GPIB INTERFACE AND TIMING GENERATOR FOR THE HEWLETT-PACKARD 2481C INTEGRA (U) AEROSPACE CORP EL SEGUNDO CA ELECTRONICS RESEARCH LAB M F BOTTJER ET AL
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GPIB Interface and Timing Generator
for the Hewlett-Packard 2401C
Integrating Digital Voltmeter

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30 September 1985

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<td>GPIB interface logic and a timing generator for the Hewlett-Packard 2401C integrating digital voltmeter were designed, constructed, and checked out. This logic enables the control of the 2401C by a Hewlett Packard 9825T calculator. This hardware is described herein. Also described is software for a typical usage for the voltmeter, calculator, and interface system with a printer and plotter as outputting devices.</td>
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</table>
CONTENTS

I. INTRODUCTION ............................................................................................................. 7
II. EXAMPLE OF A TYPICAL USAGE ............................................................................. 15
III. INSTRUCTIONS FOR USING DATA ACQUISITION AND REDUCTION PROGRAM .................................................. 29
IV. 2401C INTEGRATING DIGITAL VOLTMETER CONTROL SETTINGS AND CONNECTIONS TO THE INTERFACE BUS ................................................................. 33
APPENDIX A. REJECTION OF 60 Hz AND HARMONICALLY RELATED COMPONENTS .................................................................................................. A-1
APPENDIX B. QUANTIZATION LEVEL OF THE 2401C .................................................. B-1
APPENDIX C. EFFECT ON THE CALCULATION OF $\sigma$ OF THE TIME-BANDWIDTH PRODUCT OF THE INPUT VOLTAGE .............................................................. C-1
FIGURES

1. Functional Block Diagram .................................................. 8
2. GPIB Interface Logic for 2401C (IDVM) .................................. 9
3. Address and Mode Select GPIB Interface Circuit ....................... 10
4. GPIB Interface Drivers, Card 2 ............................................. 11
5. Data Acquisition Block Diagram ........................................... 16
6. Data Acquisition Flow Chart Using 9825T Calculator and 2401C IDVM .......................................................... 20
7. Plot of Table 3 Data Set ...................................................... 22
TABLES

1. Interconnections for 2401C and GPIB Interface Logic................. 12
2. Data Acquisition and Reduction Program.................................. 17
3. Manual Mode Output......................................................... 21
4. Automatic Mode Output....................................................... 23
I. INTRODUCTION

The GPIB interface and timing generator for the Hewlett Packard (or DYMEEC) 2401C allow calculator control of the integration time of the 2401C and also enable the calculator to read the 2401C output.

The block diagram (Fig. 1) shows the functional elements of the "GPIB/TIMING GENERATOR INTERFACE." The GPIB (IEEE 488) protocol is handled by a 74LS488 integrated circuit along with a few support integrated circuits. A 10 MHz crystal clock required for operation of the 74LS488 is divided by $10^5$ to produce a 10 ms clock for the timing generator. This clock is used for counting down a four-digit presettable counter. The timing generator provides the start/stop information for the 2401C. The timing range is 0.01 to 99.99 sec in steps of 10 ms. We should note that the time between integration times (i.e., the "dead time") is a minimum of about 17 ms for the circuit implementation described in this report. The problem of integration time selection to achieve rejection of 60 Hz and harmonic components is discussed in Appendix A. The quantization level of the 2401C and how it is set are discussed in Appendix B.

Output data from the 2401C is formatted as eight binary-coded decimal (BCD) words of six digits plus sign and exponent. These data are parallel loaded into four 8 bit shift registers. The data are then outputted sequentially over the GPIB as eight data words. The circuit details of the unit are given in Figs. 2 through 4. In Table 1 are listed the interconnections for the 2401C and GPIB interface logic.
FIG. 1. Functional Block Diagram
Fig. 2. GPIB Interface Logic for 2401C (IDVM)
Fig. 4. GPIB Interface Drivers, Card 2
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<th>2401C Connector J2 Pin No.</th>
<th>BCD Weight and Coding of Outputs from 2401C&lt;sup&gt;a&lt;/sup&gt;</th>
<th>3M Connector 3429-4005 26 Pins (2 each)</th>
<th>CA3081 Base Card 2</th>
<th>CA3081 Collector Card 2</th>
<th>On-Board Terminal</th>
<th>Shift Register 74LS166 Card 1</th>
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<td>Z4-4</td>
<td>2</td>
<td>Z9-2</td>
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<p>| 17                       | Record Pin 17                  |                                |                 |                 |                 |
| 18                       | Reset 18                       |                                |                 |                 |                 |
| 19                       | + 5 19                         |                                |                 |                 |                 |
| 20                       | Start 37                       | Z5-8                           |                 |                 |                 |
| 21                       | Ground 20                      |                                |                 |                 |                 |
| 22                       |                                |                                |                 |                 |                 |
| 23                       |                                |                                |                 |                 |                 |</p>
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*Listing is for a 1248 code (option M21). Other options use a 1224 code.*
II. EXAMPLE OF A TYPICAL USAGE

A typical data acquisition test setup is shown in Fig. 5. Following Fig. 5 is Table 2, which is a listing of a data acquisition and reduction program used with the test setup. Following the program are instructions for using the program (Section III), the 2401C control settings and connections (Section IV), and lastly a program flow chart, depicted as Fig. 6.

To illustrate the use of the program, the noise output of a LM194 op-amp set for a voltage gain of 50 and with a 2000 ohm termination was used as an input to the 2401C. Table 3 and Fig. 7 give the results for a manual mode run for 50, 1-sec integration data points. The output for a typical automatic mode sequence is shown in Table 4. The sequence is for 50 integration times of 1 and 2 sec, three blocks of each, and two iterations.
Fig. 5. Data Acquisition Block Diagram

- INPUT
- 2401C INTEGRATING DIGITAL VOLTOMETER
- GPIB INTERFACE AND TIMING GENERATOR
- 9825ST CALCULATOR
- 9876A PRINTER
- 9872A PLOTTER
Table 2. Data Acquisition and Reduction Program

0: "IDVM Ver 2.0 (MFB 831012 [12/16/83])":
1: "For use with 2401C interface Don-1":
2: "added avg std dev & avg dev":
3: dim D[4], D$[8], P$[10], L$[80], T[22], X$[80], T$[20]
4: dev "M", 723, "P", 701; fmt 8, c, z
5: 
6: ent "1 2 2' 4 code (Y)?", P$
7: if cap(P$)="Y"; sfg 8
8: ent "AUTO MODE (Y)?", P$
9: if cap(P$)="Y"; sfg 2
10: 
11: "Bgn": cll 'Time'; wrt "P", "IDVM Ver 2.0 "& T$
12: 1)T)T[1]; ent "Label", L$
13: if fgl3; X$)L$
14: L$)X$; wrt "P", L$
15: ent "NUMBER OF SAMPLES ?", N; int(N))N
16: if N<=1; jmp -1
17: if fgl2; gto "Setup"
18: ent "SAMPLE INTEGRATION TIME [Sec]?", T[1]
20: 
21: "Loop": if fgl2; gsb "GEN"
22: 0)P)0)X)Y; fxd 0; sfg 1
23: if fgl8; conv 54, 52, 55, 53, 60, 54, 61, 55, 62, 56, 63, 57
24: 10000+int(.5+100T[T]))D
25: str(D))D$; D$[3])D$
26: for I=1 to 4; 48+161+val(D$[I])D[I]; next I
27: 
28: for I=1 to N; dsp I
29: wtb "M", D[4], D[3], D[2], D[1]
30: red "M.8", d$
31: val(D$[2,7]))V
32: V/tn*val(D$[8,8]))V
33: if D$[1,1]="2"; -V)V
34: V)rI; next I
35: 
36: r1/T[T])H)L
37: for I=1 to N; rI/T[T])V)rI
38: if V>H; V)
39: if V<; V)I
40: I+X)X; V+Y)Y
41: IV+P)P; I+Q)Q
42: next I
43: (NP-XY)/(NQ-XX))A
44: (YQ-XP)/(NQ-XX))B
45: Y/N)M; 0)P)Y; for I=1 to N

17
Table 2. Data Acquisition and Reduction Program (Continued)

46: \( rI - A1 - B \)\( V;V + Y \)\( Y;V V + P \)\( P \)
47: next I
48: \( (N P - Y Y) / N(N - 1) \)\( V;V \)\( Y S \)
49: conv; if \( f l g 2 \) gto "LIST"
50: 
51: "Out": beep; ent "PLOT/LIST/NEXT (P/L/N) ?" , \( P \) S
52: if \( f l g 13 \) gto +4
53: if cap(\( P \)[$1])="P" gto "PLOT"
54: if cap(\( P \)[$1])="L" gto "LIST"
55: if cap(\( P \)[$1])="N" gto "Bgn"
56: prt "No. of Pts."=" &str(N)
57: \( f x d \) 6; prt "Mean=" , \( M \)
58: prt "Std Dv"=" , \( S \)
59: prt "Slope=" , \( A \)
60: prt "Y Int.=" , \( B \)
61: gto "Bgn"
62: "PLOT": pclr; scl 0,N,M-1.5(M-L),M+1.5(H-M)
63: \( \text{pen# } 3; f x d \) 0;xax M,1,0,N,5
64: \( \text{fxd int(.5-log((H-L)/10)))E}; yax 0,tn^(-E),L,H,2
65: \( \text{pen# } 2; \text{plt } 1,rl,-2
66: \text{for I=1 to N}; \text{plt I,rl}; \text{next I}
67: \text{scl } 0,10,0,10
68: \text{plt } 2,10,1
69: \text{pen# } 1; ibl L$
70: \text{pen# } \text{gto } "Out"
71: "LIST": wrt "P"
72: c11 'Time'; wrt "P", T$
73: \text{if} \( W=1 \) \text{gto } "L"
74: \( \text{fmt } 1,f12.7,z
75: \( \text{fmt } 2,f12.7
76: \text{for I=1 to 1+int(N/6)
77: \text{for J=1 to 6
78: \text{for } K=N \text{ or } J=6; \text{wrt } "P.2",rK}\text{gto +2
79: \text{wrt } "P.1",rK
80: \text{next } J
81: \text{next } I
82: "L": fmt 1,c18,f11.8; fxd 0; wrt "P"
83: \text{wrt } "P", 'No. of Points"=&str(N)
84: \text{wrt } "P.1", "Integ. Time", T[T
85: \text{wrt } "P.1", "Mean", M
86: \text{wrt } "P.1", "Std. Deviation"=, S
Table 2. Data Acquisition and Reduction Program (Continued)

92: wrt "P.1","Slope=" ,A
93: wrt "P.1","Y Intercept=" ,B
94: wrt "P";if flg2;gto "Loop"
95: gto "Out"
96:
97: "Setup":1)I;O)G)S)T)Z;fxd 0
98: for J=1 to 22;O)T[J];next J
99: str(I))P$;dsp "SAMPLE INTEGRATION TIME: T["&P$[2]&"]=?"
100: ent "",T[I]
101: if T[I]>99.99;jmp -2
102: if I<19 and not flg13;I+1)I;gto -3
103: ent "NUMBER OF BLOCKS OF SAMPLES？", T[20]
104: ent "NUMBER OF ITERATIONS？",T[21]
105: ent "DATA POINTS LISTED (N)？",P$
106: cap(P$)="N")W
107" gto "Loop"
108:
109: "GEN":G+1)G;if G>T[20];1)G
110: SS+Z)Z
111: if G#1;ret
112: if Z=0;gto +4
113: wrt "P.1","Avg std dev=" ,\(Z/T[20])\))/Z
114: wrt "P.1","std dev \ T=" ,Z\T[T]
115: 0)S)Z
116: T+1)T;if T[I]=0;1)T;T[22]+1)T[22]
117: if T[22]<T[21];ret
118: gto "Bgn"
119:
120: "Time":wrt 8,"R"
121: red 8,T$
122: T$[7])P$
123: "/")T$[3,3])T$[6,6];"84")T$[7,8]
124: P$&" &T$[1,8])T$;ret
*4134
Fig. 6. Data Acquisition Flow Chart Using 9825T Calculator and 2401C IDVM
Table 3. Manual Mode Output

IDVM Ver 2.0 13:20:30 04/18/84
Noise meas. LM194 G=50 input term. 2k

13:23:48 04/18/84

\[
\begin{array}{cccccc}
-0.0284150 & -0.0284150 & -0.0284470 & -0.0284260 & -0.0284360 & -0.0284100 \\
-0.0283810 & -0.0283860 & -0.0283820 & -0.0283860 & -0.0283780 & -0.0283610 \\
-0.0283660 & -0.0283520 & -0.0283580 & -0.0283810 & -0.0284030 & -0.0284130 \\
-0.0284140 & -0.0284250 & -0.0284210 & -0.0284090 & -0.0284070 & -0.0284170 \\
-0.0284570 & -0.0284530 & -0.0284330 & -0.0284420 & -0.0284650 & -0.0284760 \\
-0.0284910 & -0.0285020 & -0.0284950 & -0.0284710 & -0.0284280 & -0.0284080 \\
-0.0284280 & -0.0284430 & -0.0284400 & -0.0284630 & -0.0284390 & -0.0284450 \\
-0.0284530 & -0.0284460 & -0.0284500 & -0.0284650 & -0.0284700 & -0.0284680 \\
-0.0284830 & -0.0285100 & & & & \\
\end{array}
\]

No. of Points= 50
Integ. Time= 1.00000000
Mean=-0.02843026
Std. Deviation= 0.00002863
Slope=-0.00000180
Y Intercept=-0.02838436
Table 4. Automatic Mode Output

IDVM Ver 2.0  13:53:45 04/18/84
noise meas. LM194 G=50 input term 2k

13:57:20 04/18/84
-0.0277580 -0.0277910 -0.0277930 -0.0277530 -0.0277630
-0.0277700 -0.0277560 -0.0277320 -0.0277090 -0.0277300
-0.0277310 -0.0277130 -0.0277310 -0.0277440 -0.0277570
-0.0277420 -0.0277300 -0.0277710 -0.0277900 -0.0277880
-0.0277980 -0.0277650 -0.0277380 -0.0277490 -0.0277790
-0.0277990 -0.0277870 -0.0277590 -0.0277620 -0.0277690
-0.0278140 -0.0277970 -0.0278040 -0.0278020 -0.0277850
-0.0277900 -0.0278000 -0.0277960 -0.0278030 -0.0278110
-0.0278140 -0.0277920

No. of Points= 50
Integ. Time= 1.00000000
Mean=-0.02777114
Std. Deviation= 0.00002185
Slope=-0.00000120
Y Intercept=-0.02774059

13:58:14 04/18/84
-0.0278050 -0.0277820 -0.0277110 -0.0277650 -0.0277630 -0.0278000
-0.0278040 -0.0278070 -0.0278060 -0.0277970 -0.0278200 -0.0278140
-0.0277790 -0.0277660 -0.0277910 -0.0278040 -0.0278250 -0.0278130
-0.0278110 -0.0277970 -0.0278230 -0.0278610 -0.0278770 -0.0278630
-0.0278800 -0.0278740 -0.0278620 -0.0278470 -0.0278400 -0.0278310
-0.0277890 -0.0277720 -0.0277830 -0.0277840 -0.0277580 -0.0277640
-0.0277580 -0.0277830 -0.0277980 -0.0277930 -0.0277960 -0.0277760
-0.0277650 -0.0277650 -0.0277450 -0.0277650 -0.0277670 -0.0277440
-0.0277370 -0.0277360

No. of Points= 50
Integ. Time= 1.00000000
Mean=-0.02779712
Std. Deviation= 0.00003508
Slope= 0.00000083
Y Intercept=-0.02781835
### Table 4. Automatic Mode Output (Continued)

<table>
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<th>Data</th>
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<td>13:59:09 04/18/84</td>
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<td>-0.0277200</td>
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<tr>
<td></td>
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<td>-0.0276900</td>
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<tr>
<td></td>
<td></td>
<td>-0.0277120</td>
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<tr>
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<tr>
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<td></td>
<td>-0.02777150</td>
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- No. of Points = 50
- Integ. Time = 1.00000000
- Mean = -0.02772144
- Std. Deviation = 0.00001960
- Slope = -0.00000066
- Y Intercept = -0.02770460
- Avg std dev = 0.00002641
- std dev \( T \) = 0.00002641

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<tr>
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<th>Data</th>
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</thead>
<tbody>
<tr>
<td>14:00:53 04/18/84</td>
<td>50</td>
<td>-0.0276815</td>
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<tr>
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<td></td>
<td>-0.0276990</td>
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<td>-0.0276430</td>
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<tr>
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<td>-0.0276260</td>
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<tr>
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<td>-0.0276880</td>
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<tr>
<td></td>
<td></td>
<td>-0.0277705</td>
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<tr>
<td></td>
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<td>-0.0277400</td>
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</table>

- No. of Points = 50
- Integ. Time = 2.00000000
- Mean = -0.02766661
- Std. Deviation = 0.00004873
- Slope = -0.00000161
- Y Intercept = -0.02762565
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<th>Time</th>
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<th>Integ. Time</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Slope</th>
<th>Y Intercept</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:02:38 04/18/84</td>
<td>50</td>
<td>2.00000000</td>
<td>-0.02769404</td>
<td>0.00002406</td>
<td>0.00000384</td>
<td>-0.02769185</td>
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<tr>
<td>14:04:23 04/18/84</td>
<td>50</td>
<td>2.00000000</td>
<td>-0.02749492</td>
<td>0.00003091</td>
<td>0.00000150</td>
<td>-0.02753304</td>
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Table 4. Automatic Mode Output (Continued)

<table>
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<th>Mean</th>
<th>Std. Deviation</th>
<th>Slope</th>
<th>Y Intercept</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:05:18</td>
<td>-0.0274530</td>
<td>1.000000000</td>
<td>-0.02751146</td>
<td>0.00002718</td>
<td>-0.0000154</td>
<td>-0.02747427</td>
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<tr>
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<td>-0.0274540</td>
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<tr>
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<td>-0.0274580</td>
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<td>-0.0275460</td>
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No. of Points= 50
Integ. Time= 1.00000000
Mean=-0.02751146
Std. Deviation= 0.00002718
Slope=-0.0000154
Y Intercept=-0.02747222

<table>
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<th>Mean</th>
<th>Std. Deviation</th>
<th>Slope</th>
<th>Y Intercept</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:06:12</td>
<td>-0.0275210</td>
<td>1.000000000</td>
<td>-0.02754888</td>
<td>0.00002237</td>
<td>-0.0000114</td>
<td>-0.02751981</td>
</tr>
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<td>-0.0275190</td>
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<td>-0.0275620</td>
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<td>-0.0275680</td>
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<td>-0.0275510</td>
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</tr>
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</table>

No. of Points= 50
Integ. Time= 1.00000000
Mean=-0.02754888
Std. Deviation= 0.00002237
Slope=-0.0000114
Y Intercept=-0.02751981
### Table 4. Automatic Mode Output (Continued)

<table>
<thead>
<tr>
<th>Time</th>
<th>Points</th>
<th>Integ. Time</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Slope</th>
<th>Y Intercept</th>
<th>Avg std dev</th>
<th>std dev ( T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:07:07 04/18/84</td>
<td>50</td>
<td>1.00000000</td>
<td>-0.02757570</td>
<td>0.00003667</td>
<td>-0.00000030</td>
<td>-0.02756801</td>
<td>0.00002935</td>
<td>0.00002935</td>
</tr>
<tr>
<td>14:08:52 04/18/84</td>
<td>50</td>
<td>2.00000000</td>
<td>-0.02757816</td>
<td>0.00002184</td>
<td>-0.00000034</td>
<td>-0.02756950</td>
<td>0.00002184</td>
<td>0.00002184</td>
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</tbody>
</table>
Table 4. Automatic Mode Output (Continued)

<table>
<thead>
<tr>
<th>Time</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:10:36 04/18/84</td>
<td>-0.0275715 -0.0276125 -0.0276510 -0.0276415 -0.0276370 -0.0276460 -0.0276250 -0.0276145 -0.0275795 -0.0275225 -0.0275260 -0.0274825 -0.0274520 -0.0274545 -0.0274370 -0.0274660 -0.0274800 -0.0275183 -0.0275450 -0.0275660 -0.0275885 -0.0275910 -0.0276135</td>
</tr>
<tr>
<td>14:12:21 04/18/84</td>
<td>-0.0276275 -0.0275875 -0.0276180 -0.0276250 -0.0276135 -0.0276600</td>
</tr>
</tbody>
</table>

- No. of Points = 50
- Integ. Time = 2.0000000
- Mean = -0.02755904
- Std. Deviation = 0.00005602
- Slope = 0.00000204
- Y Intercept = -0.02754323

<table>
<thead>
<tr>
<th>Time</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:12:24 04/18/84</td>
<td>-0.0275470 -0.0275405 -0.0275455 -0.0275470 -0.0275395 -0.0275735</td>
</tr>
</tbody>
</table>

- No. of Points = 50
- Integ. Time = 2.0000000
- Mean = -0.02758487
- Std. Deviation = 0.00002284
- Slope = 0.00000204
- Y Intercept = -0.02763691

- Avg std dev = 0.00003714
- std dev / T = 0.00005252
- IDVM Ver 2.0 14:12:24 04/18/84
III. INSTRUCTIONS FOR USING DATA ACQUISITION AND REDUCTION PROGRAM

The instructions for using the data acquisition and reduction program are described herein.

I. Load Tape

Press "LOAD", enter tape file number, press "EXECUTE".

II. Run Program

Press "RUN".

III. Operation of Program

A. 122'4 code(Y)? (see Note 1)

Enter "Y" and press "CONTINUE" for 122'4 code or
Enter "N" and press "CONTINUE" or just "CONTINUE" for 1248 code.

B. Auto Mode (Y)?

Enter "Y" and press "CONTINUE" for automatic mode (see Note 2).
Enter "N" and press "CONTINUE" or just "CONTINUE" for manual mode (see Note 3).

1. Auto Mode

a. Label

Enter the title for which this test is to be conducted (up to 80 character positions) and press "CONTINUE".

b. Number of samples?

Enter number of samples desired and press "CONTINUE".

c. Sample integration time: T[1]=? (see Note 4)

Enter first integration time and press "CONTINUE".


Enter second integration time and press "CONTINUE".

e. Repeat as desired for a maximum of 19 integration times. Pressing "CONTINUE" instead of entering another integration time moves the program to the next step.
f. Number of blocks of samples? (see Note 5)
Enter number of blocks of samples and press "CONTINUE".
g. Number of iterations? (see Note 6)
Enter number of iterations and press "CONTINUE".
h. Data points listed (N)?
Enter "N" and press "CONTINUE" (see Note 7)
or
Enter "Y" and press "CONTINUE" (see Note 8)
i. Once "CONTINUE" is pressed the computer begins to collect data, automatically prints the number of samples, returns to step 1.a. ("Label") and waits for the next test sequence (see Note 9).

2. Manual Mode
   a. Label
      Enter the title (up to 80 character positions), and press "CONTINUE".
   b. Number of samples?
Enter number of samples and press "CONTINUE".
   c. Sample integration time (sec)?)
Enter integration time (≥ 0.01 to ≤ 99.99 sec) and press "CONTINUE". Data are now acquired.
   d. Plot/list/or next (P/L/N)?
Enter "P" and press "CONTINUE" for a plot of the data acquired in 2.c. vs. the number of the sample.
or
Enter "L" and press "CONTINUE" for a list of the data acquired in 2.c. (see Note 8)
or
Enter "N" and press "CONTINUE". This step returns to 2.a. for the next sample cycle
or
If no letters are used, the following information will be listed on 9825T calculator tape:
   Number of points
   Means
   Standard deviation of means
   Slope of best least squares fit straight line
   Y-intercept of best least squares fit straight line
   (See Note 8).
NOTES:

1. The .2401C with option M21 has a 1248 code. Otherwise the 2401C has a 122'4 code.

2. In the automatic mode a wide variety of data taking sequences can be specified.

3. The manual mode is used for listing and/or plotting one block of data.

4. A maximum of 19 different integration times can be selected between > 0.01 to < 99.99 sec.

5. The number of blocks indicates the number of times data are repeated for each integration time. For example if two blocks are selected for integration times of 1, 2, and 5 sec (integration times are selected in 1.c.), each of which has 50 samples (number of samples are selected in 1.b.). The computer will accumulate data as follows

   50 samples, 1 second integration time for each sample
   50 samples, 2 second integration time for each sample
   50 samples, 5 second integration time for each sample

   The total is six blocks of data, and each block is stored, processed, and outputted separately.

6. The number of iterations indicates the number of times the data sequence described in Note 5 is repeated. For example, if the three iterations were asked for the sequence described in Note 5 would be repeated 3 times for a total of 18 blocks of data. Each block would be stored, processed, and outputted separately.

7. The printer will list:
   
   - Number of points
   - Integration time
   - Mean of data
   - Standard deviation of the data about a linear least squares fit to the data
   - Slope of the linear least squares fit
   - Y intercept of the linear least squares fit
   
   The standard deviation is computed as

   \[ \sigma = \left( \frac{1}{N-1} \sum_{i=1}^{N} \left[ y_i - (mx_i + b) \right]^2 \right)^{1/2} \]
where

\[ N = \text{number of data points} \]
\[ x_i, y_i = \text{data set} \]
\[ m = \text{slope of the linear least squares fit} \]
\[ b = \text{Y intercept of the linear least squares fit} \]

In Appendix C is discussed the effect of the time-bandwidth product of the input voltage on the calculation of \( \sigma \).

8. The printer will list each measured integrated voltage (i.e., each mean) and also the information listed in Note 7 above.

9. At this time or any other time if one desires to get into the manual mode or from a manual mode into an auto mode or simply to get back to the beginning of the program because of an error, press "STOP" and press "RUN". The computer will advance to the beginning of the program which is step III.A., which asks the question "122'4 code (Y)?".
IV. 2401C INTEGRATING DIGITAL VOLTMETER CONTROL SETTINGS AND CONNECTIONS TO THE INTERFACE BUS

I. Front Panel of 2401C

A. Range: Depending on the amplitude of the input voltage, select one of five positions: 0.1, 1.0, 10, 100, or 1000 V.

B. Function: Set to "VOLT" position.

C. Sample Period: Set to "EXT SEL" position.

D. Sample Rate: Setting not important.

E. Attenuation: Setting not important.

II. Back Panel of 2401C

A. STORE DURING COUNT/DISPLAY DURING COUNT: Either position.

B. INT/EXT: Either position.

C. Program control (J1 connector): A coax is connected from the "START" BNC fitting on the interface box to J1 with the center conductor going to J1-b and the shield to J1-a and J1-z. A special coax is furnished with the interface box to make these connections.

D. Counter reset: Connect a coax from counter reset to the "RESET" input on the interface box.

E. BCD output (J2 connector): Connect to the interface box "BCD in" with 50 pin ribbon cable supplied with the interface box.

F. FREQ input: No connection.

G. 100 KHz STD, INPUT/OUTPUT: No connection.

H. 100 KHz STD, INT/EXT: Either position.

III. Interface Box to Calculator

A. Connect HP-IB from calculator to the interface box GPIB input.
APPENDIX A

REJECTION OF 60 Hz AND HARMONICALLY RELATED COMPONENTS

The addition of unwanted 60 Hz (i.e., pickup voltages) and harmonically related components to the wanted signal is a common laboratory problem. Depending on the integration time chosen the 2401C will provide a varying degree of rejection to the unwanted signal. Given an input unwanted voltage of amplitude $V_u$ at frequency $f_u$, we can define a measure of rejection $R$ as

$$ R = \frac{\sigma_i}{\sigma_o(T)} \tag{A-1} $$

where

- $\sigma_i$ = standard deviation of the unwanted voltage = $V_u/\sqrt{2}$
- $\sigma_o(T)$ = standard deviation of the output mean voltage for an integration time of $T$ and caused by the unwanted voltage

The output mean voltage $V_o(T)$ for an integration time of $T$ and caused by the unwanted voltage is given by

$$ V_o(T) = \frac{V_u}{\Delta\theta} \int_0^{\theta+\Delta\theta} \sin(2\pi f_u t) d(2\pi f_u t) = \frac{V_u}{\Delta\theta} [\cos \theta - \cos(\theta + \Delta\theta)] \tag{A-2} $$

where $\Delta\theta = \left(\frac{T}{f_u}\right) \times 2\pi$ radians

The variance of $V_o(T)$ is, by definition,

$$ \text{Var} \ V_o(T) = E[V_o - E(V_o)]^2 \tag{A-3} $$

where $E[ ]$ denotes mathematical expectation. Substituting (A-2) into (A-3), and noting that $E(V_o) = 0$ we have

$$ \text{Var} \ V_o(T) = \left(\frac{V_u}{\Delta\theta}\right)^2 E[\cos^2\theta + \cos^2(\theta + \Delta\theta) - 2\cos\theta \cos(\theta + \Delta\theta)] $$

$$ = \left(\frac{V_u}{\Delta\theta}\right)^2 \left[\frac{1}{2} + \frac{1}{2} - 2E[\cos\theta \cos(\theta + \Delta\theta)]\right] $$

A-1
\[
= \left( \frac{V_u}{\Delta \theta} \right)^2 \left[ 1 - 2 \times \frac{1}{2 \pi} \int_0^{2\pi} (\cos^2 \theta \cos \Delta \theta - \cos \theta \sin \theta \sin \Delta \theta) d\theta \right]
\]

\[
= \left( \frac{V_u}{\Delta \theta} \right)^2 (1 - \cos \Delta \theta)
\]

From which we get

\[
\sigma_o(T) = \left[ \text{Var} V_o(T) \right]^{1/2} = \frac{V_u (1 - \cos \Delta \theta)^{1/2}}{\Delta \theta}
\]

and finally

\[
R = \frac{\sigma_o}{\sigma_o(T)} = \frac{\Delta \theta}{\sqrt{2(1 - \cos \Delta \theta)^{1/2}}}
\]

A plot of $R$ vs. $\Delta \theta$ is given in Fig. A-1. Equation (A-6) was checked experimentally by putting a known 60 Hz voltage into the 2401C and then varying the sampling time. In Table A-1 are shown the results for a constant input of 10.3 mV rms for integration times of 10 through 190 ms every 10 ms. For each integration time 100 samples were taken, e.g., for an integration time of 40 ms, this means we would take 100 averages and each would be 40 ms long. As can be seen from the table the agreement between the calculated and experimental values of $R$ are within about 5%, the experimental value being consistently higher, probably due to some systematic error, e.g., an error in the 10.3 mV rms measurement.
Fig. A-1. Rejection vs. $\Delta \theta$
Table A-1. Experimental Determination of $R$ as a Function of Integration Time ($T$)

<table>
<thead>
<tr>
<th>$T$ (ms)</th>
<th>$R$ (predicted)</th>
<th>$\sigma_o$ (mV rms)</th>
<th>$10.3/\sigma_o$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.98</td>
<td>5.004</td>
<td>2.06</td>
</tr>
<tr>
<td>20</td>
<td>6.41</td>
<td>1.557</td>
<td>6.62</td>
</tr>
<tr>
<td>30</td>
<td>9.62</td>
<td>1.017</td>
<td>10.13</td>
</tr>
<tr>
<td>40</td>
<td>7.93</td>
<td>1.214</td>
<td>8.48</td>
</tr>
<tr>
<td>50</td>
<td>-</td>
<td>0.0125</td>
<td>$0.824 \times 10^3$</td>
</tr>
<tr>
<td>60</td>
<td>11.89</td>
<td>0.8081</td>
<td>12.75</td>
</tr>
<tr>
<td>70</td>
<td>22.45</td>
<td>0.4449</td>
<td>23.15</td>
</tr>
<tr>
<td>80</td>
<td>25.66</td>
<td>0.3881</td>
<td>26.54</td>
</tr>
<tr>
<td>90</td>
<td>17.84</td>
<td>0.5615</td>
<td>18.34</td>
</tr>
<tr>
<td>100</td>
<td>-</td>
<td>0.00301</td>
<td>$3.42 \times 10^3$</td>
</tr>
<tr>
<td>110</td>
<td>21.80</td>
<td>0.4446</td>
<td>23.17</td>
</tr>
<tr>
<td>120</td>
<td>38.48</td>
<td>0.2592</td>
<td>39.74</td>
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<tr>
<td>130</td>
<td>41.69</td>
<td>0.2363</td>
<td>43.59</td>
</tr>
<tr>
<td>140</td>
<td>27.75</td>
<td>0.3544</td>
<td>29.06</td>
</tr>
<tr>
<td>150</td>
<td>-</td>
<td>0.00265</td>
<td>$3.92 \times 10^3$</td>
</tr>
<tr>
<td>160</td>
<td>31.71</td>
<td>0.3114</td>
<td>33.08</td>
</tr>
<tr>
<td>170</td>
<td>54.52</td>
<td>0.1831</td>
<td>56.25</td>
</tr>
<tr>
<td>180</td>
<td>57.72</td>
<td>0.1706</td>
<td>60.38</td>
</tr>
<tr>
<td>190</td>
<td>37.66</td>
<td>0.2645</td>
<td>38.94</td>
</tr>
</tbody>
</table>
APPENDIX B

QUANTIZATION LEVEL OF THE 2401C

The 2401C consists of a very precise voltage to frequency converter (VFC) and a counter with a six digit display. The highest frequency out of the VFC is 310 kHz. In general, the number of counts, C, displayed on the counter is given by

\[ C = \frac{10^5 V_i}{S} \times T \]

where

- \( V_i \) = input voltage
- \( S \) = voltage scale setting, choice of 0.1, 1, 10, 100, or 1000 V
- \( T \) = counting time, choice of 0.01, 0.1, or 1.0 sec or can be externally controlled

Since the maximum frequency out of the VFC is 310 kHz, this means that the maximum allowed value of \( V_i \) is 3.1 \( S \). Values above that level will result in an overload indication. The maximum quantization level if the internal time base is used is then 1 part in 310,000 for a 1 sec count, 1 part in 31,000 for a 0.1 sec count, and 1 part in 3100 for a 0.01 sec count. If the count time is controlled externally, the maximum quantization is 1 part in 999,999. This of course requires that \( T \) be at least \( 1/0.31 = 3.2258 \) sec.
APPENDIX C

EFFECT ON THE CALCULATION OF $\sigma$ OF THE TIME-BANDWIDTH PRODUCT OF THE INPUT VOLTAGE

For an ideal low-pass input bandwidth of $B$ Hz and for an integration time of $T$, the error in $\sigma$ has been shown\(^1\) to be about 5, 2.5, and 1% for $BT = 1$, 2, and 4, respectively. To eliminate problems with overload of the 2401C caused by large high-frequency inputs, e.g., as might be caused by sharp spike pickup, we commonly low pass the input to the 2401C. Therefore, in order to make accurate calculations of $\sigma$, we choose the low-pass bandwidth $B$ such that $BT \gg 1$.

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military space systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

**Aerophysics Laboratory:** Launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion, propellant chemistry, environmental hazards, trace detection; spacecraft structural mechanics, contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; cw and pulsed laser development including chemical kinetics, spectroscopy, optical resonators, beam control, atmospheric propagation, laser effects and countermeasures.

**Chemistry and Physics Laboratory:** Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiation transport in rocket plumes, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

**Computer Science Laboratory:** Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence and microelectronics applications.

**Electronics Research Laboratory:** Microelectronics, GaAs low noise and power devices, semiconductor lasers, electromagnetic and optical propagation phenomena, quantum electronics, laser communications, lidar, and electro-optics; communication sciences, applied electronics, semiconductor crystal and device physics, radiometric imaging; millimeter wave, microwave technology, and RF systems research.

**Materials Sciences Laboratory:** Development of new materials: metal matrix composites, polymers, and new forms of carbon; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

**Space Sciences Laboratory:** Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.