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AN INEXPENSIVE MICRO-COMPUTER FOR LABORATORY
DATA ACQUISITION AND TEST EQUIPMENT CONTROL

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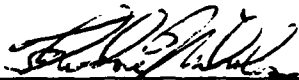E

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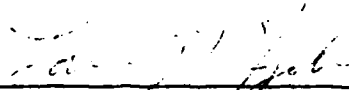This technical report has been reviewed and is approved for publication.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A versatile, inexpensive laboratory data acquisition and control unit has been developed. A VIC-20 microcomputer is used in conjunction with an expansion chassis and plug in interfaces which make it applicable to a wide variety of real time laboratory control and data acquisition tasks. A system of this type can be built for much less than one thousand dollars.

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FOREWORD

This work was performed under a contract with the Metals Behavior

Branch (MLLN) of the Materials Laboratory, USAF Contract Number F33615-81-C-

5015, under the administration of Dr. Theodore Nicholas. Part of the contract

was to provide more efficient usage of the test equipment and to enhance the

testing capability in the laboratory. The electronics components which were

designed and developed under this contract were manufactured and assembled by

the technical staff of the 4750th Fabrication and Modification Test Wing.

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# SECTION 1

## INTRODUCTION

Many laboratory tests and procedures require the continuous data
acquisition and control of one or more process variables to maintain proper
test conditions. It is often impractical to perform these functions manually
24 hours a day. Micro- and mini-computers have been purchased to automate
much of the testing equipment in the laboratory. However, there are several
cases where the cost of existing micro- and mini-computer systems is not
justified by the intended application.

The VIC-20 system was originally developed as an inexpensive control
system for the Schenck resonant machines in the MLLN Laboratory. As the capa-
bilities of the unit became apparent, additional applications were identified
and the necessary interface hardware was designed and built. At the present
time, three applications have been identified and will be discussed:

1. Control of four Schenck resonant fatigue testing machines,

2. Control of a furnace used for automated heat treating, and

3. Control of data acquisition for a electropneumatic shaker system
   used for crack growth studies.

The MLLN Laboratory has several Schenck fatigue machines. All of
these machines are over 30 years old and all of the original control systems
were in poor condition. A prototype analog control system was built and

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proved to be functional, however, this system was expensive to construct and install and was difficult for new operators to learn. The VIC-20 control system was developed as an alternative and has proved to be inexpensive to construct and install and easy to operate.

The automated furnace controller was designed to eliminate the need for manual 24 hour monitoring of heat treatments. Many of these heat treatments require a constant heating or cooling rate. With the existing manual controls, this required constant setpoint adjustments by the operator. The VIC-20 system allowed the operator to set up the desired heat treatment temperature profile and the computer would complete the heat treatment.

The control and data acquisition system for the electropneumatic shaker system is currently being developed. The system will control a pneumatic actuator which applies a quasistatic load to the sample. In addition, the unit will provide a DC signal to the shaker to control the amplitude of high frequency loads superimposed on the quasistatic load. Cycle counts will be monitored and stored and the operator will enter optical crack length readings. The optical crack length readings will be used to determine the appropriate load amplitudes necessary to maintain a constant stress intensity at the crack tip. Electric potential techniques may be used to provide a direct crack length measurement. Using the electric potential technique would eliminate the need of many optical crack length measurements and would totally automate the system.

# SECTION 2

## HARDWARE COMPONENTS

The control and data acquisition system is comprised of the following parts:

- VIC-20 Microcomputer

- Television or Monitor

- Expansion Chassis

- Power Supply

- Interface Boards:

  - Analog to Digital Converter

  - Digital to Analog Converter

  - Counter and Digital Input/Output

  - Strain Gage Conditioner

  - 0.1 Ampere Current Driver

A VIC-20, a television or monitor, an expansion chassis, and a power supply constitute the base system. The interface boards can be used in any combination requiring less than eight card slots in the expansion chassis. Board layouts, parts lists, and schematics of each of the boards are included in the appendices. Figure 1 shows the expansion chassis with all the boards necessary for the Schenck control application.
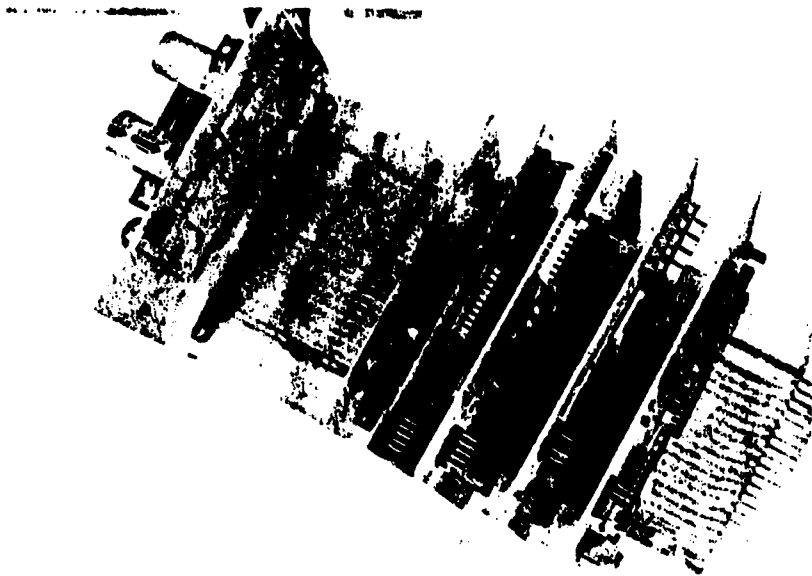
Figure 1. Expansion Chassis With Interface Boards
for Schenck Control Application.

## 2.1 VIC-20 MICROCOMPUTER

The VIC-20 is a 6502 based eight bit microcomputer including an integral keyboard and a five volt power supply. Complete documentation of the system is available from the manufacturer in the VIC-20 programmers reference guide. All interfaces to the VIC are made via the 44 pin expansion port at the back of the unit. This interface provides data, addressing, and handshake lines as well as five volt power for the expansion chassis. See Section 2.3 for details about power requirements.

## 2.2 TELEVISION OR MONITOR

The display unit for the VIC is either a standard television or any monitor that accepts composite video signal. Interconnecting cables are supplied with the computer.

## 2.3 EXPANSION CHASSIS

The VIC expansion port provides space for installation of a single interface card. Since many applications require use of more than one interface card, it was necessary to design an expansion chassis to provide room for up to eight interface boards. The expansion chassis carries all forty-four signals to each card slot and equipment sold by the manufacturer, such as memory expansion cartridges, will work with the expansion chassis.

The internal five volt supply in the VIC will provide up to one amp of power to the expansion chassis. Table 1 shows the power requirements for each of the interface boards. If the application under consideration requires a total for all interface boards of more than one amp on the five volt supply then jumper JP-1 on the expansion chassis should be removed and an external five volt supply with sufficient current capacity should be connected to the solder posts at the far end of the expansion chassis.

## 2.4 POWER SUPPLY

Because the VIC provides a five volt supply only, an external power supply providing +15 and -15 volts is required. Table 1 shows the power requirements of each of the interface boards. The external supply should have a current capacity that exceeds the total requirements for all boards for both the +15 and -15 voltages.

A plug in power supply card has been developed for the VIC-20 expansion chassis. Mounting the supply on the expansion chassis requires less work space than a separate supply and reduces the length of the power supply leads. The plug-in supply has a .250 amp capacity for both the +15 and -15 volt supplies.

The power supply and each of the interface boards has a 10 pin connector in the upper left hand corner for external power connections (J-1). The following pin assignments have been established:

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## TABLE 1

### POWER REQUIREMENTS FOR INTERFACE BOARDS

| BOARD | CURRENT REQUIREMENT (AMPS) | | |
| --- | --- | --- | --- |
| | +5 VOLTS | +15 VOLTS | -15 VOLTS |
| Analog to Digital | .160 | .010 | .020 |
| Digital to Analog | .100 | .020 | .030 |
| Counter/Dio | .100 | .012 | .012 |
| Strain Gage Conditioner | .000 | **** | **** |
| Current Driver | .100 Max. | ——— NA | ——— NA |

****Supply Requirements Depend on Excitation Voltage and Strain

Gage Bridge Resistance.

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| | |
|---|---|
| Pin 1 | No Connection |
| Pin 2 | +15 Volts |
| Pin 3 | -15 Volts |
| Pin 4 | Power Supply Common |
| Pins 5-10 | No Connection |

A ribbon type cable with multiple connectors is recommended for connecting more than one board to the power supply.

## 2.5   INTERFACE BOARDS

The interface boards can be divided into two categories, those using an address slot and those that do not.  The following sections describe each of the interface boards in detail.  Some examples of board operation are included in the following sections and additional examples are contained in Section 3.

### 2.5.1   Boards Requiring Address Slots

The following boards each require one address slot:

1.  Analog to Digital Converter,

2.  Digital to Analog Converter, and

3.  Counter and Digital Input/Output

There are eight address slots set aside for boards which require them. The base address of the board is selected by closing one of the switches in SW-1. Only one of the switch contacts should be closed at a time. Table 2 shows the possible board base addresses and the appropriate switch contacts.

Each of the interface boards requiring an address slot is interfaced to the VIC-20 through a versatile interface adaptor (VIA) on the interface card. The VIA provides temporary storage for data, the counter and dio port for the counter/dio board, and other functions. It can be seen from Table 2 that each board occupies 16 addresses. These addresses correspond to registers in the VIA. The function of the registers is shown for each board in Table 3.

The actual address of a register is the sum of the board base address and the register number. For example:

It is necessary to read the low byte of the A/D converter set up as board number four. We will assume that the A/D converter has completed a conversion. The low byte data is in register number one. The board base address is 38960. The address of the low byte data is then 38960 + 1 = 38961 decimal or 9831 hex. Peek (38961) in basic or LDA $9831 in assembler will retrieve the low byte data.

## TABLE 2

## SWITCH SETTINGS AND BOARD BASE ADDRESSES

| CLOSED CONTACT IN SW-1 | BASE ADDRESS | |
|---|---|---|
| | HEX | DECIMAL |
| 1 | 9800 | 38912 |
| 2 | 9810 | 38928 |
| 3 | 9820 | 38944 |
| 4 | 9830 | 38960 |
| 5 | 9840 | 38976 |
| 6 | 9850 | 38992 |
| 7 | 9860 | 39008 |
| 8 | 9870 | 39024 |

## TABLE 3

### REGISTER FUNCTIONS FOR THE INTERFACE BOARDS

| REGISTER | A/D | D/A | COUNTER/DIO |
|---|---|---|---|
| 0 | High Byte Data | High Byte Data | Not Used |
| 1 | Low Byte Data | Low Byte Data | Digital I/O Port |
| 2 | Set to 0 | Set to 255 | Set to 0 |
| | | *DETERMINES DIGITAL DATA DIRECTION FOR REGISTER 0* | |
| 3 | Set to 0 | Set to 255 | See Section 2.5.3 |
| | | *DETERMINES DIGITAL DATA DIRECTION FOR REGISTER 1* | |
| 4-7 | Not Used | Not Used | Not Used |
| 8 | Not Used | Not Used | Counter Low Byte |
| 9 | Not Used | Not Used | Counter High Byte |
| 10 | Not Used | Not Used | Not Used |
| 11 | Not Used | Not Used | Set to 32 to Count Down |
| 12-15 | Not Used | Not Used | Not Used |

### 2.5.1.1 Analog to Digital Converter Board

The A/D board provides one channel of 12 bit resolution single ended analog to digital conversion at a maximum rate of 40 KHZ. The following steps should be performed to set up an A/D board for use with the system.

1. Determine the voltage range required and strap connector P-2 according to Table 4.
2. Connect the signal input according to Table 4.
3. Select the board number by turning on the appropriate switch in SW-1 (closed contacts are considered on).
4. Insert the board either directly into the VIC or into the expansion chassis.
5. Connect the ±15 volt power supply to connector J-1.

For each voltage range, the input voltage can be calculated from the A/D converter output by the following formula:

$$\text{Input Voltage} = \frac{\text{Voltage Range}}{4095} \times \text{A/D Converter Output} + \text{Minimum Voltage}$$

For example:

Voltage Range = 20          Minimum Voltage = -10

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## TABLE 4

### VOLTAGE RANGE SELECTION AND INPUT CONNECTIONS FOR THE A/D BOARD

| VOLTAGE RANGE | MINIMUM VOLTAGE | OUTPUT TYPE | CONNECTIONS |
|---|---|---|---|
| 20 | -10 | Complementary Offset Binary | Pin 2 to Pin 4<br>Input to Pin J2-2<br>Common Pin J2-1 |
| 10 | -5 | Complementary Offset Binary | Pin 2 to Pin 4<br>Input to Pin J2-3<br>Common Pin J2-1 |
| 5 | -2.5 | Complementary Offset Binary | Pin 2 to Pin 4<br>Pin 4 to Pin 1<br>Input to Pin J2-3<br>Common Pin J2-1 |
| 5 | 0 | Complementary Binary | Pin 2 to Pin 5<br>Pin 4 to Pin 1<br>Input to Pin J2-3<br>Common Pin J2-1 |
| 10 | 0 | Complementary Binary | Pin 2 to Pin 5<br>Input to Pin J2-3<br>Common Pin J2-1 |

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A/D Converter Output = 1111000101001110 Complementary Binary

= 0000111010110001 Binary

= 2048+1024+512+128+32+16+1 = 3761 Decimal

Input Voltage = 20/4095 x 3761 + (-10)

= 8.369 Volts

The resolution of the converter is calculated from the following formula:

Resolution = Voltage Range/4095

For the case above:

Resolution = Voltage Range/4095

= 20/4095

= .0049 Volts

= 4.9 Millivolts

The data registers zero and one (see Table 3) should be set as inputs by setting registers two and three to zero. The A/D converter is then triggered by writing to register zero. Since register zero is set as an input, writing to it has no effect on the data and the write pulse is used to trigger the A/D. The converter has a maximum conversion time of 25 microseconds and software should be designed with enough time between triggering the A/D and reading a sample to allow the converter to complete a conversion.

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It is impossible in BASIC to poke register 0 and read the data in less than about 40 milliseconds and therefore, BASIC routines will never overrun the A/D speed. Machine code, however, can be written which will attempt to read the A/D data before the A/D conversion is complete. Null instructions or timing loops should be added if this occurs. Machine code instruction times are given in the programmers reference guide.

The upper four bits of the high data byte are permanently set to one by the hardware on the board. The output of the A/D converter is complementary so that when the complementary data is converted to straight binary the upper four bits become zeros and thus do not affect the magnitude of the upper byte. In this way, a twelve bit A/D sample can be read in as an eight bit low byte and a four bit high byte with the four most significant bits of the high byte set to zero. For an example of A/D operation, see Figure 2.

The A/D board provides gain and offset trim for calibration purposes. The following procedure should be used to calibrate the A/D board:

1. Apply the minimum voltage for the range chosen to the A/D board inputs.

2. Adjust resistor R2 to obtain zero digital output from the board.

3. Apply the maximum voltage for the range chosen.

4. Adjust resistor R4 to obtain the digital code 111111111111 from the board.

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```
5 REM********************************************************************
6 REM    A/D BOARD TEST
7 REM       BY   GEORGE A. HARTMAN
8 REM           10/15/83
9 REM********************************************************************
10 REM
11 REM    SET 6522 PORTS AS INPUTS
12 REM
13 POKE 38914,0:POKE 38915,0
20 REM
21 REM    CLEAR SCREEN
22 REM
25 PRINT"⊃"
26 REM
27 REM    TRIGGER AND READ A/D.   WRITING TO THE 6522 PORT WHEN IT IS SET AS AN
28 REM    INPUT DOES NOTHING TO THE DATA ON THE OUTPUT PINS OF  THE A/D IT DOES
29 REM    HOWEVER TRIGGER THE A/D.   THE A/D OUTPUT IS COMPLEMENTARY SO CORRECT BY
30 REM    SUBTRACTING FROM 256
31 REM
32 POKE 38912,0
35 C=255-PEEK(38913)+(255-PEEK(38912))*256:PRINT"⊃";C;"▉"     ":GO TO 32

READY.
```

Figure 2.   A/D Board Test Routine.

5. Repeat Steps 1 through 4 until no further adjustments are necessary.

### 2.5.1.2   Digital to Analog Converter Board

The D/A board provides one channel of 12 bit resolution digital to analog conversion at a maximum rate of 200 KHZ. The following steps should be performed to set up a D/A board for use with the system:

1. Determine the voltage range required and strap connector P-2 according to Table 5.

2. Insert the board either directly into the VIC or into the expansion chassis.

3. Select the board number by turning on the appropriate switch in SW-1 (closed contacts are considered on).

4. Connect the external power supply to connector J-1.

5. Connect the output signal according to Table 5.

For each range, the output voltage output can be calculated from the following formula:

$$\text{Output Voltage} = \frac{\text{Voltage Range}}{4095} \times \text{D/A Converter Binary Input} + \text{Minimum Volt}$$

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## TABLE 5

### VOLTAGE RANGE SELECTION AND OUTPUT CONNECTIONS FOR THE D/A BOARD

| VOLTAGE RANGE | MINIMUM VOLTAGE | OUTPUT TYPE | CONNECTIONS |
|---|---|---|---|
| 20 | -10 | Complementary Offset Binary | Pin 5 to Pin 2<br>Pin 4 to Pin 1<br>Output to J2-2<br>Common Pin J2-1 |
| 10 | -5 | Complementary Offset Binary | Pin 5 to Pin 3<br>Pin 4 to Pin 1<br>Output to J2-2<br>Common Pin J2-1 |
| 5 | -2.5 | Complementary Offset Binary | Pin 5 to Pin 3<br>Pin 4 to Pin 1<br>Pin 2 to Pin 1<br>Output to J2-2<br>Common Pin J2-1 |
| 10 | 0 | Complementary Binary | Pin 5 to Pin 3<br>Output to J2-2<br>Common Pin J2-1 |
| 5 | 0 | Complementary Binary | Pin 5 to Pin 3<br>Pin 2 to Pin 1<br>Output to J2-2<br>Common Pin J2-1 |

For example:

Voltage Range = 20                    Minimum Voltage = -10


D/A Converter Input = 1111111010110001 Complementary Binary

= 0000000101001110 Binary

= 2048+1024+512+128+32+16+1 = 3761 Decimal


Output Voltage = 20/4095 x 3761 + (-10)

= 8.369 Volts


The resolution of the converter is calculated from the following formula:


Resolution = Voltage Range/4095


For the case above:


Resolution = Voltage Range/4095

= 20/4095

= .0049 Volts

= 4.9 Millivolts


Data registers zero and one (see Table 3) should be set as outputs by setting registers two and three to 255. The output voltage is changed by writing the appropriate digital code to registers zero and one. The converter has a maximum conversion time of five microseconds.

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Note that it is impossible to change both registers zero and one at exactly the same time. The D/A output will begin to change as soon as the new code is present at either register zero or one. Machine code software can be written to reduce the time between the two byte transfers to about 10 microseconds. The minimum transfer gap in BASIC is about 20 milliseconds.

As with the A/D converter board the upper four bits of the high data byte are irrelevant since only twelve bits are significant. Writing a number larger than binary 1111 (15 decimal) to register zero will produce the same result as writing any other number with the same lower four bits. The upper four bits are ignored. For example, writing 16 to register zero will cause an output equal to writing 1 to register zero. See Figure 3 for an example of D/A operation.

2.5.1.3   Counter and Digital Input/Output Board

The counter/DIO board provides a sixteen bit counter with selectable divide by 10, 100, or 1,000 and eight bits of TTL level input or output.

2.5.1.3.1   Counter

The counter can be operated in two modes. TTL level pulses can be counted directly or sinusoidal or other periodic functions can be counted using the signal conditioners on the board.

```
1 REM*********************************************************
3 REM    D/A BOARD TEST
5 REM       BY: GEORGE A. HARTMAN
7 REM            10/16/...
8 REM    PRODUCES ABOUT A 1.2 HZ SINE WAVE OF FULL AMPLITUDE ON THE D/A.
9 REM*********************************************************
10 REM
11 REM    SET 6522 PORTS AS OUTPUTS
12 REM
13 POKE 38914,255:POKE 38915,255
20 REM
21 REM    CLEAR SCREEN
22 REM
23 PRINT"⊃"
25 REM
26 REM    SET UP THE SINE WAVE TABLES TO SEND TO THE D/A.
27 REM    QL% = LOW BYTE OUTPUT  QH% = HIGH BYTE OUTPUT
28 REM    QH% AND QL% ARE INTEGER VARIABLES SO INT(A/256) IS
29 REM    PERFORMED IN LINE 38 AND INT(A-256*H%(I)) IS PERFORMED IN LINE 39
31 REM
33 DIM H%(100),L%(100)
35 FORI=1TO100
37 A=SIN(2*π*I/100)*2047+2048
38 H%(I)=A/256
39 L%(I)=A-256*H%(I)
40 NEXT I
42 REM
43 REM    SEND THE HIGH AND LOW BYTES TO THE D/A
44 REM
45 FORI=1TO100
46 POKE38912,H%(I):POKE38913,L%(I)
49 NEXT I
50 REM
51 REM    LOOP BACK FOR ANOTHER . THE WAVE
52 REM
53 GO TO 45

READY.
```

Figure 3.  D/A Board Test Routine.

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The mode is selected by pole 1 of switch 2. Pressing the rocker away from the C1 label activates the direct TTL mode. Toward C1 activates the periodic function mode.

The counter is a sixteen bit unit and counts down from a preset count. The preset count is set by writing the desired low byte value into register eigh and the desired high byte value to register nine. The coune will dec ement the values in these two registers as one sixteen bit numb r. For exa ple, if we want to keep track of the number of pulses applied t he counte , we would initially load the counter with 65535 and subtract t e subsequen readings from 65535 to produce the pulse count. Counter inputs are shown in Table 6.

2.5.1.3.1.1   TTL Pulse Counting

Zero to five volt pulses with rise times of less than about one microsec can be counted. Divide by ten functions do not operate in this mode. Maximum count rate is approximately 500 Kilohertz.

2.5.1.3.1.2   Periodic Function Counting

Sinusoidal or other periodic functions cannot be counted by the via directly and require conversion to digital pulses first. This is accomplished by adjusting a low pass filter to remove any unwanted high frequency components from the

## TABLE 6

### COUNTER CONNECTIONS AND MODE SWITCH SETTINGS
### FOR COUNTER/DIO BOARD

| COUNTER MODE | CONNECTIONS | SWITCH 2 - POLE 1 SETTING |
| --- | --- | --- |
| TTL Pulse Counting | Input to J2-12 | Away From C1 Label |
| Periodic Waveform Counting | Input to J2-10 | Toward C1 Label |
| Signal Common | J2-11 | |

signal and adjusting the high pass filter to remove the DC component of the signal and any unwanted low frequency components. Once the noise and DC components of the signal have been removed, a threshold adjustment is made so that the counter is insensitive to signals smaller than the threshold. Finally, the conditioned signal is passed through a Schmitt trigger to provide the fast rise time needed by the VIA. The Schmitt trigger also has hysteresis characteristics which eliminate multiple counts at the threshold by requiring the voltage to exceed the threshold by a few tenths of a volt before the device will rearm for the next count. Specifications for the on board signal conditioning are:

● 0.15 to 150 Hz cutoff high pass filter.
● 15 to 1500 Hz cutoff low pass filter.
● Threshold sensitivity adjustment from 10 millivolts to ten volts.

In many cases, it is desirable to count events where the total count may exceed 65535. The counter board can be set to divide the incoming pulses by factors of ten. Divide by functions are activated using poles two through four of switch 2. Pressing the rockers toward the C2, C3, or C4 labels activates one stage of divide by ten. Away from C2, C3, or C4 deactivates the divide by function for the stage. Divide by one hundred and divide by one thousand are obtained by activating multiple divide by ten stages.

Certain registers in the VIA must be initialized in order to use the counter. Table 3 shows the various registers and their uses. The manufacturers data catalog for the

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6522 VIA chip contains additional information on the register functions.
To use the counter, the following steps must be performed:

1. Set register 11 to 32. This initiates the countdown mode of the
   6522 versatile interface adaptor.

2. Set register 2 to zero. This sets the counter port as an input.

3. Set the counter low byte (register 8) to the preset count low byte.

4. Set the counter high byte (register 9) to the present count high
   byte.

5. Apply input signal and read the count from registers 8 and 9.

Figure 4 shows an example using the counter.

### 2.5.1.3.2 Digital Input/Output

In addition to the counter, eight bits
of digital input or output are available. These bits can be individual set
as inputs or outputs in any combination. Each output can drive one standard
TTL load and each input is one standard TTL load. To set a bit as an input,
the corresponding bit in register three must be set to one. For example,
if the lower four bits are to be inputs and the upper four bits are to be
outputs, set register three to 11110000 binary or 128+64+32+16 = 240 decimal.
Sending data to bits set as inputs has no effect on the port. Reading data
from outputs may yield random results. When reading input from the port,
always mask off any bits not of interest using the BASIC or ASSEMBLER "AND"
functions. The digital input and output connections are shown in Table 7.
Figure 5 shows an example using the digital input/output port.

25

```
5 REM*********************************************************
6 REM     COUNTER/TIMER/DIO BOARD TEST
7 REM      BY:  GEORGE A. HARTMAN
8 REM            10/11/83
9 REM*********************************************************
10 REM
11 REM    SET 6522 PORTS AS INPUTS
12 REM
13 POKE 38914,0:POKE 38915,0
16 REM
17 REM    SET 6522 TO COUNT PULSES ON PB-6
18 REM
19 POKE 38923,32
20 REM
21 REM    CLEAR SCREEN AND INITIALIZE COUNTER TO 65535
22 REM
25 PRINT"⊃":POKE 38920,255:POKE 38921,255
26 REM
27 REM    DISPLAY COUNT DOWN FROM 65535
28 REM
30 C=PEEK(38920)+PEEK(38921)*256:PRINT"⊞";C;"⊞    ":GO TO 30

READY.
```

Figure 4.  Counter Test Routine.

# TABLE 7

## DIGITAL INPUT/OUTPUT CONNECTIONS FOR
## THE COUNTER/DIO BOARD

| BIT | CONNECTOR J-2 PIN NUMBER |
|-----|--------------------------|
| 0 | 8 |
| 1 | 7 |
| 2 | 6 |
| 3 | 5 |
| 4 | 4 |
| 5 | 3 |
| 6 | 2 |
| 7 | 1 |
| Common | 11 |

```
5 REM*****************************************************
6 REM        COUNTER/TIMER/DIO BOARD TEST
7 REM        BY  GEORGE A. HARTMAN
8 REM            10/17/83
9 REM*****************************************************
10 REM
11 REM      SET DIO PORT BITS 0-3 AS INPUTS, BITS 4-7 AS OUTPUTS
12 REM      11110000 = 240 DECIMAL
13 REM
14 POKE 38915,240
20 REM
21 REM      CLEAR SCREEN
22 REM
25 PRINT"⊐"
26 REM
27 REM      OSCILLATE OUTPUTS
28 REM
30 POKE38913,240:POKE38913,0
32 REM
34 REM      READ AND DISPLAY INPUTS.
35 REM      AND THE REGISTER CODE TO SELECT THE APPROPRIATE OUTPUT BIT
36 REM
40 I=PEEK(38913)
45 PRINT"∎";(I AND 8)/8;
46 PRINT(I AND 4)/4;
47 PRINT(I AND 2)/2;
48 PRINT I AND 1;
50 GO TO 30

READY.
```

Figure 5.   Digital Input/Output Test Routine.

28

### 2.5.1.3.3  Board Setup

The following steps should be performed to set up a counter/DIO board for use with the system.

1.  Select the board number by turning on the appropriate switch in SW-1 (closed contacts are considered on).

2.  Select type of input using switch SW-2 pole 1.

3.  Connect the signals according to Table 6 for the counter or Table 7 for the digital input/output.

4.  Insert the board either directly into the VIC or into the expansion chassis.

5.  Connect the external power supply to connector J-1.

If periodic function mode is selected for the counter:

6.  Select divide by 1, 10, 100, 1,000 using switch SW-2 poles 2-4. Each pole switched on divides by ten.  If no poles are selected then the unit will divide by one, if one pole is selected, the unit will divide by ten, etc.

7.  Adjust low and high pass filters for desired bandwidth.  The low pass filter is adjusted using resistor R4 and the high pass filter is adjusted using resistor R2.

8.  Adjust the threshold sensitivity using resistor R7.

## 2.5.2   Boards Not Requiring Address Slots

There are currently two boards that do not require address slots:

1.   Strain gage conditioner, and

2.   Current driver.

These boards do not interface with the computer but are signal conditioning boards for general application.  They were developed in order to eliminate the need for separate analog signal conditioners and to expand the capability of the system.

### 2.5.2.1   Strain Gage Conditioner

The strain gage conditioner board is intended to provide excitation and amplification for full strain gage bridges and has the following features:

- Continuously variable gain one to ten thousand.
- Switch selectable filtering.  Cutoff frequencies are determined by user selected capacitors.
- Continuously variable excitation levels 3.5 to 13.5 volts.

Single and double arm bridges can also be connected provided external completion resistors are added.  Input and output connections are labelled on the board.

The following steps should be performed to
calibrate the strain gage conditioner board:

1.  Select the filter cutoff frequency from the following equation:

$$\text{Cutoff Frequency} = \frac{1}{2 * PI * R3 * C}$$

R3 is ten thousand ohms and the filter capacitors should be
selected to give a range of cutoff frequencies suitable to the
application.  Table 8 lists the suggested values and the
corresponding filter characteristic.

2.  Short the amplifier inputs (IN1 and IN2) to common.  Adjust the
amplifier offset trimpot to obtain 0.000 volts at the output
terminal.  Remove the short circuit from the inputs.

3.  Adjust the excitation trimpot to obtain the desired excitation
voltage at the EX+ terminal.  The maximum allowable current drain
in approximately 0.075 amps.

4.  Select the coarse gain from the ten pole gain select switch
according to Table 9.  Select a gain slightly lower than the
expected final gain.  The coarse gain is the sum of the gains from
all closed switches.  The gain trimpot will be used to perform the
final amplifier calibration in Step 6.

5.  Connect the bridge and adjust the bridge balance to obtain zero
volts at the output terminal with the bridge in the null position.

## TABLE 8

### FILTER CAPACITORS AND FILTER CUTOFF FREQUENCIES FOR THE STRAIN GAGE CONDITIONER

| CUTOFF FREQUENCY | CAPACITOR | CAPACITOR VALUE | SWITCH POLE |
|---|---|---|---|
| 1.6 Hertz | C7 | 10.0 uF | 1 |
| 16. Hertz | C6 | 1.0 uF | 2 |
| 160 Hertz | C5 | 0.1 uF | 3 |
| 1600 Hertz | C4 | 0.01 uf | 4 |
| Wideband | -- | ------- | All Open |

# TABLE 9

## COARSE GAIN SWITCH VALUES FOR THE STRAIN GAGE
## CONDITIONER BOARD

| SWITCH POLE | GAIN |
|:-----------:|:----:|
| None | 1 |
| 1 | 2 |
| 2 | 4 |
| 3 | 8 |
| 4 | 16 |
| 5 | 32 |
| 6 | 64 |
| 7 | 128 |
| 8 | 256 |
| 9 | 256 |
| 10 | 512 |

6. Apply full scale to the bridge and adjust the gain trimpot to obtain full scale output from the bridge conditioner board. Full scale output should not exceed 12 volts. The gain trimpot has a range of approximately one to ten times the coarse gain from the gain switch.

7. Repeat Steps 5 and 6 until no further adjustments are necessary.

### 2.5.2.2   Current Driver

The current driver board provides an interface between the D/A card and controllers or other devices requiring more than two milliamps of current to function properly. Typical laboratory controllers require zero to twelve, four to twenty, or zero to ten milliamps input current.

The following steps should be performed to interface the current driver board to external devices. The input and output terminals are labelled on the board.

1. Select the current limiting resistor from the following equation:

Current Limiting Resistor = 250 - Load Resistance

2. Install the current limiting resistor as R1.

3. Connect the inputs and outputs as labelled on the board. Note that the high output is tied directly to the five volt supply. Use care not to short this lead to common.

4. Short the board inputs and adjust the offset resistor to obtain the desired minimum output current.

5. Apply five volts to the input and adjust the gain resistor to obtain the maximum desired output current (< .075 amps).

6. Repeat Steps 4 and 5 until no further adjustments are necessary.

# SECTION 3

## APPLICATIONS

The system described in Section 2 has been applied to two laboratory control problems:

- Schenck resonant fatigue testing machine control, and
- Automated furnace control.

The electropneumatic shaker application is still in the development stage and will not be described in further detail here.

The Schenck controller was the original application, however, the furnace controller will be discussed first since it is the simpler of the two.

### 3.1   AUTOMATED FURNACE CONTROLLER

One of the problems associated with long term heat treating of materials or curing procedures is that constant operator supervision is necessary if complicated temperature profiles are required.  The VIC-20 system provides a means to preprogram the required profile and allow the computer to control the heat treating operation.  Figure 6 shows the software that is currently being used to control a heat treating furnace in the MLLN laboratory.

```
100 REM******************************************************************
101 REM          FURNACE CONTROL PROGRAM
102 REM     GEORGE A. HARTMAN     7/23/1983
103 REM     USES A VIC-20 D/A BOARD SET AS BOARD #1 WITH 0-5 VOLT OUTPUT
105 REM******************************************************************
106 REM
110 PRINT"⬛     FURNACE CONTROL          PROGRAM"
134 REM
135 REM     SET D/A PORTS AS OUTPUTS
136 REM
140 POKE38914,255:POKE38915,255
141 REM
142 REM     SET OUTPUT TO ZERO
143 REM
145 POKE38912,255:POKE38913,255
146 REM
147 REM     DIMENSION FOR 50 BLOCKS MAX
148 REM
150 DIM S(50),T(50)
200 REM**********************************
201 REM    GET BLOCK DATA
202 REM**********************************
206 REM
207 REM     PRINT HEADER
208 REM
210 GOSUB3005
212 REM
213 REM     INITIALIZE THE ZERO BLOCK AND SET UP N FOR TOTAL BLOCKS
214 REM
218 PRINT" 0        75        0"
219 N=0
220 S(0)=75
```

Figure 6.  Furnace Control Program.

```
221 T(0)=0
222 DAYS=0
224 REM
225 REM    CHANNEL 1 IS THE KEYBOARD.  USING GET# DOESN'T PRINT THE ?
226 REM
228 OPEN1,0
230 REM
231 REM    TAKE BLOCK DATA UNTIL THE OPERATOR ENTERS AN R
232 REM
233 INPUT#1,A$
234 IFA$="R"THEN260
235 GOSUB1010
237 PRINT
238 GO TO 233
255 REM
256 REM    PRINT SCREEN TITLES
257 REM
260 GOSUB2005
270 REM
271 REM    INITIALIZE BLOCK NUMBER AND TIME FUNCTION
272 REM
280 I=0
285 TI$="000000"
290 TZ=TI
300 REM*****************************
301 REM   MAIN LOOP GENERATES OUTPUT SIGNAL
302 REM*****************************
305 I=I+1
306 REM
307 REM    SET START TIME FOR THIS BLOCK
308 REM
```

**Figure 6 (Continued).  Furnace Control Program.**

```
309 T0=TZ
310 REM     CHECK FOR LAST BLOCK
311 REM
312 REM
313 IFI>NTHEN510
314 REM     CALCULATE RATE OF TEMPERATURE CHANGE AND PRINT IT
315 REM
316 REM
319 RATE=(S(I)-S(I-1))/T(I)
320 GOSUB 5000
339 REM
340 REM     C=D/A UNITS PER DEGREE FAHRENHEIT
345 REM     ERR=BARBER-COLEMAN CONTROLLER ERROR IN DEGREES F
350 REM     D=OFFSET FOR 1 VOLT.  RANGE OF CONTROLLER IS 1 TO 5 VOLTS
352 REM
355 C=4096/2500
360 ERR=0
365 D=500
400 REM**********************************
401 REM     CALCULATE OUTPUT (LINEAR INTERPOLATION BETWEEN SETPOINTS)
402 REM**********************************
409 REM
410 REM     OUT=SETPOINT IN DEGREES FAHRENHEIT
411 REM     OH%=HIGH BYTE OUTPUT
412 REM     OL%=LOW BYTE OUTPUT
413 REM
420 TX=TI
421 REM
422 REM     CHECK FOR NEW DAY
423 REM
425 IFTZ-DAYS>TXTHENDAYS=DAYS+86400*60
426 TZ=TX+DAYS
```

Figure 6 (Continued).  Furnace Control Program.

39

```
427 OUT=S(I-1)+RATE*(TZ-T0)/60+D+ERR
428 OH%=C*OUT/256
430 OL%=C*OUT-256*OH%
431 REM
432 REM      SEND OUTPUT TO D/A
433 REM
434 POKE38912,255-OH%
435 POKE38913,255-OL%
436 REM
437 REM      PRINT CURRENT TIME
438 REM
439 H$=STR$(INT(TZ/3600/60)):IFVAL(H$)>9THENH$=RIGHT$(H$,2)
440 M$=MID$(TI$,3,2):S$=RIGHT$(TI$,2)
441 PRINT"000000";H$;":";M$;":";S$;TAB(12);
442 REM
443 REM      PRINT CURRENT SETPOINT IN OPERATOR UNITS
444 REM
445 PRINTINT(OUT-D-ERR);"0    "
446 REM
447 REM      PRINT TIME LEFT IN THIS BLOCK
448 REM
450 PRINT"00000000000000000000";INT((T(I)*60-TZ+T0)/360)/10+.1);"0    "
451 REM
452 REM      IF THIS BLOCK IS OVER THEN GET THE NEXT ONE
453 REM
455 IF(TZ-T0)>T(I)*60THEN305
459 REM
460 REM      IF MENU IS REQUESTED THEN PRINT IT
461 REM
465 GETA$
467 IFA$=CHR$(133)THENGOSUB4007
470 GOTO420
500 REM**********************
501 REM      STOP PROGRAM
```

Figure 6 (Continued). Furnace Control Program.

40

```
502 REM***********************
504 REM
505 REM    SHUT OFF D/A
506 REM
510 POKE38912,255:POKE38913,255
515 PRINT"PROGRAM ENDED"
520 END
1000 REM***********************
1001 REM    STRIP OFF BLOCK NUMBER, SETPOINT, AND TIME FROM STRING
1002 REM***********************
1010 I=VAL(MID$(A$,1,2))
1012 REM
1013 REM    KEEP TRACK OF BIGGEST BLOCK NUMBER
1014 REM
1015 IFI>NTHENN=I
1020 S(I)=VAL(MID$(A$,3,10))
1030 T(I)=VAL(MID$(A$,13,10))*60
1040 RETURN
2000 REM***********************
2001 REM    PRINT HEADER
2002 REM***********************
2005 PRINT"ELAPSED    SETPOINT    TIME    DEGREES    HH:MM:SS    FAHRENHEIT"
2010 PRINT"********    **********"
2020 PRINT"BLOCK    RATE    NO.    DEG/MIN    *****    *********"
2030 PRINT"TIME LEFT    THIS BLOCK    (MINUTES
)"
2040 PRINT"**********"
2045 PRINT"PRESS F1 FOR PROFILE";
2050 RETURN
3000 REM***********************
3001 REM    PRINT DATA INPUT HEADER
3002 REM***********************
```

Figure 6 (Continued). Furnace Control Program.

```
3005 PRINT"ENTER SET POINTS AND    THE TIME TO COMPLETE  THE TRANSITION"
3010 PRINT"(ENTER R TO RESUME      PROGRAM)"
3020 PRINT"NO SETPOINT    TIME        DEGREES F   MINUTES ** ********** ********"
3030 RETURN
4000 REM*************************
4001 REM   REVIEW PROFILE
4002 REM*************************
4004 REM
4005 REM    CLEAR SCREEN
4006 REM
4007 PRINT"J"
4008 REM
4009 REM    PRINT HEADER AND BLOCK DATA
4010 REM
4011 GOSUB3020
4012 FORK=1TON
4014 PRINTK;TAB(5);S(K);TAB(15);T(K)/60
4020 NEXT
4025 REM
4026 REM    TIMING LOOP
4027 REM
4030 FORJ=1TO10000:NEXT
4035 REM
4036 REM    GO BACK TO NORMAL EXECUTION
4037 REM
4040 GOSUB2005
4045 GOSUB 5000
4050 RETURN
5000 PRINT"                        ";I,INT(RATE*600)/10;"   "
5010 RETURN

READY.
```

Figure 6 (Concluded).  Furnace Control Program.

42

The software is designed to allow up to fifty setpoint changes within a single profile. The D/A output is fed into a Barber-Coleman 520 series controller with external one to five volt linear input. The program as listed requires too much memory to run without a memory expansion cartridge. A running version for the VIC-20 with no memory expansion is generated by removing the remark statements.

The program prompts the operator for the block number, the time for the block, and temperature at the end of the block. The operator may change parameters for any block at any time during the data entry segment of the program. The profile may be reviewed at any time during the heat treatment by pressing the user defined key F1.

A planned improvement in the system will be to install an A/D board to read the actual temperature and include a closed loop control section similar to the one in the Schenck controller described in the next section. This would eliminate the need for the Barber-Coleman controller and digital pyrometer display that are now required.

3.2   SCHENCK RESONANT FATIGUE TEST MACHINE CONTROLLER

The original application of the VIC system was to control four of the Schenck fatigue machines in the MLLN laboratory. The machine controls were not operating and refit was estimated to cost ten thousand dollars each.

The VIC controls have been installed on two of the four machines. The remaining two will be converted if demand for their use increases.

### 3.2.1   Schenck Characteristics

The Schenck testing machines are based on the resonance principle. The machine base acts as a large reaction mass to which one end of the specimen is attached. The other end of the specimen is attached to one end of a spring. The other end of the spring is attached to a mass mounted eccentrically on a shaft. The shaft is rotated by an electric motor which sets up a vibration of the spring. The speed of the motor controls the frequency of vibration and the spring stiffness and eccentric mass are designed to have a natural frequency of about 50 Hz. As the motor speed approaches the natural frequency, the magnitude of the load transmitted through the specimen to the frame of the machine increases in a highly nonlinear fashion. This means that a small change in the motor speed yields a large change in the specimen load.

### 3.2.2   VIC Controller

The VIC A/D is interfaced to the Schenck via a strain gage conditioner board which provides an output signal proportional to the specimen load. The D/A board drives the motor through a commercial DC motor controller. The cycle count is obtained by driving the counter board with the sinusoidal load waveform.

The software used to control the Schenck is shown in Figure 7. The program as listed is too large to run without a memory expansion card for the unexpanded VIC-20. A version which will run without memory expansion can be generated by removing the remark lines from the program.

The routine requires that the A/D board be set as board one, the D/A board be set as board two, and the counter board be set as board three. As with the furnace controller program, the Schenck program prompts the operator for all required input data.

Much of the program is formatting which makes the operator interface easier. Although this is not necessary, it makes it possible for inexperienced operators to use the controller without having to decipher unclear controls.

The routine at line 600 sets up the machine language subroutine which reads the A/D 2550 times and calculates the maximum and minimum load in about .2 seconds. The subroutine was written in ASSEMBLY language and is shown in Figure 8. The ASSEMBLY language program was converted to a series of decimal numbers which are contained in the data statements in lines 640-690. In the way the BASIC program is self-contained and the operator simply loads the routine from tape or disk and when it is run, it sets up the machine language routine by itself. Line 610 changes the top of memory so that the BASIC interpreter will not destroy the machine code.

```
1 REM**********************************************************
2 REM  SCHENCK CONTROL PROGRAM  BY: GEORGE A. HARTMAN  10/12/83
3 REM  BOARDS:    A/D ... #1    D/A ... #2    COUNTER/TIMER/DIO ... #3
4 REM**********************************************************
5 REM
6 REM    SET UP MACHINE LANGUAGE ROUTINE.
7 REM
8 GOSUB610
9 REM
10 REM    SET A/D PORTS AS INPUTS AND D/A PORTS AS OUTPUTS AND TURN D/A OFF
11 REM
12 POKE38914,0:POKE38915,0
13 POKE38930,255:POKE38931,255
14 POKE38928,255:POKE38929,255
15 REM
16 REM    GET SYSTEM OF UNITS
17 REM
18 GOSUB 406
19 REM
20 REM
21 REM    P3=FULL SCALE A/D (POUNDS)
22 REM    P4=COMAND AMPLITUDE (POUNDS)
23 REM    P5=COMAND AMPLITUDE (A/D UNITS)
24 REM    P6=POUNDS/A/D UNIT
25 REM
26 P3=4000
27 REM    GET DESIRED LOAD
28 REM
29 GOSUB 505
30 P4=P2-P1
32 P6=P3/2048
34 P5=INT(P4/P6)
```

Figure 7a.  Schenck Control Program.

46

```
35 REM
36 REM   SET MEAN LOAD
37 REM
38 GOSUB310
39 REM
40 REM   GET MAXIMUM CYCLES TO RUN
41 REM
42 GOSUB705
43 REM
44 REM   START TEST
45 REM
46 PRINT"]PUSH RESET SWITCH TO  START AND RELEASE IT. PRESS RETURN TO START TEST
"
47 INPUTA$
48 REM
49 REM   PRINT SCREEN LABELS SO WE DON'T HAVE TO DO IT IN THE CONTROL LOOP
50 REM
52 PRINT"]";TAB(8);B$;" MAX"
54 PRINT:PRINTTAB(8);B$;" MIN"
60 PRINT:PRINTTAB(11);"CYCLES"
65 PRINT:PRINTTAB(11);"OUTPUT %"
70 PRINT"⬛⬛⬛⬛⬛⬛PRESS F1 TO STOP TEST"
100 REM*******************************
101 REM  MAIN CONTROL LOOP
102 REM*******************************
103 REM  Z=INTEGRAND
104 REM  G=GAIN
105 REM  R=RESET VALUE
106 REM
107 Z=2400:G=.015:R=2.6/SQR(P4)
108 REM
109 REM  Y=ERROR
```

Figure 7a (Continued).  Schenck Control Program.

47

```
110 REM    01,02=D/A OUTPUT BYTES
111 REM    SYS7536 CALLS A/D  SUBROUTINE
112 REM    ON RETURN TO BASIC MAX IS STORED AT 7678,7679 MIN AT 7676,7677
122 REM    AVERAGE 5 READINGS
123 REM
125 H=0:L=0
126 FORK=1TO5
127 SYS7536
130 H=H+PEEK(7679)*256+PEEK(7678)
132 L=L+PEEK(7677)*256+PEEK(7676)
133 NEXT
135 H=H/5
136 L=L/5
138 V=P5-H+L
140 Z=Y*R+Z
150 O=Y*G+Z
156 IFO>4095THENO=4095
158 IFO<0THENO=0
160 REM
161 REM COUNTER IS COUNTING DOWN FROM 65535  SO COUNT=65535-READING
163 REM
164 C=65535-PEEK(38953)*256-PEEK(38952)
165 REM    CHECK ERROR AT 2000 CYCLES AND CHECK IF MAXIMUM COUNT IS EXCEEDED
166 REM
167 REM
168 IFC<2THEN170
169 IFY>100THEN205
170 IFC>=TC/1000THEN205
171 REM
172 REM    CALCULATE OUTPUT AND SEND TO D/A
173 REM
175 O1=INT(O/256)
```

Figure 7a (Continued).   Schenck Control Program.

48

```
176 O2=INT(O-256*O1)
177 POKE38928,15-01
178 POKE38929,255-02
180 REM
181 REM    CHECK IF THE OPERATOR WANTS TO STOP THE TEST
183 REM
184 GETA$
186 IFA$=CHR$(133)THEN205
187 REM
188 REM    PRINT CURRENT STATUS
189 REM
190 PRINT"█";INT(B*(H-2047)*P6/10)*10;"█ "
192 PRINT:PRINTINT(B*(L-2047)*P6/10)*10;"█ "
193 PRINT:PRINTC*1000
194 PRINT:PRINTINT(O/4095*10000)/100;"█ "
199 GOTO125
200 REM************************
201 REM    PROGRAM END
202 REM************************
203 REM    SHUT OFF D/A
204 REM
205 POKE38928,255:POKE38929,255
207 REM
208 REM    PRINT FINAL CYCLE COUNT
209 REM
210 PRINT"CYCLE COUNT= ";C*1000
211 REM
212 REM    PROMPT OPERATOR FOR RESTART
213 REM
215 PRINT"CHECK FOR BROKEN    SAMPLE"
216 PRINT"DO YOU WANT TO RESTART(Y/N)"
218 INPUTA$
```

Figure 7a (Continued).  Schenck Control Program.

49

```
219 IFA$="Y"THEN18
220 REM
222 REM    PROMPT OPERATOR TO SHUT OFF MACHINE
224 REM
230 PRINT"SET RESET SWITCH TO   OFF THEN PRESS RETURN"
235 INPUTA$
240 REM
242 REM    DISPLAY END MESSAGE AND STOP PROGRAM
244 REM
250 PRINT".............PROGRAM ENDED..........."
255 END
300 REM*********************
301 REM   MANUAL ADJUST MEAN LOAD AND DISPLAY MEAN LOAD
302 REM*********************
303 REM
304 REM    DISPLAY INSTRUCTIONS
305 REM
310 PRINT"ADJUST BALANCE WITH NOSAMPLE.   INSTALL        SPECIMEN AND ADJUST  MEA
N LOAD."
315 PRINT:PRINT"SET PRELOAD SWITCH TO OFF AND PRESS F3 WHEN DONE"
317 REM
318 REM    DISPLAY DESIRED MEAN LOAD CALCULATED FROM MAX AND MIN INPUTS
319 REM
320 PRINT:PRINT:PRINTINT((P1+P4/2)*B+.5);TAB(7);B$;" DESIRED"
322 REM
323 REM    DISPLAY TITLE SO WE DON'T HAVE TO DO IT IN THE LOOP
324 REM
330 PRINT:PRINTTAB(7);B$;" ACTUAL"
335 REM
336 REM    AVERAGE 10 READINGS AND FIX RESOLUTION TO 10 POUNDS
337 REM
340 H=0
```

Figure 7a (Continued).  Schenck Control Program.

50

```
342 FORK=1TO10
343 REM
344 REM    TRIGGER A/D
345 REM
346 POKE38912,0
347 REM
348 REM    GET ANSWER FROM A/D, CALCULATE LOAD, AND SUM UP RESULTS
349 REM
350 H=H+F6*B*(-2047+(255-PEEK(38912))*256+255-PEEK(38913))
355 NEXTK
356 REM
357 REM    RECOVER AVERAGE
358 REM
359 H=INT(H/100)*10
360 REM
361 REM    PRINT RESULT
362 REM
363 PRINT"]";H;"█ "
364 REM
365 REM    CHECK IF OPERATOR HAS PRESSED F3 KEY
366 REM
370 GETA$
373 IFA$=CHR$(134)THENRETURN
375 REM
376 REM    GO BACK FOR ANOTHER READING
377 REM
380 GOTO340
400 REM****************************
402 REM    GET SYSTEM OF UNITS
404 REM****************************
406 PRINT"]ARE YOU USING:":PRINT"            POUNDS (P)":PRINT"            NEWTONS (N)":
408 INPUT B$
410 IFB$="P"THENB=1:B$="POUNDS":RETURN
420 B=4.448:B$="NEWTONS"
430 RETURN
500 REM*****************************
501 REM    GET MAX AND MIN LOAD FROM OPERATOR
```

Figure 7a (Continued).  Schenck Control Program.

51

```
502 REM*****************************
505 PRINT"ENTER MAXIMUM LOAD FORTHIS TEST IN ";B$
507 INPUTP2
508 P2=P2/B
510 REM
511 REM    CHECK IF LARGER THAN MACHINE CAPACITY
512 REM
515 IFABS(P2)>P3THENPRINT"OUT OF RANGE - TRY   AGAIN":GOTO505
520 PRINT"ENTER MINIMUM LOAD FORTHIS TEST IN ";B$
522 INPUTP1:P1=P1/B
524 P1=P1/B
525 REM
526 REM    CHECK IF:
527 REM       PAST MACHINE CAPACITY
528 REM       LOAD RANGE PAST MACHINE CAPACITY
529 REM       LOAD RANGE TOO SMALL FOR MACHINE TO CONTROL
530 REM       MEAN LOAD PAST MACHINE CAPACITY
531 REM
535 IFP1<-P3ORP1>P2ORP2-P1>P3ORR2-P1<4000R(P2+P1)/2>P3/2THENPRINT"OUT OF RANGE":
GOTO520
540 RETURN
600 REM*****************************
601 REM    SET MACHINE CODE BY POKING IN DECIMAL EQUIVALENTS OF ASSEMBLY CODE
602 REM*****************************
604 REM
606 REM    SET BASIC TOP OF MEMORY BELOW MACHINE CODE AREA
608 REM
610 POKE51,111:POKE52,29:POKE55,111:POKE56,29
620 REM
622 REM    READ MACHINE CODE FROM DATA STATEMENTS AND POKE INTO MEMORY
624 REM
630 FORI=7536TO7664
```

Figure 7a (Continued).  Schenck Control Program.

52

```
632 READC
634 POKEI,C
636 NEXT
640 DATA141,0,152,169,10,141,249,29,169,255,141,252,29,141,253,29,169,0,141,254,
29,141
650 DATA255,29,162,255,173,1,152,73,255,141,250,29,173,0,152,73,255,141,251,29,1
41,0,152
660 DATA205,255,29,240,14,144,26,141,255,29,173,250,29,141,254,29,76,190,29,173,
250,29
670 DATA205,254,29,144,6,173,251,29,76,164,29,173,251,29,205,253,29,240,14,176,2
6,141
680 DATA253,29,173,250,29,141,252,29,76,226,29,173,250,29,205,252,29,176,6,173,2
51,29,76
690 DATA200,29,202,240,3,76,138,29,206,249,29,240,3,76,136,29,96
699 RETURN
700 REM*****************************
701 REM   GET MAXIMUM NUMBER OF CYCLES TO RUN AND SET UP COUNTER
702 REM*****************************
705 PRINT"ENTER CYCLES TO RUN (30 MILLION MAX)":INPUTTC
709 REM
710 REM   SET COUNTER PORT AS INPUT AND SET COUNTER MODE REGISTER TO 32
711 REM
720 POKE38946,0
721 POKE38955,32
722 REM
723 REM   SET INITIAL COUNT TO 65535
724 REM
725 POKE38952,255:POKE38953,255
730 RETURN

READY.
```

Figure 7a (Concluded).   Schenck Control Program.

53

```
A,A1 ............ D/A ENABLE ADDRESSES (DATA DIRECTION REGISTERS
                  FOR PORTS A AND B ON VIA #3)
A2,A3 .......... A/D ENABLE ADDRESSES (DATA DIRECTION REGISTERS
                  FOR PORTS A AND B ON VIA #4)
A$ ............. CHARACTER VARIABLE FOR KEYBOARD RESPONSES
A% ............. (NUMBER OF CYCLES TO RUN) / 1000
B .............. UNITS CONVERSION FACTOR (1 FOR POUNDS OR
                  4.448 FOR NEWTONS)
B$ ............. UNITS STRING ('POUND' OR 'NEWTONS')
B% ............. DUMMY VARIABLE
C$ ............. CARRIAGE RETURN VARIABLE
C% ............. (CYCLES RUN) / 1000
H .............. MAXIMUM LOAD FROM MACHINE LANGUAGE ROUTINE
I .............. LOOP INDEX
K .............. LOOP INDEX
L .............. MINIMUM LOAD FROM MACHINE LANGUAGE ROUTINE
O .............. CALCULATED D/A OUTPUT VALUE
O1 ............. D/A OUTPUT HIGH BYTE
O2 ............. D/A OUTPUT LOW BYTE
P1 ............. COMMANDED MINIMUM LOAD (POUNDS)
P2 ............. COMMANDED MAXIMUM LOAD (POUNDS)
P3 ............. FULL SCALE (POUNDS)
P4 ............. COMMANDED AMPLITUDE (POUNDS)
P5 ............. COMMANDED AMPLITUDE (A/D UNITS)
P6 ............. POUNDS PER LEAST SIGNIFICANT BIT
R .............. CONTROL LOOP RESET VALUE FOR INTEGRATION
Y .............. CONTROL LOOP ERROR VALUE
Z .............. CONTROL LOOP INTEGRATED ERROR
```

Figure 7b.  Variable Definitions for the Schenck Control Application.

| MEMORY | OP CODE | DATA | REMARKS |
|--------|---------|------|---------|
| ****** | ****** | **** | *************************** |
| 1D70 | STA | $9800 | TRIGGER A/D |
| 1D73 | LDA | #$0A | COUNT DOWN |
| 1D75 | STA | $1DF9 | FROM 10 TO 0 |
| 1D78 | LDA | #$FF | |
| 1D7A | STA | $1DFC | INITIALIZE MINIMUM |
| 1D7D | STA | $1DFD | |
| 1D80 | LDA | #$00 | |
| 1D82 | STA | $1DFE | INITIALIZE MAXIMUM |
| 1D85 | STA | $1DFF | |
| 1D88 | LDX | #$FF | COUNT DOWN FROM 255 |
| 1D8A | LDA | $9801 | GET LOW BYTE, COMPLEMENT |
| 1D8D | EOR | #$FF | IT AND STORE IT |
| 1D8F | STA | $1DFA | |
| 1D92 | LDA | $9800 | GET HIGH BYTE, |
| 1D95 | EOR | #$FF | COMPLEMENT AND STORE IT |
| 1D97 | STA | $1DFB | |
| 1D9A | STA | $9800 | RETRIGGER A/D |

Figure 8.  Machine Language Program Listing for the Schenck Control Application.

55

```
**********************    CHECK MAXIMUM ROUTINE    **********************

                    1D9D    CMP    $1DFF    COMPARE WITH OLD HIGH
                    1DA0    BEQ    $1DB0    BYTE, BRANCH IF EQUAL
                    1DA2    BCC    $1DBE    BRANCH IF LESS

                    1DA4    STA    $1DFF    STORE MAXIMUM AND JUMP
                    1DA7    LDA    $1DFA    TO MINIMUM ROUTINE
                    1DAA    STA    $1DFE
                    1DAD    JMP    $1DBE

                    1DB0    LDA    $1DFA    GET LOW BYTE, COMPARE
                    1DB3    CMP    $1DFE    WITH OLD
                    1DB6    BCC    $1DBE    BRANCH IF LESS

                    1DB8    LDA    $1DFB    GET HIGH BYTE AND JUMP
                    1DBB    JMP    $1DA4    TO STORE MAX ROUTINE


**********************    CHECK MINIMUM ROUTINE    **********************

                    1DBE    LDA    $1DFB    GET HIGH BYTE
                    1DC1    CMP    $1DFD    COMPARE WITH OLD VALUE
                    1DC4    BEQ    $1DD4    BRANCH IF EQUAL
                    1DC6    BCS    $1DE2    BRANCH IF GREATER THAN

                    1DC8    STA    $1DFD    STORE MINIMUM AND JUMP
                    1DCB    LDA    $1DFA    TO COUNTER ROUTINE
                    1DCE    STA    $1DFC
                    1DD1    JMP    $1DE2

                    1DD4    LDA    $1DFA    GET LOW BYTE
                    1DD7    CMP    $1DFC    COMPARE WITH OLD VALUE
                    1DDA    BCS    $1DE2    BRANCH IF GREATER THAN

                    1DDC    LDA    $1DFB    GET HIGH BYTE AND JUMP
                    1DDF    JMP    $1DC8    TO STORE MINIMUM ROUTINE
```

Figure 8 (Continued). Machine Language Program Listing for the Schenck Control Application.

```
**************        COUNTER ROUTINE        ****************

                                            ARE WE DONE WITH THIS
1DE2                    DEX                  SET OF 255 SAMPLES ?
1DE3                    BEQ      $1DE8
1DE5                    JMP      $1D8A

1DE8                    DEC      $1DF9       ARE WE DONE WITH ALL 10
1DEB                    BEQ      $1DF0       SETS OF 255 SAMPLES ?
1DED                    JMP      $1D88

1DF0                    RTS                  RETURN TO BASIC

                                            MAX IS STORED AT
                                            HIGH BYTE ......  $1DFF
                                            LOW BYTE  ......  $1DFE

                                            MIN IS AT
                                            HIGH BYTE ......  $1DFD
                                            LOW BYTE  ......  $1DFC
```

Figure 8 (Concluded).  Machine Language Program Listing for the Schenck Control Application.

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The main closed loop control routine starts at line 125.
Note that in line 107, the reset (integral) term "R" for the loop is a
function of the load amplitude and is not a constant. This was necessary
because of the exponential nature of the load - motor speed relationship.

The error trap in line 169 is not executed unless the cycle
count is greater than 2000. This gives the motor time to come up to speed
without being shut down due to too large an error signal "Y".

The control loop is executed about five times per second.
This is fast enough to control the motor speed and the specimen load on the
Schenck machine but may be too slow for other applications. Control loop
execution time can be reduced to less than a millisecond by eliminating all
basic commands and reprogramming the loop calculations in machine code.

# SECTION 4

## SUMMARY

The VIC system described is an inexpensive and versatile data acquisition and real time control system that is applicable to a range of laboratory problems. The system has been successfully applied to two control problems and additional applications have been identified.

The unit is a modular design which allows it to be reconfigured easily as new applications are identified. The use of the VIC-20 provides the capability to easily program clear displays and input formats which reduce opeartor errors and the time to learn the system for a given application.

# APPENDIX A

## PARTS LISTS FOR THE INTERFACE BOARDS

# PARTS LIST FOR EXPANSION CHASSIS

| ITEM | QTY. | DESCRIPTION | MANUFACTURER | MANUFACTURER'S PART NUMBER |
|------|------|-------------|--------------|----------------------------|
| J1-J8 | 8 | 44 Pin Card Edge Connectors | TRW Cinch | 44B-10M-1 |

PARTS LIST FOR A/D BOARD

| ITEM | QTY. | DESCRIPTION | MANUFACTURER | MANUFACTURER'S PART NUMBER |
|---|---|---|---|---|
| IC-1 | 1 | 1 of 8 Decoder | Signetics | 74LS138 |
| IC-2 | 1 | Versatile Interface Adaptor | Synertech | SY6522 |
| IC-3 | 1 | Quad Nor Gate | Motorola | MC14001B |
| IC-4 | 1 | 12 Bit 25 uSec A/D Converter | Analog Devices | AD ADC80-12 |
| C1-C3,C5 | 3 | .1 uF 35 V Nonpolarized Cap. | Centralab | CY20C104M |
| C4,C6 | 2 | 1 uF 35 V Nonpolarized Cap. | Centralab | CY30C105M |
| R1 | 1 | 1.8 Meg 1/4 Watt Resistor | Corning | RLR07C1804GR |
| R2,R4 | 2 | 10 K Trimpots | Bourns | 3009P-1-103 |
| R3 | 1 | 10 Meg 1/4 Watt Resistor | Corning | RLR07C1005GR |
| S1,S3 | 2 | IC Socket 14 Pin Dip | Cambion | 703-3777-01-04-1 |
| S2 | 1 | IC Socket 40 Pin .1" x .6" | Cambion | 703-3766-01-04-1 |
| S4 | 1 | IC Socket 32 Pin .1" x .9" | Aires | 32-9513-10 |
| SW-1 | 1 | 8 Pole SPST Dip Switch | Grayhill | 76MSB08 |
| J1 | 1 | PC Mount Jack | T&B Ansley | 609-1002M |
| J2 | 1 | Terminal Strip | Buchannan | SSB4S4S11 |
| P2 | 1 | Pin Strip | Electrovert | 8140 Series |

PARTS LIST FOR D/A BOARD

| ITEM | QTY. | DESCRIPTION | MANUFACTURER | MANUFACTURER'S PART NUMBER |
|------|------|-------------|--------------|---------------------------|
| IC-1 | 1 | 1 of 8 Decoder | Signetics | 74LS138. |
| IC-2 | 1 | Versatile Interface Adaptor | Synertech | SY6522 |
| IC-3 | 1 | 12 Bit D/A Converter | National | DAC1280ACD |
| C1-C4 | 4 | .1 uF 35 V Nonpolarized Cap. | Centralab | CY20C104M |
| S1 | 1 | IC Socket 14 Pin Dip | Cambion | 703-3777-01-04-1 |
| S2 | 1 | IC Socket 40 Pin .1" x .6" | Cambion | 703-3766-01-04-1 |
| S3 | 1 | IC Socket 24 Pin .1" x .6" | Cambion | 703-3790-01-04-1 |
| S4 | 1 | IC Socket 16 Pin Dip | Cambion | 703-3778-01-04-1 |
| SW-1 | 1 | 8 Pole SPST Dip Switch | Grayhill | 76MSB08 |
| J1 | 1 | PC Mount Jack | T&B Ansley | 609-1002M |
| J2 | 1 | Terminal Strip | Buchannan | SSB4S4S11 |
| P2 | 1 | Pin Strip | Electrovert | 8140 Series |

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PARTS LIST FOR COUNTER AND DIGITAL INPUT/OUTPUT BOARD

| ITEM | QTY. | DESCRIPTION | MANUFACTURER | MANUFACTURER'S PART NUMBER |
|---|---|---|---|---|
| IC-1 | 1 | 1 of 8 Decoder | Signetics | 74LS138 |
| IC-2 | 1 | Versatile Interface Adaptor | Synertech | SY6522 |
| IC-3-5 | 3 | Decade Counter | National | CD4017B |
| IC-6 | 1 | Quad Schmitt Trigger | National | CD4093B |
| IC-7 | 1 | Quad OP Amp | Texas Instr. | TL084 |
| C1-C3 | 3 | .1 uF 35 V Nonpolarized Cap. | Centralab | CY20C104M |
| C4 | 1 | 1 uF 35 V Nonpolarized Cap. | Centralab | CY30C105M |
| R1 | 1 | 2.2 K 1/4 Watt Resistor | Corning | RLR07C2201GR |
| R2 | 1 | 1 Meg Trimpot | Bourns | 3009P-1-105 |
| R3,R5,R6 | 3 | 1 K 1/4 Watt Resistor | Corning | RLR07C1001GR |
| R4,R7 | 2 | 100 K Trimpot | Bourns | 3009P-1-104 |
| D1 | 1 | 5.1 Volt Zener Diode | Motorola | IN751 |
| S1,S6,S7 | 3 | IC Socket 14 Pin Dip | Cambion | 703-3777-01-04-1 |
| S2 | 1 | IC Socket 40 Pin .1" x .6" | Cambion | 703-3766-01-04-1 |
| S3,S4,S5 | 3 | IC Socket 16 Pin Dip | Cambion | 703-3778-01-01-1 |
| SW-1 | 1 | 8 Pole SPST Dip Switch | Grayhill | 76MSB08 |
| SW-2 | 1 | 4PDT Dip Switch | Grayhill | 76SC04 |
| J1 | 1 | PC Mount Jack | T&B Ansley | 609-1002M |
| J2 | 1 | Terminal Strip | Buchannan | SSB4S12S11 |

PARTS LIST FOR STRAIN GAGE CONDITIONER BOARD

| ITEM | QTY. | DESCRIPTION | MANUFACTURER | MANUFACTURER'S PART NUMBER |
|------|------|-------------|--------------|----------------------------|
| R1 | 1 | 10K Ohm Metal Film Resistor | Corning | RLR07C1002GR |
| R2 | 1 | 100K Ohm Metal Film Resistor | Corning | RLR07C1003GR |
| R3 | 1 | 10K Ohm Metal Film Resistor | Corning | RLR07C1002GR |
| R4 | 1 | 10K Ohm Metal Film Resistor | Corning | RLR07C1002GR |
| R5 | 1 | 10K Ohm Metal Film Resistor | Corning | RLR07C1002GR |
| R6 | 1 | 5 Ohm 1 Watt Carbon Resistor | Allen Bradley | GB56G5 |
| R7 | 1 | 10K Ohm Metal Film Resistor | Corning | RLR07C1002GR |
| Balance | 1 | 10K Ohm 15 Turn Trim Resistor | Bourns | 3009P-1-103 |
| Excit. | 1 | 50K Ohm 15 Turn Trim Resistor | Bourns | 3009P-1-503 |
| Gain | 1 | 100K Ohm 15 Turn Trim Resistor | Bourns | 3009P-1-104 |
| Offset | 1 | 100K Ohm 15 Turn Trim Resistor | Bourns | 3009P-1-104 |
| C1 | 1 | 100 pF Ceramic Capacitor | Kemet | C052C101G5X5CA |
| C2 | 1 | 0.1 uF Ceramic Capacitor | Kemet | C052C104G5X5CA |
| C3 | 1 | 0.1 uF Ceramic Capacitor | Kemet | C052C1D4G5X5CA |
| SW-1 | 1 | 10 Pole Dip Switch | Grayhill | 76MSB10 |
| SW-2 | 1 | 4 Pole Dip Switch | Grayhill | 76MSB04 |
| IC1 | 1 | 723 Precision Regulator | National | LB723C |
| IC2 | 1 | AD612BD Precision Instr. Amp. | Analog Devices | AD612BD |
| IC3 | 1 | uA741 or LF356 OP Amp | National | LM741A or LF356 |
| C4-C7 | 4 | Filter Capacitors | Kemet | User Chooses |

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PARTS LIST FOR CURRENT DRIVER BOARD

| ITEM | QTY. | DESCRIPTION | MANUFACTURER | MANUFACTURER'S PART NUMBER |
|------|------|-------------|--------------|----------------------------|
| R1 | 1 | Current Limiting Resistor | Allen Bradley | User Chooses |
| TR1 | 1 | 2N696 NPN Silicon Transistor | Motorola | 2N696 |
| Offset | 1 | 100K Ohm 15 Turn Trim Resistor | Bourns | 3009P-1-104 |
| Gain | 1 | 100K Ohm 15 Turn Trim Resistor | Bourns | 3009P-1-104 |

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APPENDIX B

SCHEMATICS FOR THE INTERFACE BOARDS

# VIC-20
# A/D BOARD No. 830801
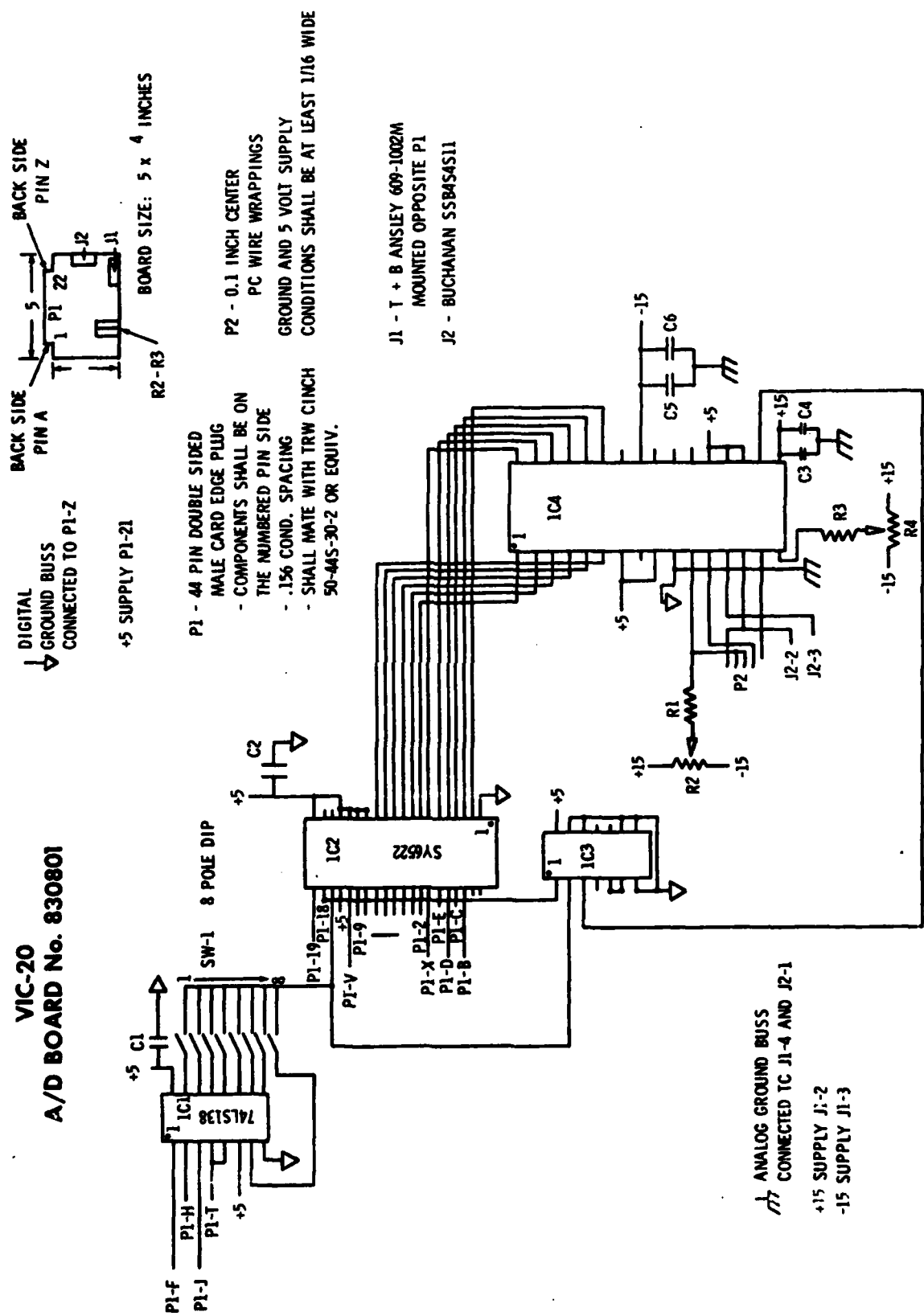
BACK SIDE PIN Z

BACK SIDE PIN A

BOARD SIZE: 5 x 4 INCHES

P1  22
1  5

J2
J1

R2 - R3

DIGITAL GROUND BUSS CONNECTED TO P1-2

+5 SUPPLY P1-21

P1 - 44 PIN DOUBLE SIDED MALE CARD EDGE PLUG
- COMPONENTS SHALL BE ON THE NUMBERED PIN SIDE
- .156 COND. SPACING
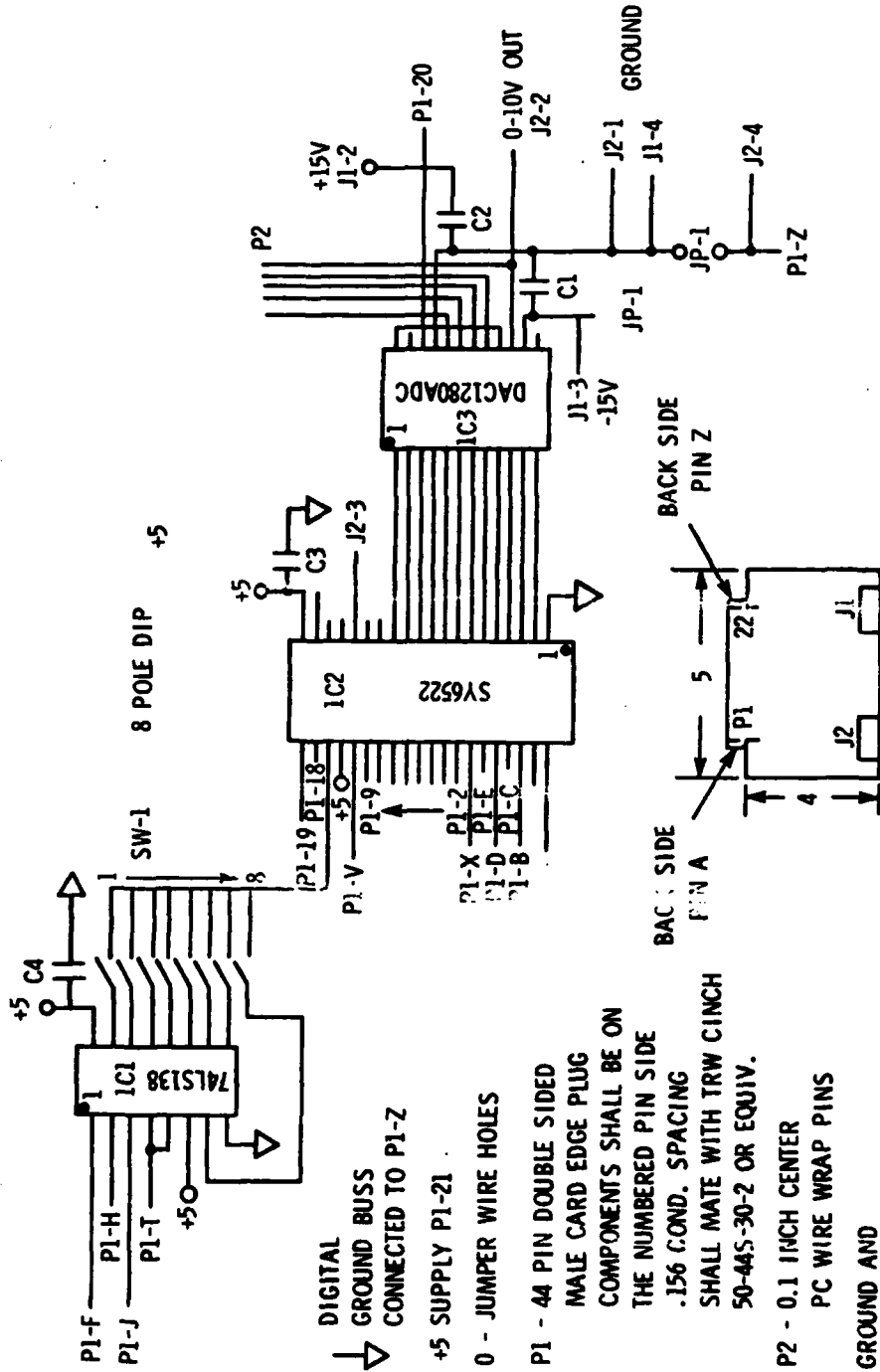- SHALL MATE WITH TRW CINCH 50-44S-30-2 OR EQUIV.

P2 - 0.1 INCH CENTER PC WIRE WRAPPINGS

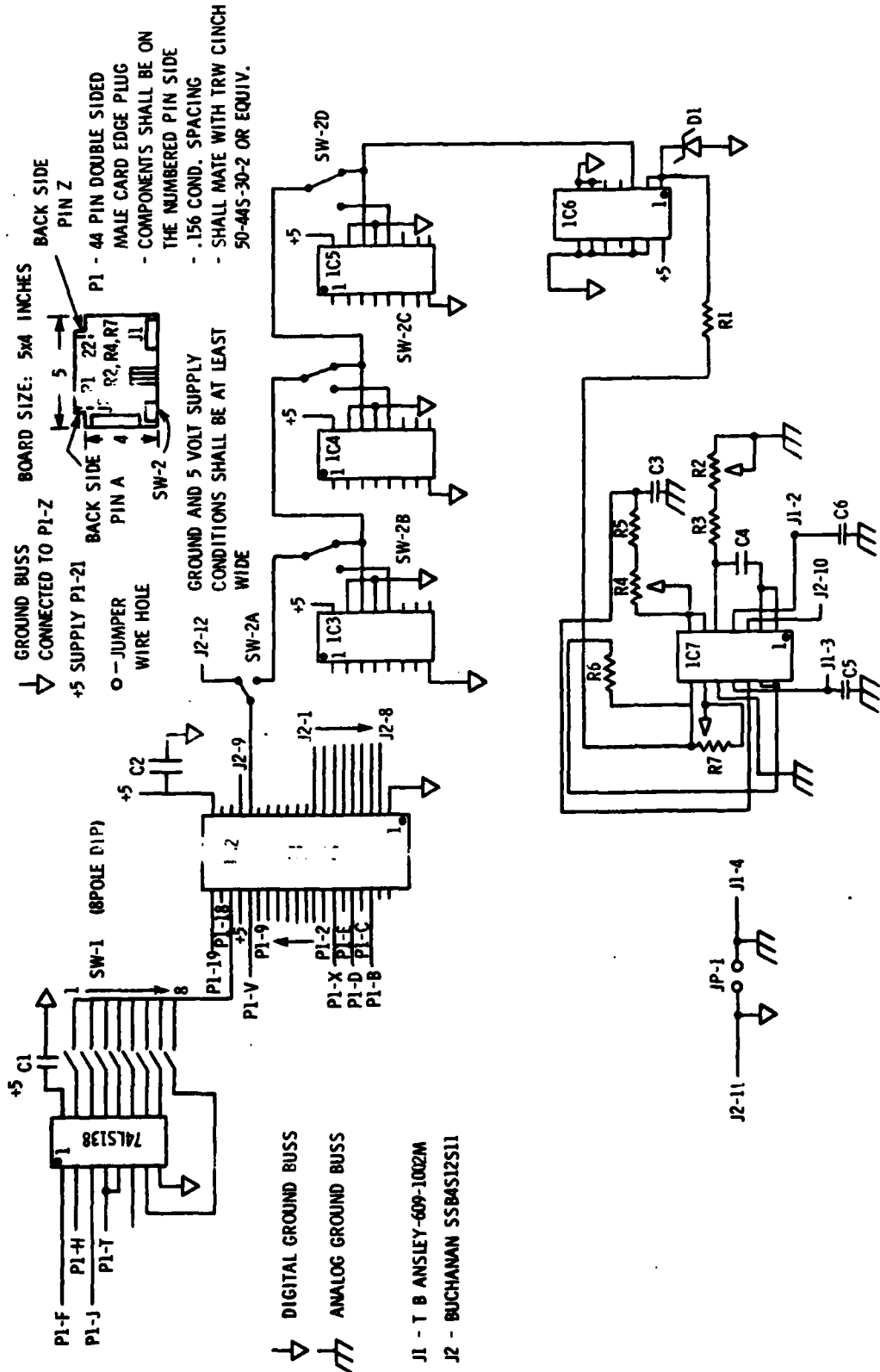GROUND AND 5 VOLT SUPPLY CONDITIONS SHALL BE AT LEAST 1/16 WIDE

J1 - T + B ANSLEY 609-1002M MOUNTED OPPOSITE P1

J2 - BUCHANAN SSB4S4S11

SW-1   8 POLE DIP

74LS138   IC1

IC2   SY6522

IC3

IC4

C1   +5

C2   +5

P1-F
P1-J
P1-H
P1-J
P1-T
+5

P1-19
P1-18
P1-V
+5
P1-9
P1-X   P1-2
P1-D   P1-E
P1-B   P1-C

R1
R2   +15   -15
R3
R4
-15   +15

P2
J2-2
J2-3
+5

C3   C4   +15
C5   C6   -15
+5

ANALOG GROUND BUSS CONNECTED TC J1-4 AND J2-1

+15 SUPPLY J1-2
-15 SUPPLY J1-3

# VIC-20 D/A BOARD 830722



DIGITAL
GROUND BUSS
CONNECTED TO P1-Z

+5 SUPPLY P1-21

0 - JUMPER WIRE HOLES

P1 - 44 PIN DOUBLE SIDED
MALE CARD EDGE PLUG
COMPONENTS SHALL BE ON
THE NUMBERED PIN SIDE
.156 COND. SPACING
SHALL MATE WITH TRW CINCH
50-44S-30-2 OR EQUIV.

P2 - 0.1 INCH CENTER
PC WIRE WRAP PINS

GROUND AND
5 VOLT SUPPLY COND'S.
SHALL BE AT LEAST 1/16 WIDE

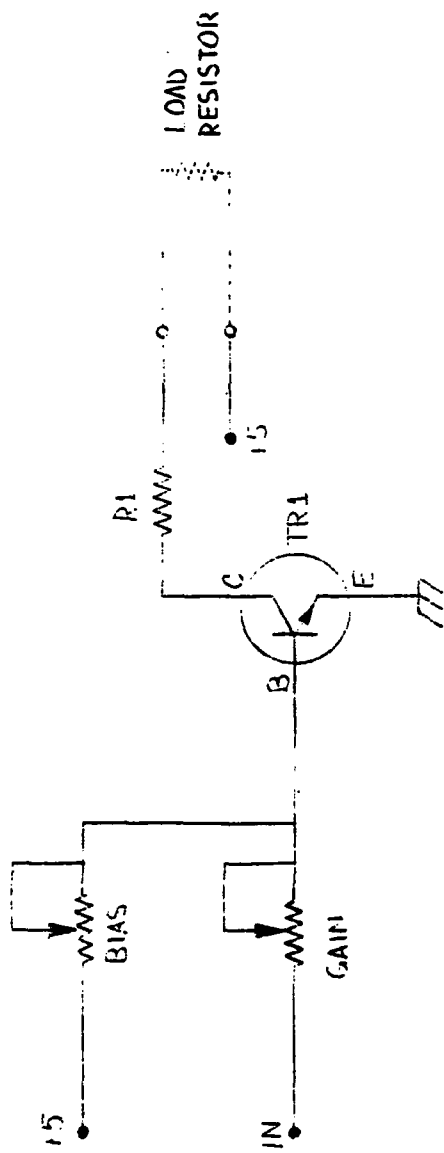J1 - T + B ANSLEY 609-1002M
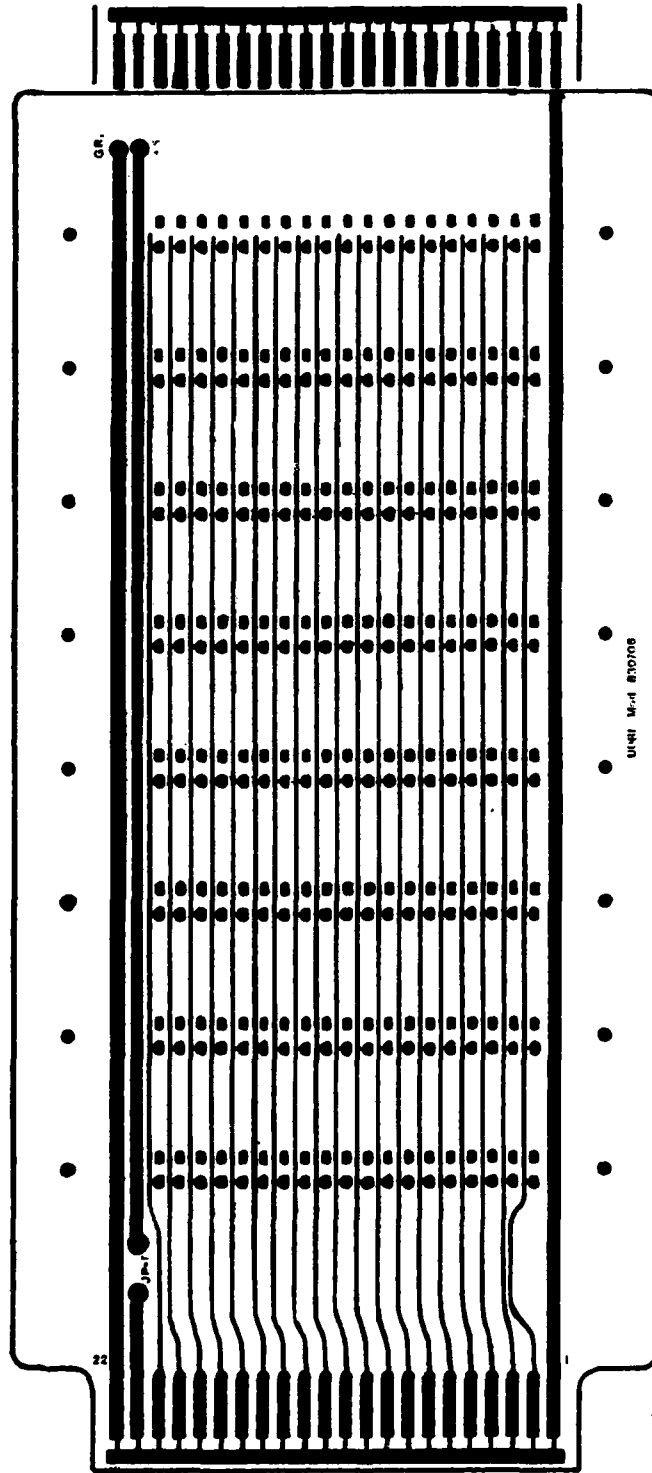MOUNTED OPPOSITE P1

J2 - BUCHANAN SSB4S4S11
TERMINAL STRIP

BOARD SIZE: 5 x 4 INCHES

# VIC-20 COUNTER/TIMER/DIO BOARD 830729

BOARD SIZE: 5x4 INCHES

GROUND BUSS CONNECTED TO P1-Z

+5 SUPPLY P1-21

O — JUMPER WIRE HOLE

P1 - 44 PIN DOUBLE SIDED MALE CARD EDGE PLUG
- COMPONENTS SHALL BE ON THE NUMBERED PIN SIDE
- .156 COND. SPACING
- SHALL MATE WITH TRW CINCH 50-44S-30-2 OR EQUIV.

BACK SIDE PIN Z

BACK SIDE PIN A

GROUND AND 5 VOLT SUPPLY CONDITIONS SHALL BE AT LEAST WIDE

SW-2

R2, R4, R7

SW-2A  SW-2B  SW-2C  SW-2D

1C3  1C4  1C5  1C6

SW-1 (8 POLE DIP)

74LS138

DIGITAL GROUND BUSS

ANALOG GROUND BUSS

J1 - T B ANSLEY-609-1002M
J2 - BUCHANAN SSB4S12S11

P1-F
P1-H
P1-J

P1-V  P1-X  P1-D  P1-B  P1-C

P1-19  P1-18  P1-9  P1-2

J2-12  J2-9  J2-1  J2-8

C1  C2  C3  C4  C5  C6

R1  R2  R3  R4  R5  R6  R7

1C7

D1

J1-2  J1-3  J1-4

J2-10  J2-11

JP-1

+5

70

| LTR | DESCRIPTION | DATE |
|---|---|---|

V$_{IN}$ (+15)

R6

R7

Rf

I C 1

C4

BALANCE
ADJ.

EXCIT.
ADJ.

R5

R2

GAIN SELECT
SW-1

IC 2

R3

R1

GAIN
ADJ.

IC3

SW-2
FILTER
SELECT

C1  C5  C6  C7

AMPLIFIER
OFFSET

O +15

C2

C3

C-15

+EX

CONT

IN 1

IN 2

OUT

71

LOAD
RESISTOR

R1

TR1

C

E

B

+5

BIAS

GAIN

+5

IN

4 TO 20 MA CURRENT DRIVER | UDRI 840205

SCALE : NONE

72

# REVISIONS

| LTR | DESCRIPTION |
|-----|-------------|

C1

IC2

C2

$+ V_c$

D1 D4

D3 D2

$- V_b$

IC1

C2

C1

COMMON

T1

AC
IN
120v

## PARTS LIST

| | STM | NOMENCLATURE | CODE IDENT | IDENTIFYING NO | MATERIAL / SPECIFICATION |
|---|---|---|---|---|---|

**U.S. AIR FORCE**

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
FRACTIONS  DECIMALS  ANGLES

TITLE: POWER SUPPLY

UDR1

SIZE **B**

QUANTITY REQUIRED PER DASH NO.

| CURRENT CODE IDENT NO. | NEXT ASSEMBLY | USED ON |
|---|---|---|

**APPLICATION**

AF FORM 1653

ENGINEERING

APPENDIX C

BOARD LAYOUTS FOR THE INTERFACE BOARDS

COMPONENT SIDE

BACK SIDE
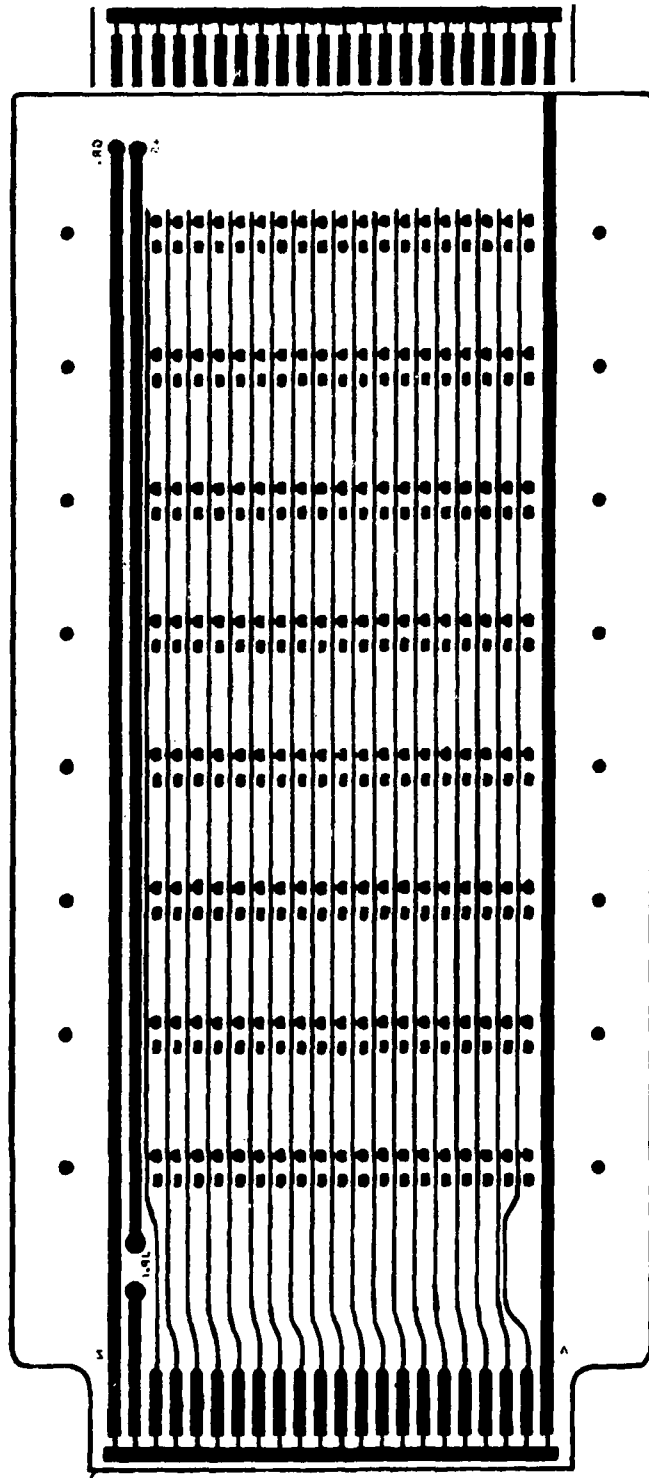
COMPONENT SIDE

A/D CONVERTER BOARD LAYOUT

77
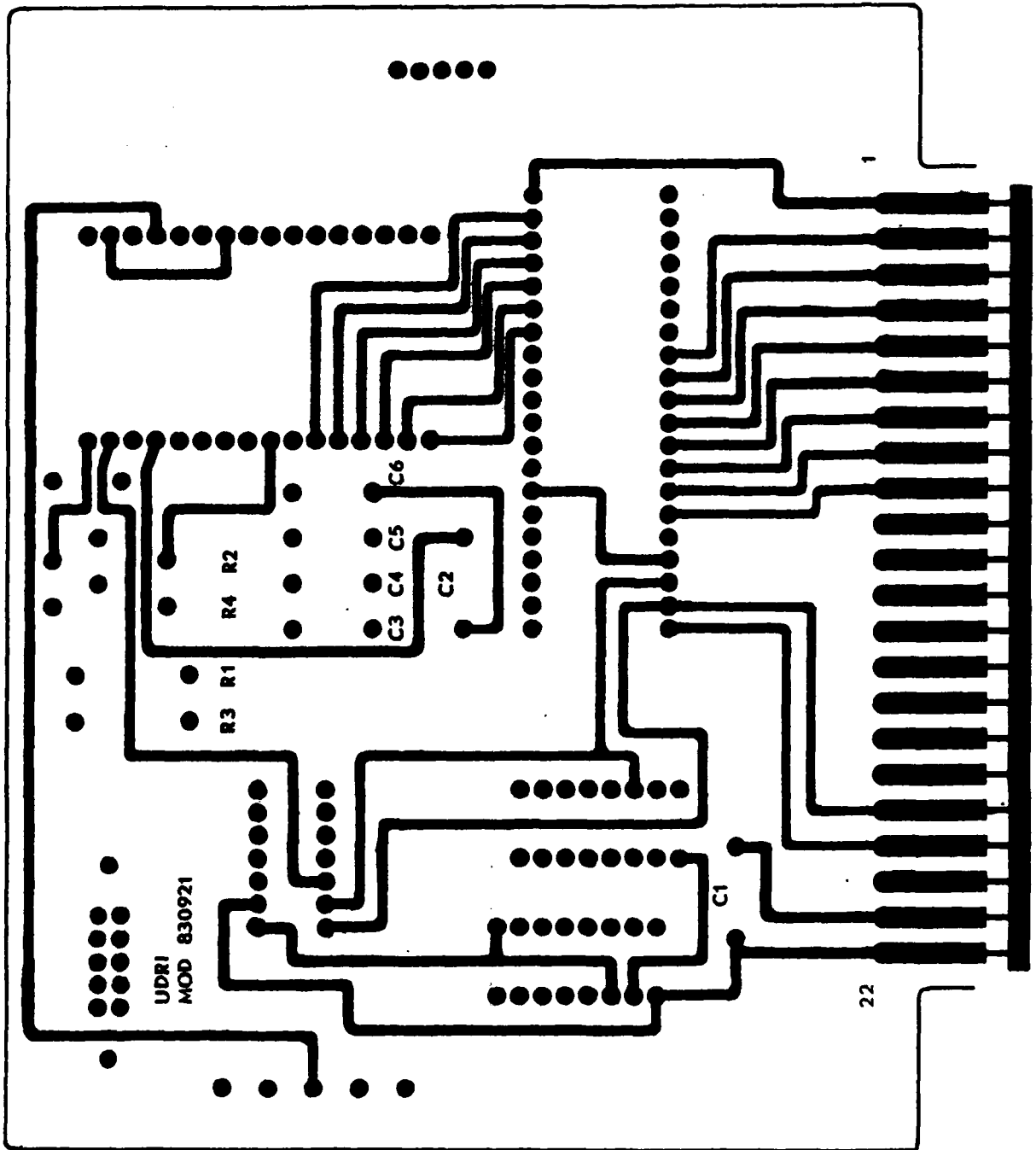
BACK SIDE

A/D CONVERTER BOARD LAYOUT

78
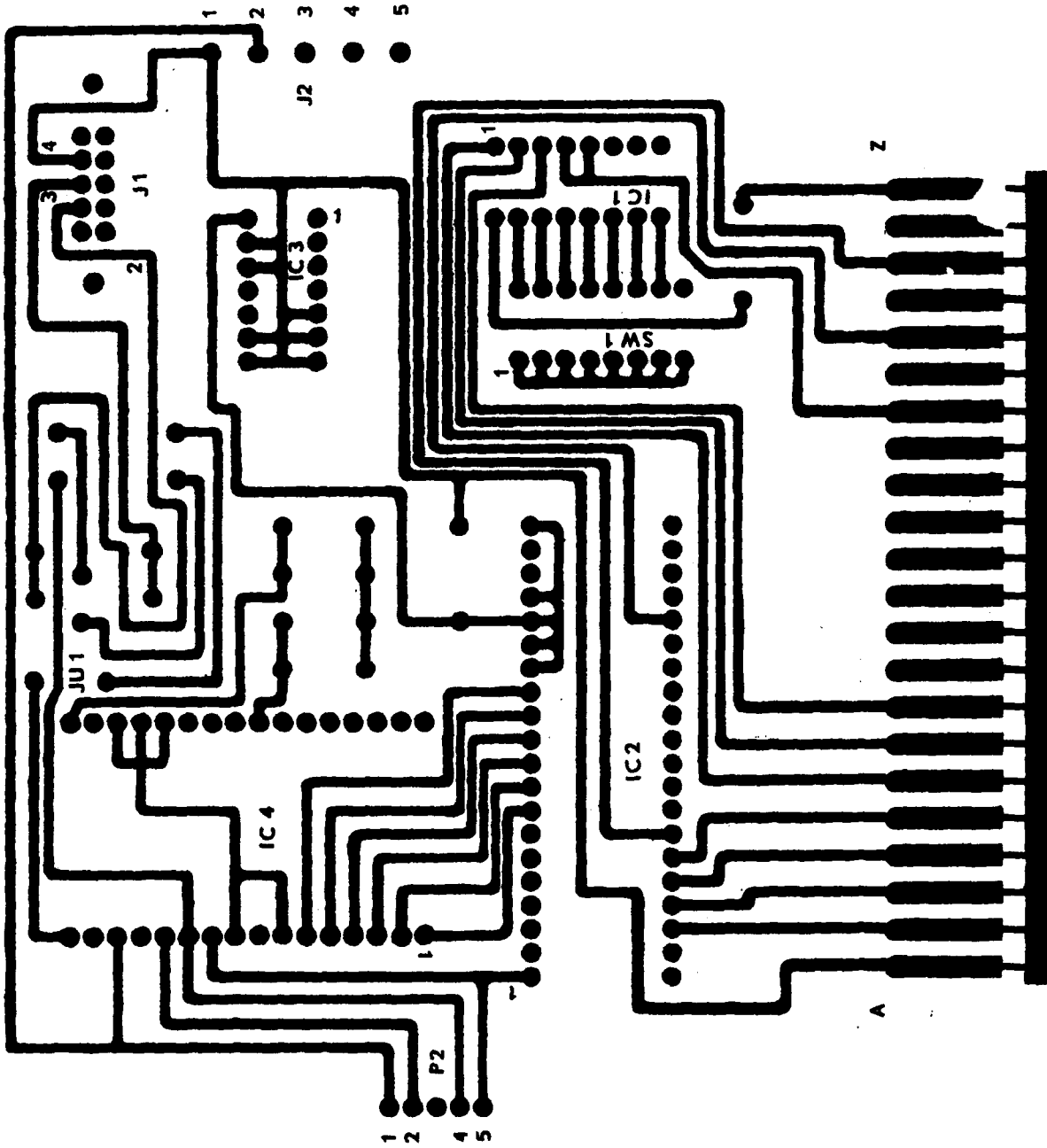
COMPONENT SIDE

D/A CONVERTER BOARD LAYOUT
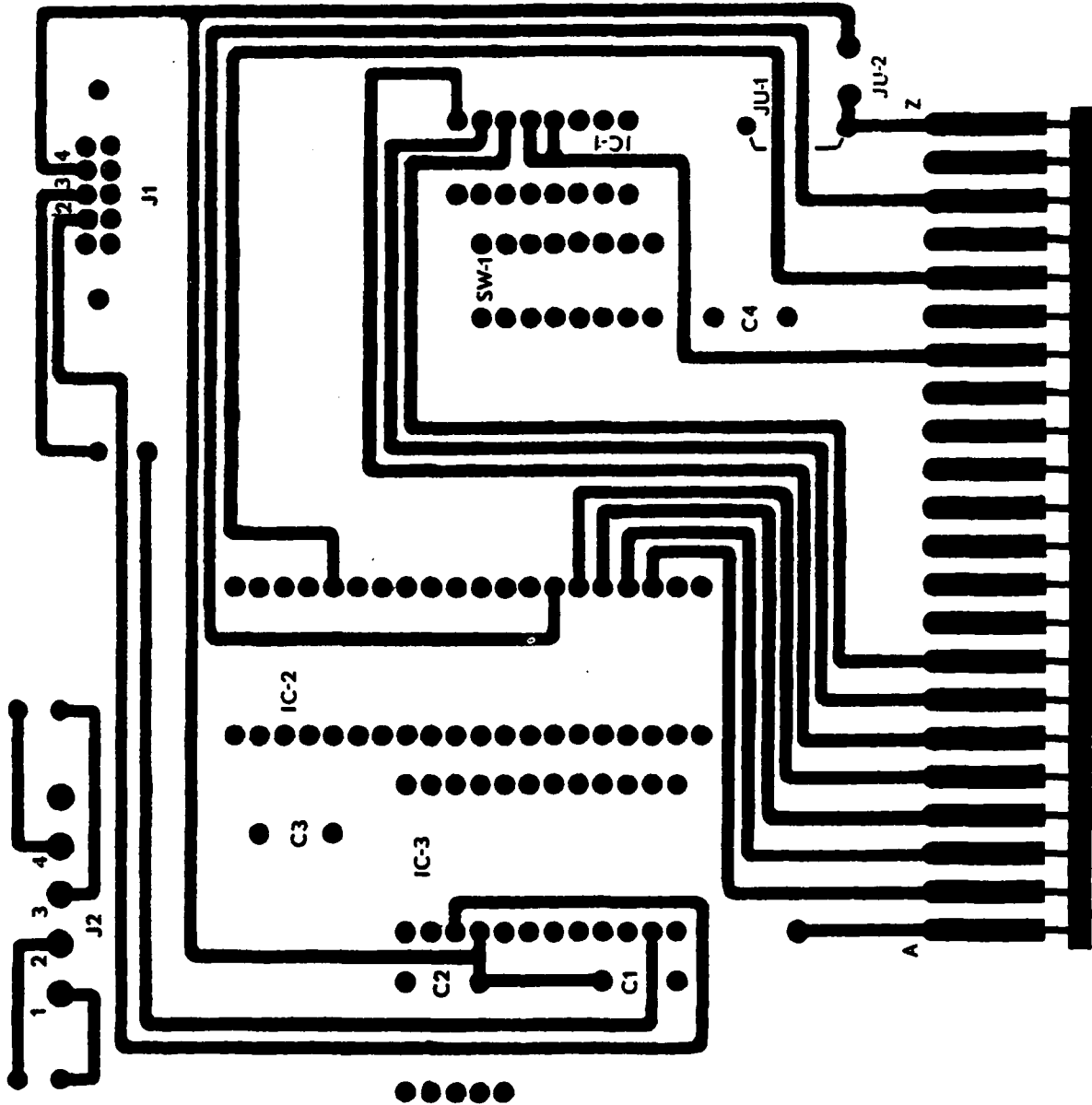
79

BACK SIDE

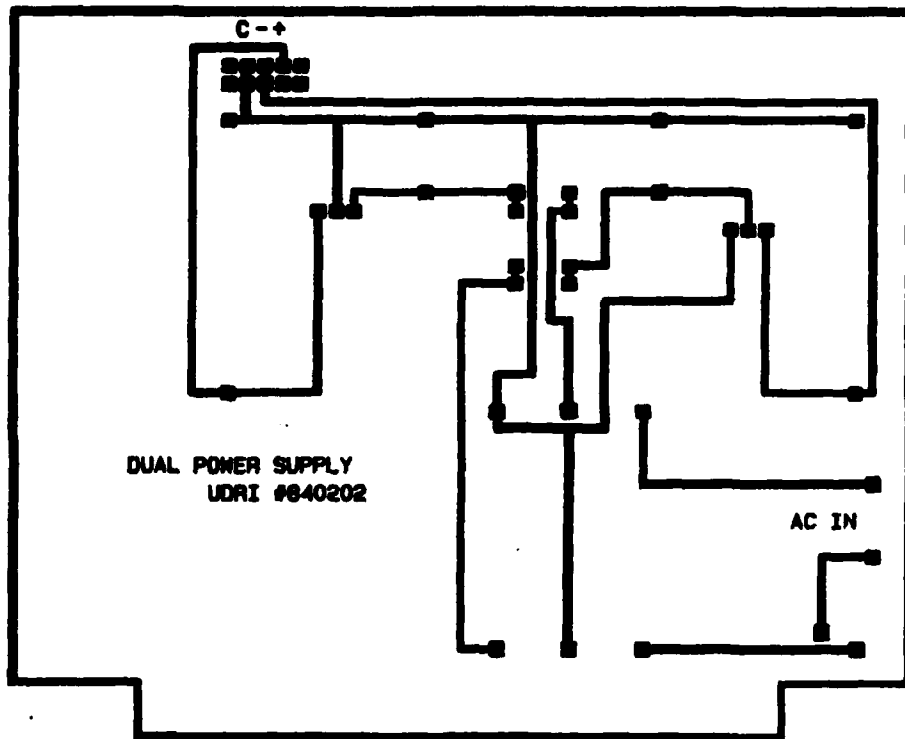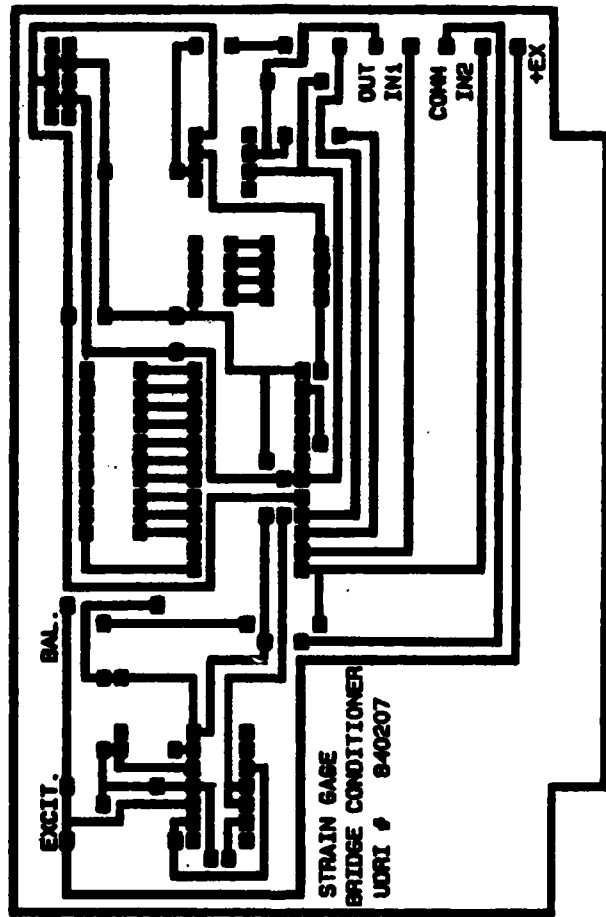D/A CONVERTER BOARD LAYOUT
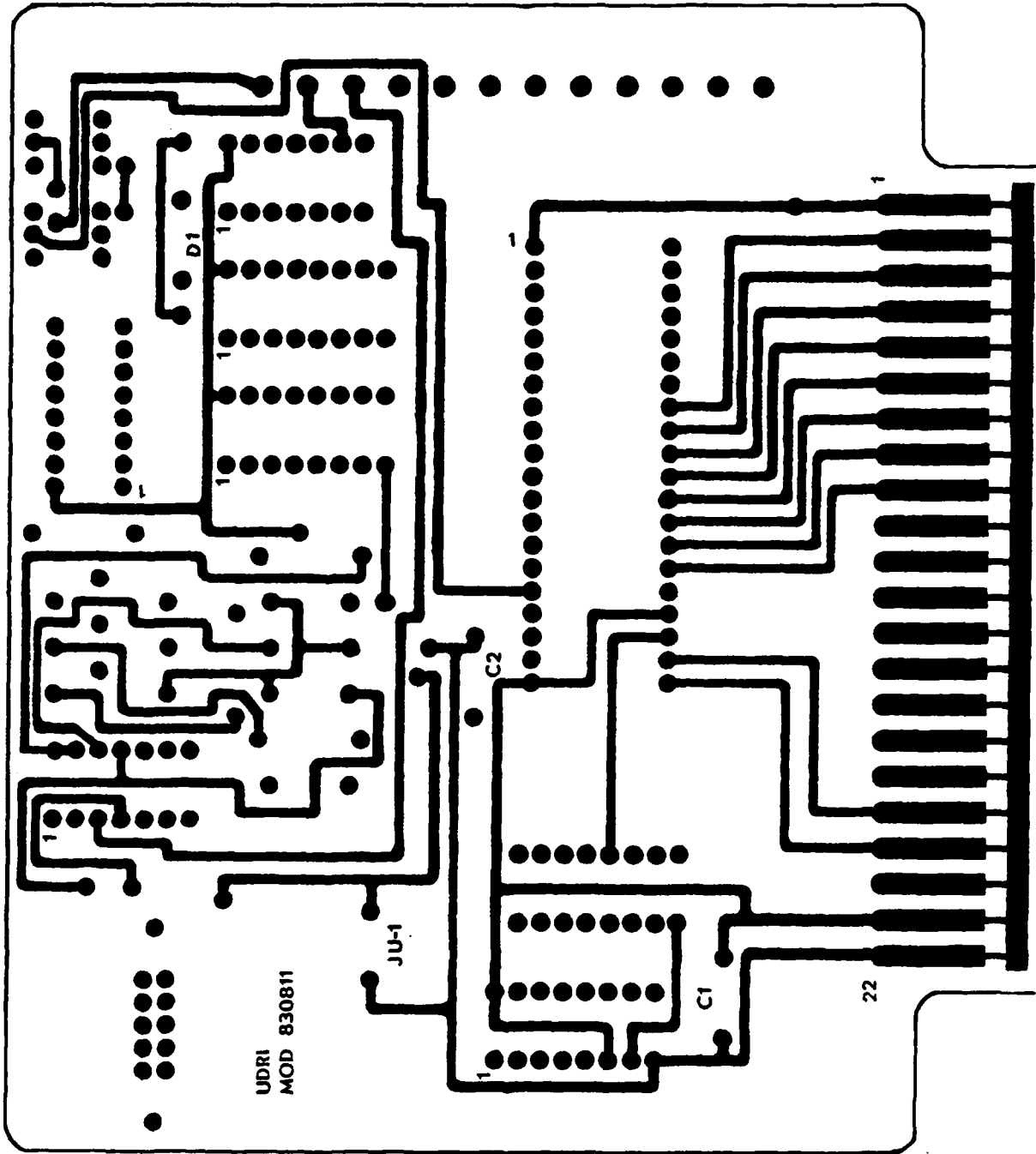
80

COMPONENT SIDE

UDRI
MOD 830811

COUNTER/TIMER/DIO BOARD LAYOUT

81

COUNTER/TIMER/DIO BOARD LAYOUT

82

ETCHED SIDE

C – +
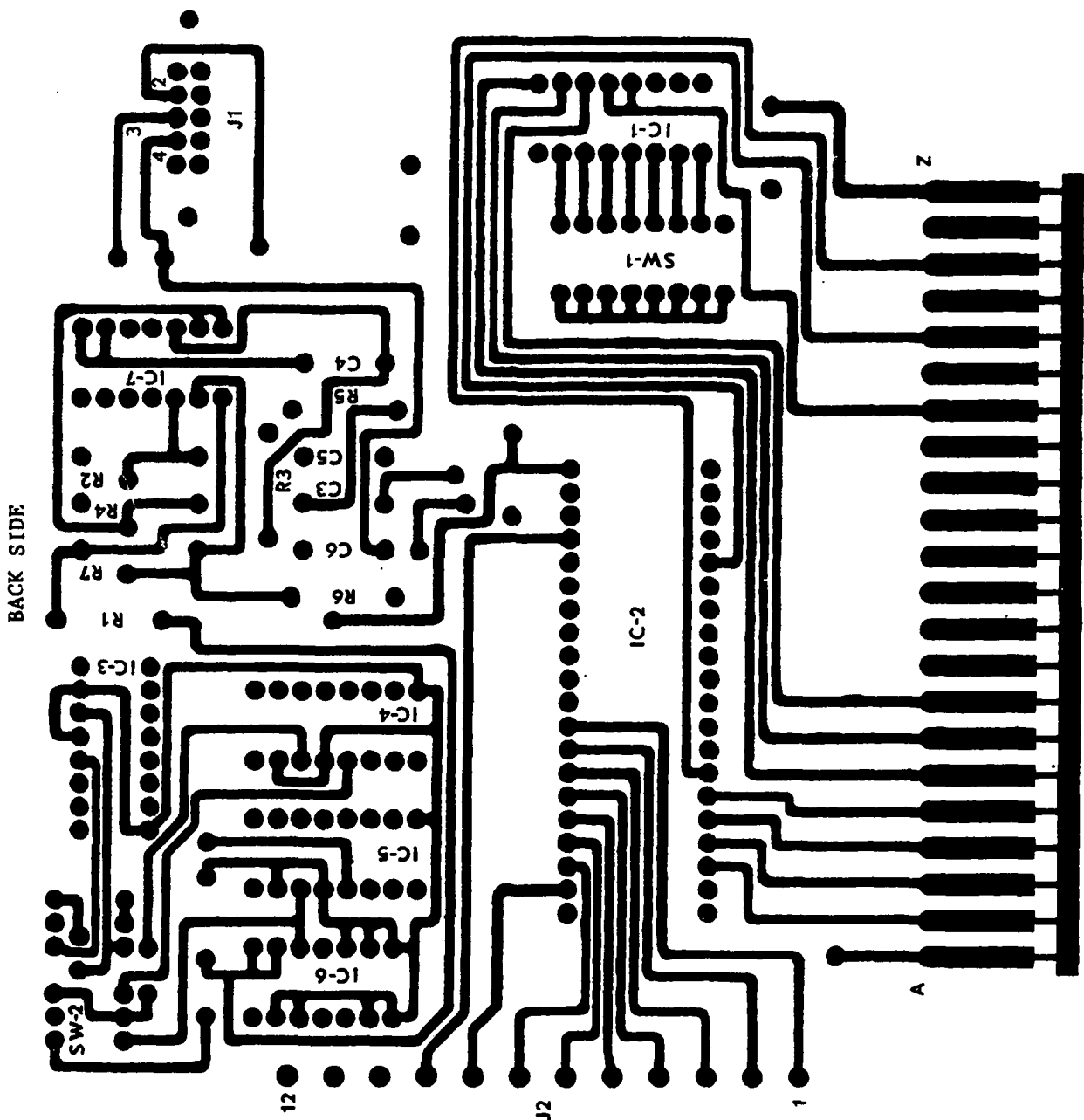
DUAL POWER SUPPLY
UDRI #640202

AC IN

ETCHED SIDE

STRAIN GAGE
BRIDGE CONDITIONER
UDRI # 840207

ETCHED SIDE

OUT HI (+5)
OUT LO
IN HI
IN LO (COM)

4 TO 20 MA
CURRENT DRIVER
UDRI #840203

GAIN

BIAS

R1

B

C
TR1
E

# END

## FILMED

10-84

## DTIC