTO SELECTED REGISTE
682 2651                WRR                 ;STROBE L LINE
683 2652                CLB
684 2653                WRR
685 2654                BBL     0
686 2655    RDM:        INC     1           ;INCREMENT MEM ADDRESS AND READ
687 2656                SRC     0
688 2657                RDM                 ;READ CHARACTER
689 2660                SRC     2
690 2661                WRR                 ;WRITE DATA TO OUTPORT 2
691 2662                BBL     0
692 2663    SHATIO:     FIM     0,4,0
693 2665                FIM     2,2,0
694 2667                FIM     3,3,0
695 2671                SRC     0           ;DROP LSD TO EFFECT A DIVISION OF
696 2672                RDM
697 2673                SRC     2
698 2674                WRR
699 2675                LDM     C
700 2676                JMS     FILL        ;LOAD 02 IN LSD
701 2700                INC     1
702 2701                SRC     0
703 2702                RDM
704 2703                SRC     2
705 2704                WRR
706 2705                LDM     8
707 2706                JMS     FILL
708 2710                INC     1
709 2711                SRC     0
710 2712                RDM
711 2713                SRC     2
712 2714                WRR
713 2715                LDM     A
714 2716                JMS     FILL
715 2720                INC     1
716 2721                SRC     0
717 2722                RDM
718 2723                SRC     2
719 2724                WRR
720 2725                LDM     9,
721 2726                JMS     FILL
722 2730                CLB
723 2731                SRC     2
724 2732                WRR
725 2733                LDM     0
726 2734                JMS     FILL        ;PUT A 0 IN MSD
727 2736                BBL     0
728 2737    CALRDY1:    JMS     DELAY
729 2741                FIM     3,2,2
730 2743                FIM     2,1,0
731 2745                SRC     3
732 2746    READ1:      RDR                 ;READ PORT 2
733 2747                AN7                 ;AND 2
734 2750                JCN     A0,READ1    ;WHEN RDY1 = 1 THEN CONTINUE
735 2752    READ2:      RDR
```

```
736 2753                AN7             ;AND BIT 2
737 2754                JCN     A1,READ2
738 2756                LDM     4
739 2757                SRC     2
740 2760                WRR             ;SET HOLDX
741 2761                SRC     3
742 2762  READ3:        RDR
743 2765                AN7
744 2766                JCN     A0,READ3  ;WHEN RDYI = 1 THEN CONTINUE
745 2770                FIM     5,2,F
746 2772                JMS     LOAD      ;SEND MASTER CLEAR
747 2774                FIM     5,2,3
748 2776                JMS     LOAD      ;SEND ERROR CLEAR
749 3000                FIM     5,2,2
750 3002                JMS     LOAD      ;SEND SCIENTIFIC NOTATION
751 3004                BBL     0
752 3005  DELAY:  FIM     0,0,0
753 3007                FIM     1,0,0
754 3011  WAIT:   ISZ     0,WAIT
755 3013                ISZ     1,WAIT
756 3015                ISZ     2,WAIT
757 3017                ISZ     3,WAIT
758 3021                BBL     0
759 3022  SUBT:   JMS     LDRAM
760 3024                FIM     5,3,A
761 3026                JMS     LOAD
762 3030                JMS     OUTPUT
763 3032                BBL     0
764 3033  LOAD:           FIM     2,2,4
765 3035                FIM     1,1,0
766 3037                SRC     2
767 3040                LD      0
768 3041                WRR             ;SEND PART 1 OF OP CODE
769 3042                SRC     1
770 3043                LD      A
771 3044                WRR             ;SEND PART 2 OF OP CODE
772 3045                SRC     2
773 3046  RDYA:   RDR
774 3047                RAR
775 3050                RAR             ;SHIFT TWICE
776 3051                JCN     C1,RDYA
777 3053                LD      A
778 3054                ORS     0
779 3055                SRC     1
780 3056                WRR             ;SET HOLDX
781 3057                SRC     2
782 3060  RDYB:   CLB
783 3061                RDR
784 3062                RAR
785 3063                RAR
786 3064                JCN     C0,RDYB   ;LOOP UNTIL RDYI = 1
787 3066                CLB
788 3067                BBL     0
789 3070  OUTPUT: FIM     5,1,6
790 3072                JMS     LOAD
791 3074                SB1
792 3075                FIM     1,1,0
793 3077                FIM     2,2,0
794 3101                SRC     1
795 3102                LDM     4
796 3103                WRR             ;SET HOLDX
797 3104                LDM     C
798 3105                WRR             ;SET RDYOUT RESET=KEEP HOLD
799 3106                LDM     4
800 3107                WRR             ;CLEAR RYDOUT RESET=KEEP HOLDX
801 3110                CLB
802 3111                WRR
```

```
803 3110                SRC     2
804 3111        READY:  CLB
805 3112                RDR
806 3113                RAR
807 3114                RAR
808 3115                JCN     C1, READY
809 3117                SRC     1
810 3120                LDM     4
811 3121                WRR
812 3122                FIM     2,0,4
813 3124                FIM     3,2,1
814 3126        STRT:   SRC     3
815 3127        AGN1:   RDR
816 3130                AN7
817 3131                JCN     A0,AGN1
818 3133                SRC     2
819 3134                RDR
820 3135                WRM
821 3136                INC     5
822 3137                SRC     3
823 3140        AGN2:   RDR
824 3141                AN7
825 3142                JCN     A1,AGN2
826 3144                SRC     2
827 3145                RDR
828 3146                WRM
829 3147                ISZ     5,STRT
830 3151                SRC     3
831 3152        AGN3:   RDR
832 3153                JCN     A0,AGN3
833 3155                FIM     2,1,0
834 3157                FIM     3,2,0
835 3161                LDM     4
836 3162                SRC     2
837 3163                WRR
838 3164                LDM     C
839 3165                WRR
840 3166                LDM     4
841 3167                WRR
842 3170                SRC     5
843 3171        COMP:   RDR
844 3172                RAR
845 3173                RAR
846 3174                JCN     C1,COMP
847 3176                CLB
848 3177                BBL     0
849 3200        LDRAM:  FIM     5,5,0   ;OP CODE ADDR
850 3202                FIM     7,1,0       ;RAM ADDRESS REGISTER
851 3204                SRC     7
852 3205                RDM
853 3206                XCH     B           ;LOAD OP CODE INTO RB FIRST HALF
854 3207                CLB
855 3210                XCH     A           ;LOAD OP CODE INTO RA SECOND HALF
856 3211                JMS     LOAD
857 3213                INC     F
858 3214                SRC     7
859 3215                FIM     5,0,A       ;DECIMAL POINT OP CODE
860 3217                JMS     LOAD
861 3221                INC     F           ;INCREMENT MEMORY A2
862 3222                SRC     7
863 3223                RDM                 ;READ D2
864 3224                XCH     B           ;LOAD OP CODE FIRST HALF
865 3225                LDM     0
866 3226                XCH     A           ;LOAD OP CODE SECOND HALF
867 3227                JMS     LOAD
868 3231                INC     F
869    2                SRC     7
```

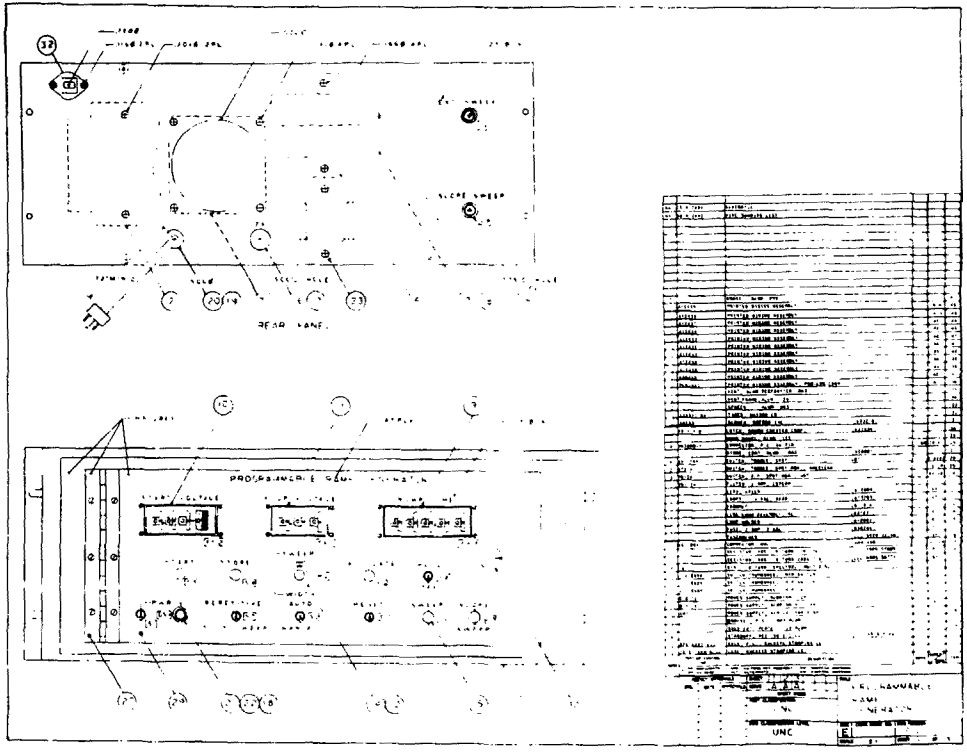
```
870 3233                RDM             ;READ D2
871 3234                XCH     B
872 3235                LDM     0
873 3236                XCH     A
874 3237                JMS     LOAD
875 3241                INC     F       ;A4
876 3242                SRC     7
877 3243                RDM             ;READ D4
878 3244                XCH     B
879 3245                LDM     0
880 3246                XCH     A
881 3247                JMS     LOAD
882 3251                INC     F       ;A5
883 3252                SRC     7
884 3253                RDM             ;READ D5
885 3254                XCH     B
886 3255                LDM     0
887 3256                XCH     A
888 3257                JMS     LOAD
889 3261                INC     F       ;A6
890 3262                SRC     7
891 3263                RDM             ;READ D6
892 3264                XCH     B
893 3265                LDM     0
894 3266                XCH     A
895 3267                JMS     LOAD
896 3271                INC     F       ;A7
897 3272                SRC     7
898 3273                RDM             ;READ D7
899 3274                XCH     B
900 3275                LDM     0
901 3276                XCH     A
902 3277                JMS     LOAD
903 3301                INC     F       ;A8
904 3302                SRC     7
905 3303                RDM             ;READ D8
906 3304                XCH     B
907 3305                LDM     0
908 3306                XCH     A
909 3307                JMS     LOAD
910 3311                FIM     5,0,M   ;EXPONENT OP CODE
911 3313                JMS     LOAD
912 3315                INC     F       ;A9
913 3316                SRC     7
914 3317                RDM             ;D9
915 3320                JCN     A0,EXP  ; 0 IS + F IS -
916 3322                FIM     5,0,C
917 3324                JMS     LOAD
918 3326    EXP:        INC     F       ;AA
919 3327                SRC     7
920 3330                RDM             ;READ EXPONENT 10
921 3331                XCH     B
922 3332                LDM     0
923 3333                XCH     A
924 3334                JMS     LOAD
925 3336                INC     F       ;AB
926 3337                SRC     7
927 3340                RDM             ;READ EXPONENT 1
928 3341                XCH     B
929 3342                LDM     0
930 3343                XCH     A
931 3344                JMS     LOAD
932 3346                BBL     0
933 3347    ENTER:      JMS     LORAM   ;ENTER OP CODE
934 3351                FIM     5,2,1
935 3353                JMS     LOAD
936 3355                BBL     0
```

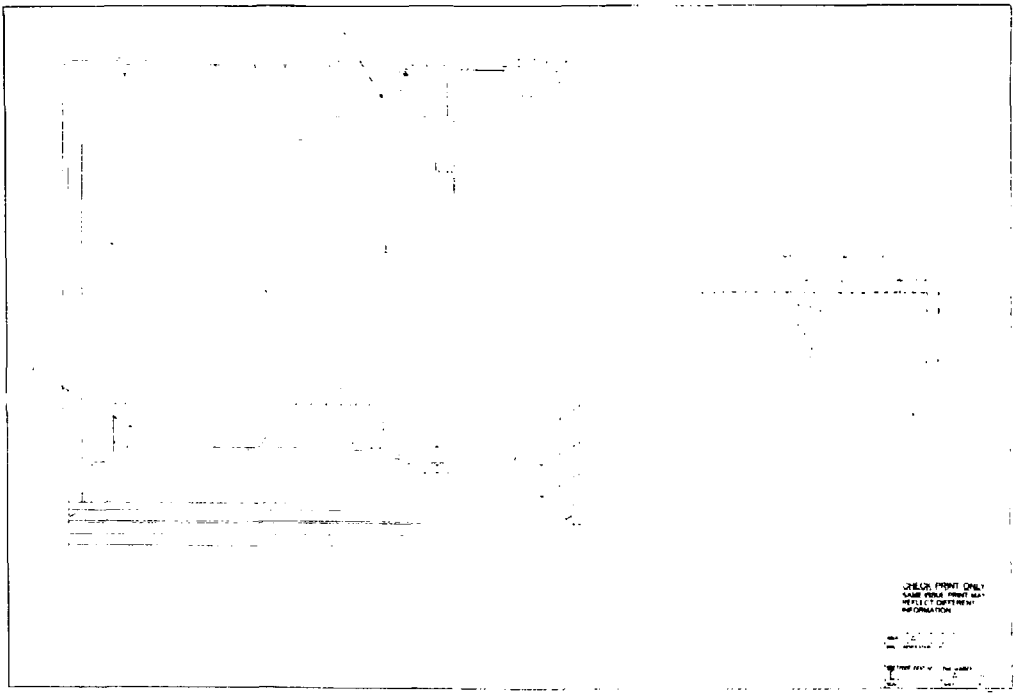
```
937 3356          CLR1    FIM     3,2,F     /MAST OF CLEAR OP CODE
938 3360                  JMS     LOAD
939 3362                  BBL     0
940 3363          DIV1    JMS     LDRAM
941 3365                  FIM     5,5,C     /DIVIDE OP CODE
942 3367                  JMS     LOAD
943 3371                  JMS     OUTPUT
944 3373                  BBL     0
945       000001',END
```

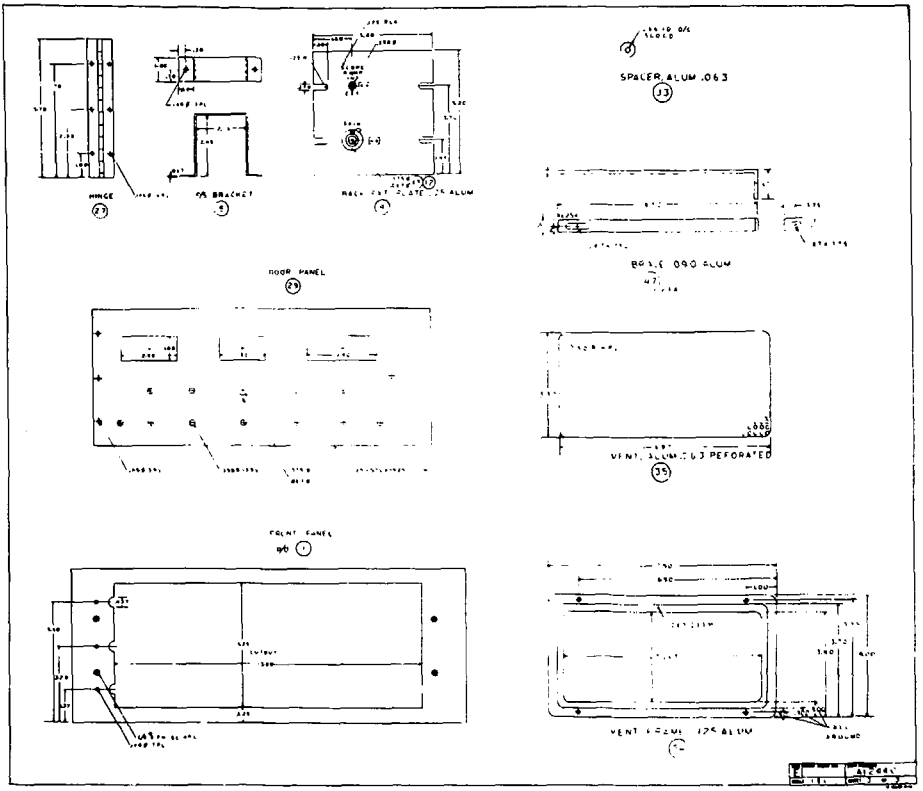
```
$NTEL-4040 MACRO DEFINITIONS
SYMBOL TABLE

A       = 000012        AA      001561      AAA     001614
AGN1    003127          AGN2    003140      AGN3    003152
A0      = 000004        A1      = 000014    B       = 000013
BB      001570          BBB     001661      BEGIN   001003
C       = 000014        CALRDY  002737      CC      001576
CCC     001722          CLR     003356      COMP    003171
COUN1   001141          CYCC    002065      C0      = 000012
C0A1    = 000016        C1      = 000002    D       = 000015
DD      001604          DDO     001763      DE      001213
DEB     001314          DEBOUC  001042      DELAY   003003
DIFF    002335          DIV     003363      DONE    001256
E       = 000016        EE      001612      EEE     002024
ENTER   003347          EXP     003326      F       = 000017
FILL    002650          FILLA   002633      FILLB   002636
FILLC   002641          FILLD   002644      GO      001146
HOP     001224          INIT    001001      J       = ******
LDRAM   003200          LDSTP   001316      LDSTR   001363
LDSTR1  001324          LDTIME  002241      LOAD    003031
MANU    001030          MANUAL  001310      MATT    001116
MINEXP  002563          MINUS   001457      NONE    002577
NTWO    002621          NDEXP   002345      ONEEXP  002375
OUTPUT  003066          PLSEXP  002452      PLU     001464
PONE    002530          PTN     002532      PTWO    002514
PZER    002465          ROM     002655      ROYA    003044
ROYB    003056          READ1   002746      READ2   002752
READ3   002762          RED     001177      REDA    001203
REDB    001207          REDY    003111      RESTOR  001413
SCPLEV  002322          SHIFT   002310      SHIFT2  002416
SRATIO  002663          ST      001043      START   001052
STLEVA  001504          STOP    002676      STOP2   002100
STORE   001550          STORE1  002174      STORE2  002176
STRIBE  001502          STRT    003126      SUBT    003020
SWNLST= 000001          SW4040= 000001      TEMPST  001374
TIME    002134          TIMEA   002156      TWANS   001402
TRATIO  002434          T0      = 000001    T1      = 000011
T1A1    = 000015        T1C0    = 000013    T1C0A1= 000017
UN      = 000010        WAIT    003007      ZERO    001354
ZEROB   001431          ZERO2   002307
. ABS.  011000      000
        000000      001
ERRORS DETECTED: 0
FREE CORE: 16192. WORDS

QUAD,LP:=MCS40,QUAD/N:MEB
```

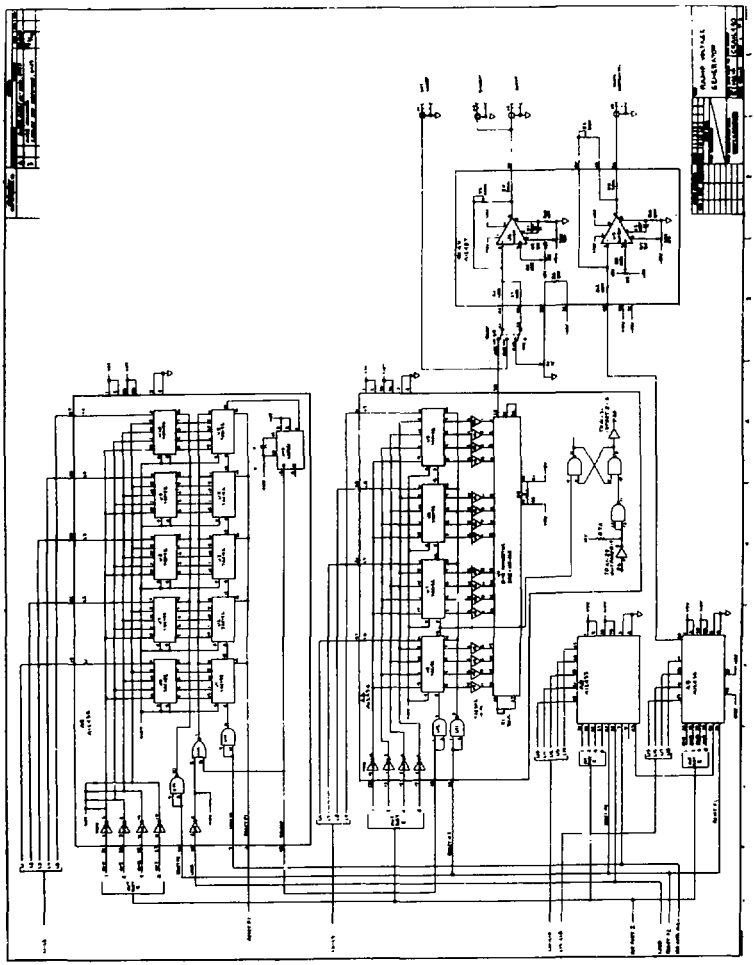
APPENDIX B

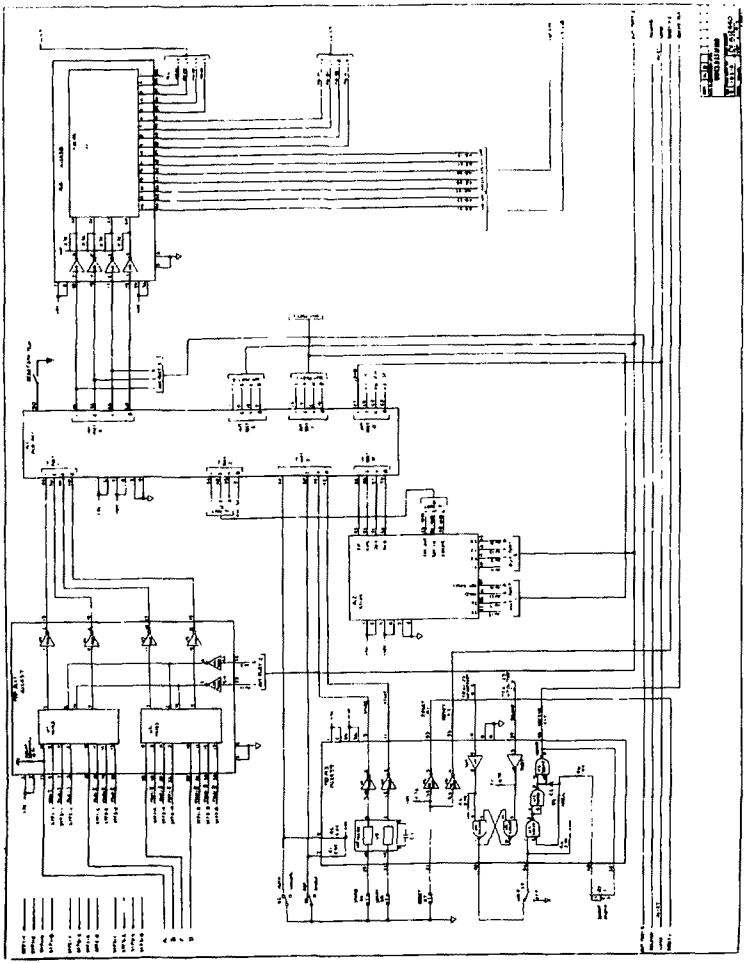
DETAILED SCHEMATIC, WIRING LIST, AND CHASSIS MECHANICAL DRAWINGS FOR THE RAMP GENERATOR

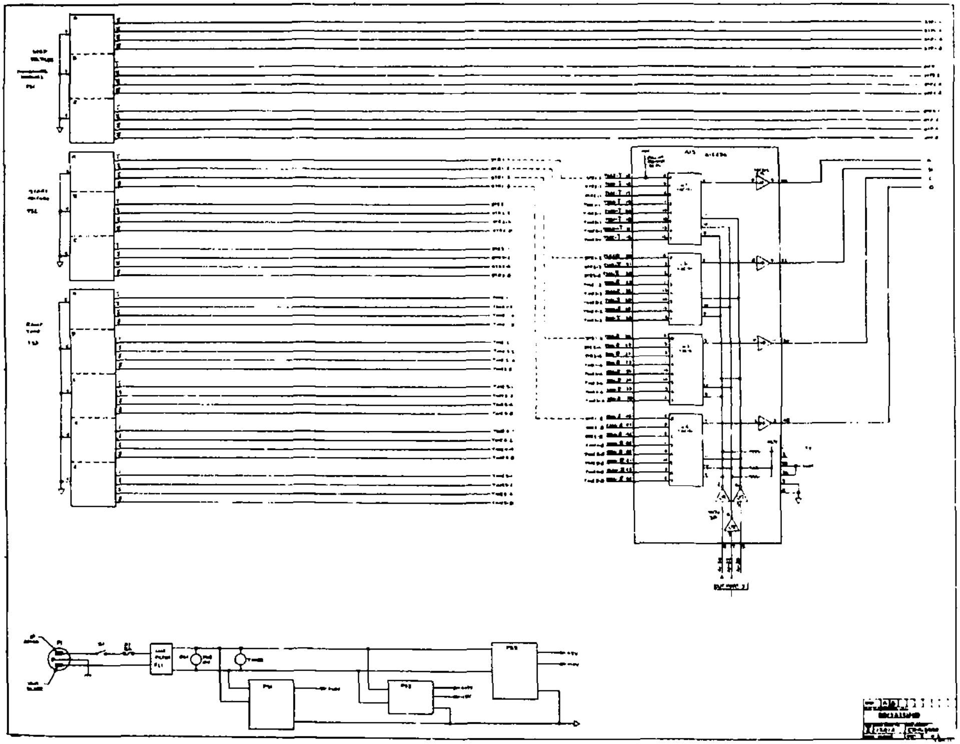

REAR PANEL
UNC


CHECK PRINT ONLY


HINGE
SPACER, ALUM .063
DOOR PANEL
FRONT PANEL







REVISIONS				
LTR	DESCRIPTION	PREPARED BY	DATE	APP'D
A	COOLEY B271, HOPWOOD 8423		9/13/78	

	FROM		TO		TO		TO		TO		TO		TO		TO		REF:	
		PIN		PIN		PIN		PIN		PIN		PIN		PIN		PIN		
2	XA1	44	XA11	13													IN PORT 1	1
3	▲	50	XA11	15													▲	2
4	▼	54	XA11	17													▼	4
5	▼	40	XA11	19													IN PORT 1	8
6	XA1	12,62	XA2	1,2	XA3	1,2	XA 4	1,2	XA5	1 2	X	1,2	XA8	1,2	XA9	1,2	GO TO LINE #7	
7	XA11	1,2	XA13	1,2			PS 3	+5V									+5V	
8	XA1	3,4	XA2	3,4	XA3	3,4	XA 4	3,4	XA5	3,4	X	3,4	XA8	3,4	XA9	3,4	GO TO LINE #9	
9	XA11	3 4	XA13	3,4			GND		R1								GND	
10	XA1	5,6	XA2	5,6	XA3	5,6	XA11	29	PS 3	-10V	R1	1					10V	
11	▲	34	XA2	45													IN PORT 2	1
12		38	XA2	51														2
13		35	XA2	49													IN PORT 2	4
14		46	XA3	9	S2	N/C	[AUTO]										IN PORT 3	1
15		48	XA3	7	S3	N/C	[REP]											2
16		52	XA3	13														4
17		42	XA3	11,109													IN PORT 3	8
18		32	XA2	33													IN PORT 0	1
19		36	XA2	35														2
20		37	XA2	37														4
21		33	XA2	30													IN PORT 0	8
22		24	XA4	13	XA13	5											OUT PORT 3	1
23		22	XA4	15	XA13	7												2
24	▼	26	XA4	17	XA13	9												4
25	XA1	20	XA4	19													OUT PORT 3	8
26																		
27																		
28																		

NOTES:

AGENCY APPROVALS		
CMO	DATE	INITIALS

SHEET 1 2 3 4 5 6
ISSUE A
SHEET INDEX

PART CLASSIFICATION: UNCLASSIFIED

DWG. CLASSIFICATION LEVEL: UNCLASSIFIED

TITLE: RAMP VOLTAGE GENERATOR

SIZE	CODE IDENT NO.	DWG. NUMBER
B	14214	WD-A12440

SCALE —— SHEET 1 OF 6

	FROM		TO		TO		TO		TO		TO		TO		TO		REF:	
1		PIN		PIN		PIN		PIN		PIN		PIN		PIN		PIN		
2	XA1	11	XA2	10	XA5	31	XA6	23	XA8	31	XA9	23	XA11	33			OUT PORT 2	1
3	↑	9	↑	14	↑	29	↑	29	↑	29	↑	13	XA11	25				2
4		13		12	↓	25	↓	15	↓	25	↓	15						4
5		7		28	XA5	27	XA6	19	XA8	27	XA9	19					OUT PORT 2	8
6		19		22	XA3	6											OUT PORT 1	
7		17		26	XA3	10												2
8		21	↓	16														4
9	↓	15	XA2	47													OUT PORT 1	8
10	XA1	27	XA5	33	XA8	33	XA14	6										
11																		
12	XA3	27	S4	—O	* O—	GND											STORE	SW
13	↑	31	S5	—O	O												START	SW
14		29	S6	—O	O												CALCULATE	SW
15		21	S7	—O	O—	GND											RESET	SW
16		43	S8	COM													HOLD/OFF	SW
17		54	S8	N C													HOLD/OFF	SW
18		48	R2	1,2													SWEEP WIDTH POT	
19		52	R2	3													SWEEP WIDTH POT	
20																		
21		33	XA5	5													RESET 1	
22		35	XA5	41	XA6	35	XA9	41	XA9	35							RESET 2	
23		39	XA5	43													RELOAD	
24		46	XA5	7	XA8	7											100 KHZ CLOCK	
25																		
26		8	XA9	25													L17	
27	↓	12	XA9	11													L18	
28	XA3	5556	XA4	5556	XA5	5556	XA9	5556	XA8	5556	XA5	5556	XA13	5556	XA14	5556	+ 10V PS1	

NOTES:

	FROM		TO		TO		TO		REF:
1		PIN		PIN		PIN		PIN	
2	XA4	30	XA9	41					L16
3		32	XA9	47					L15
4		54	XA8	47					L14
5		51	XA8	45					L13
6		53	XA8	35					L12
7		49	XA8	21					L11
8		47	XA8	15					L10
9		48	XA6	11					L9
10		45	XA6	25					L8
11		43	XA6	41					L7
12		41	XA6	47					L6
13		39	XA5	47					L5
14		40	XA5	45					L4
15		37	XA5	35					L3
16		35	XA5	21					L2
17	XA4	33	XA5	19					L1
18									
19	XA6	43							
20		53	S9	N/C	INT				RAMP SA
21		49	XA9	49	XA11	49	PS2	+15V	+15V
22	XA6	51	XA9	51	XA11	51	PS2	-5V	-5V
23									
24									
25									
26									
27									
28									

NOTES:

WD-A12440

SHT 3 OF 6

	FROM		TO		TO		REF:
1		PIN		PIN		PIN	
2	XA11	44	S9	COM1			RAMP SW
3	▲	46	S9	COM2			
4		39	R1	1			
5		48	XA9	53			RAMP SW
6		43	J2	C/C	J4	C/C	SWEEP BNL
7		54	J3	C/C			SCOPE HORIZONTAL
8		11	XA13	54			A
9		9	TSIA	T			STP 1 - 1
10		7	TSIB	T			STP 2 - 1
11		5	TSIC	T			STP 3 - 1
12		18	XA13	52			B
13		16	TSIA	2			STP 1 - 2
14		14	TSIB	2			STP 2 - 2
15		20	TSIC	2			STP 3 - 2
16		28	XA13	50			
17		26	TSIA	4			STP 1 4
18		24	TSIB	4			STP 2 4
19		22	TSIC	4			STP 3 4
20		30	XA13	48			
21		31	TSIA	8			STP 1 6
22	▼	32	TSIB	8			STP 2 6
23	XA11	36,33	TSIC	8			STP 3 8
24				23			
25				1			
26							
27							
28							

NOTES:

WD A12440
SH 4 OF 6

	FROM		TO		REF:	
1		PIN		PIN		
2	XA13	14	TS2A	1	STR 1	1
3	↑	15	TS2B	1	STR 2	1
4		17	TS2C	1	STR 3	1
5		19	TS3A	1	TIME	1 – 1
6		20	TS3B	1	↑	2 – 1
7		18	TS3C	1	↕	3 – 1
8		11	TS3D	1	↓	4 – 1
9		13	TS3E	1	TIME	5 – 1
10		23	TS2A	2	STR 1	2
11		21	TS2B	2	STR 2	2
12		24	TS2C	2	STR 3	2
13		22	TS3A	2	TIME	1 – 2
14		32	TS3B	2	↑	2 – 2
15		28	TS3C	2	↕	3 – 2
16		25	TS3D	2	↓	4 – 2
17		26	TS3E	2	TIME	5 – 2
18		36	TS2A	4	STR 1	4
19		29	TS2B	4	STR 2	4
20		27	TS2C	4	STR 3	4
21		34	TS3A	4	TIME	1 – 4
22		37	TS3B	4	↑	2 – 4
23		35	TS3C	4	↕	3 – 4
24		33	TS3D	4	↓	4 – 4
25		38	TS3E	4	TIME	5 – 4
26		45	TS2A	8	STR 1	8
27	↓	47	TS2B	8	STR 2	8
28	XA13	42	TS2C	8	STR 3	8

NOTES:

DWG NUMBER
WD-A12440
SHT 5 OF 6

	FROM		TO		TO		TO		TO		TO		TO		TO		REF:
		PIN		PIN		PIN		PIN		PIN		PIN		PIN		PIN	
2	XA13	40	TS3A	8													TIME 1-8
3	▲	39	TS3B	8													▲ 2-A
4	‖	41	TS3C	8													3-8
5	▼	43	TS3D	8													▼ 4-8
6	XA13	46	TS3E	8													TIME 5-8
7																	
8	TS1A	C	TS1B														
9	TS3C	C	TS3D	C	TS.C	C	TS2A	C	TS2B	C	TS2C	C	TS3A	C	TS3B	C	GO TO LINE #9
10	S2	C	GND	C	TS3E	C	GND										GND
11	S3	C	GND														AUTO MANUAL SW
12	J1	C/C	S9	N/O1	[EXT]												REP SINGLE SW
13	R1	3	S9	N/C2													EXT SWEEP
14																	
15																	
16	P1	Ø	S1	C	F1	*	FL1	AC	DS1		PS1	AC	PS2	AC	PS3	AC	AC PWR, HOT
17	P1	N	FL1	AC	DS1	*	PS1	AC	PS2	AC	PS3	AC					AC PWR NEUT
18	P1	GND	PS1	-10V	PS2	COM	PS3	COM	GND								AC PWR, GND
19																	
20																	
21																	
22																	
23																	
24																	
25																	
26																	
27																	
28																	

NOTES: * TIMER

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SIZE	FSCM NO.	DWG. NO.
B	14214	WD-A12440

SCALE | SHEET 6 OF 6

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