DESIGN OF VERSATILE, MULTI-CHANNELED, DATA ACQUISITION MODULE

by

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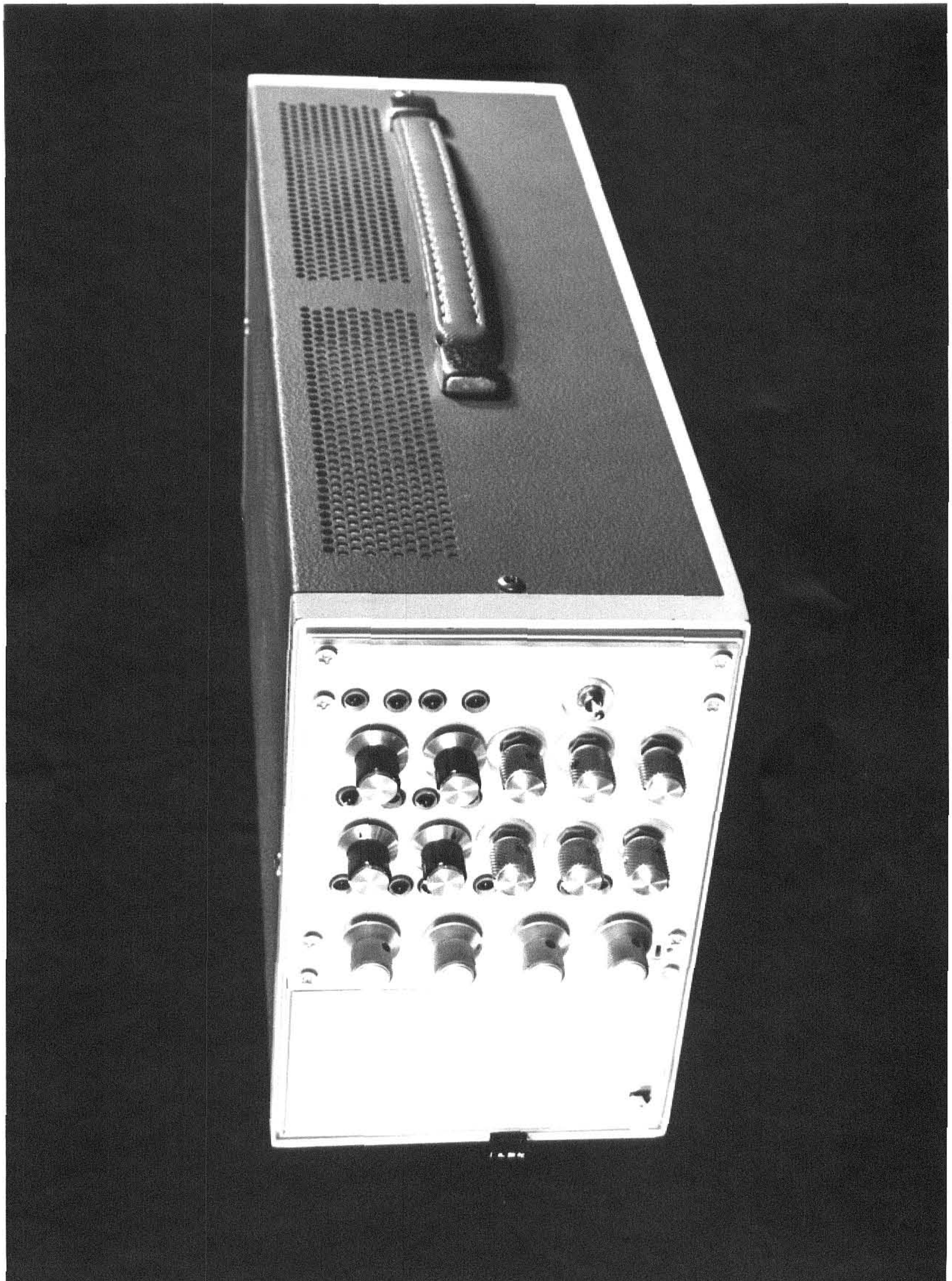

I. INTRODUCTION

1.1 PURPOSE OF THE DATA ACQUISITION MODEL (DAM)

1.1.1 General Description of Purpose and Characteristics of Data Acquisition Module.

The primary purpose of the design of the Data Acquisition Module (DAM) was to convert analog signals into digital signals. Typical examples of analog signals are those related to biological signals generated from cardiopulmonary experiments, e.g. gas flow meter and gas mass spectrometer signals. Signal characteristics must be considered; namely, frequency components of signal, amplitude response of signal and precision of signal sampling.

The significant frequency components of the signals range from a few Hertz to several hundred Hertz. This is typical of naturally occurring biological signals related to the respiratory system. Also in order to reduce the amount of noise the significant frequency components of the signal must be contained within the bandwidth of the instrument.

The second consideration is the amplitude of the signal. In order to utilize the instrument properly the signal has to be amplified in order to obtain a better S/N ratio. If the signal is amplified properly the conversion from analog to digital form is more accurate.

Also, the sensitivity of the instrument, should be considered. The component that contributes significantly to the determination of sensitivity is the A/D converter; as a consequence it should have the best sensitivity for the lowest price. A sensitivity of 5 mv/step was used on the design.

Finally, the instrument is multichanneled with the ability to simultaneously accept eight channels. All eight channels do not have the same flexibility because of space limitations and packaging considerations.

1.2 FUNCTIONS OF DATA ACQUISITION MODULE

1.2.1 General Description

There are several methods by which the components of a DAM can be arranged. These are shown in Fig. 1.2. Only three alternatives are promising (Fig. 1.2.A, 1.2.B and 1.2.C). From these three forms the best is to be selected.

Fig. 1.2.A is the least expensive and simplest of the three alternatives, since there is only one component, the Sample and Hold (S/H) circuit, that has to be repeated for every channel. Unfortunately this system does not meet the application requirements and the S/N ratio requires improvement.

In order to improve the system shown in Fig. 1.2.A an Amplifier (AMP) and an Analog-to-Digital converter (A/D) are included in each channel of the second alternative, Fig. 1.2.B. Some signal conditioning would be necessary. This would be accomplished by the Serial-to-Parallel converter (STPC). The S/N ratio shows improvement with this alternative, but is accompanied by additional complexity and cost.

The third alternative is shown in Fig. 1.2.C where each channel has a amplifier (AMP) and a S/H circuit. This alternative is relatively inexpensive, simple, and has a good S/N. As a consequence this was the block diagram used for the instrument.

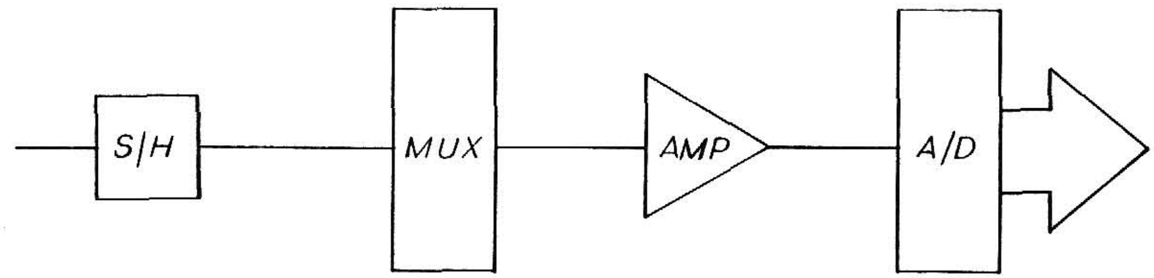

Fig. 1.2.A First Block Diagram of DAM

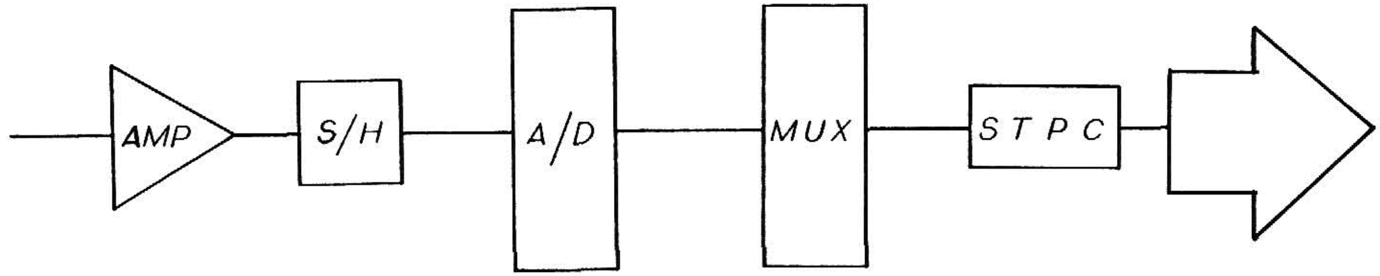

Fig. 1.2.B Second Block Diagram of DAM

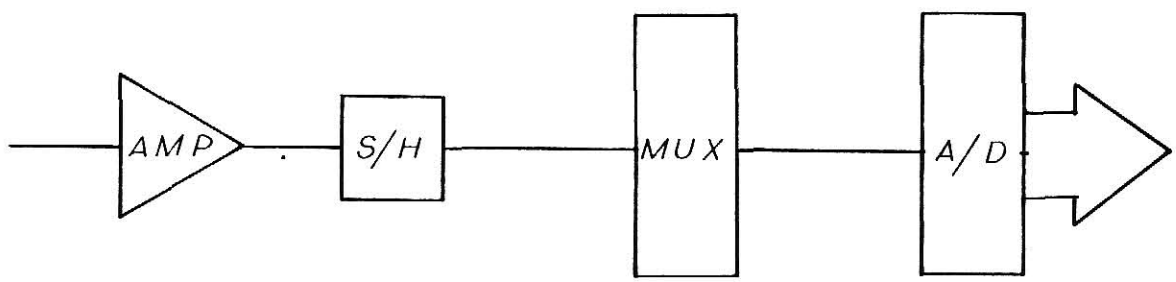

Fig. 1.2.C Third Block Diagram of DAM

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1.2.2 Analog Section

Fig. 1.2.C can be divided into two sections. The first section is the Analog Section and the last section is the Digital Section. Here the Analog Section will be considered in more detail. The Digital Section will be considered in Section 1.2.3.

Fig. 1.2.D deals with the Analog Section of the block diagram. As expected the first device in the Analog Section is an amplifier. Again this is used to improve the S/N ratio. After amplification some signal conditioning has to be accomplished. First, in order to assure the proper operation of the DAM, the amplification of the signal is limited. Secondly, in order to further improve the S/N, the bandwidth needs to be confined to the frequency components of the signal. This is accomplished by a bandpass filter. Finally the signal is converted into a constant voltage by a S/H.

1.2.3 Digital Section

The function of this section of circuitry is to convert the analog signal into a digital signal so that the computer (HP 9845) can interpret the information.

The First Block in Fig. 1.2.E is a multiplexer, MUX. This device selects in sequence each of the eight signals. The output of the MUX is converted to a digital signal by the A/D. Finally, there is a peripherial device called a Programmable Timer (PTM) used to control the rate at which the signals are converted into digital signals.

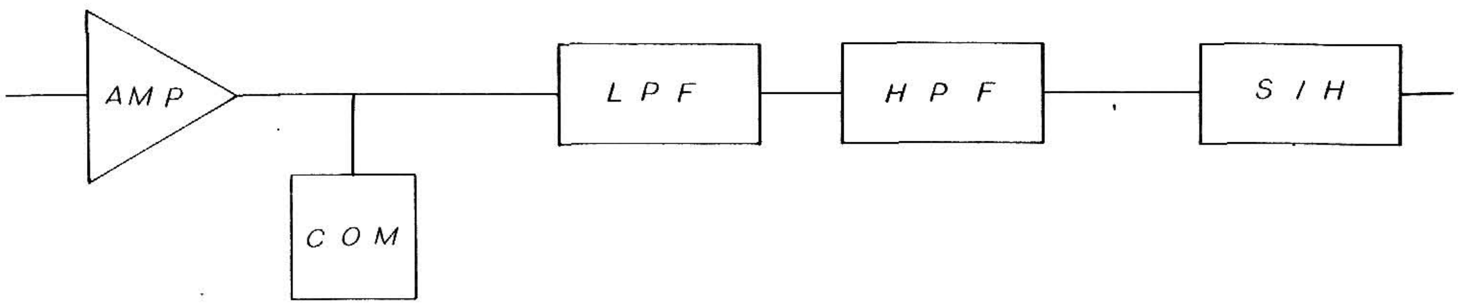

Fig. 1.2.D Analog Section of Block Diagram

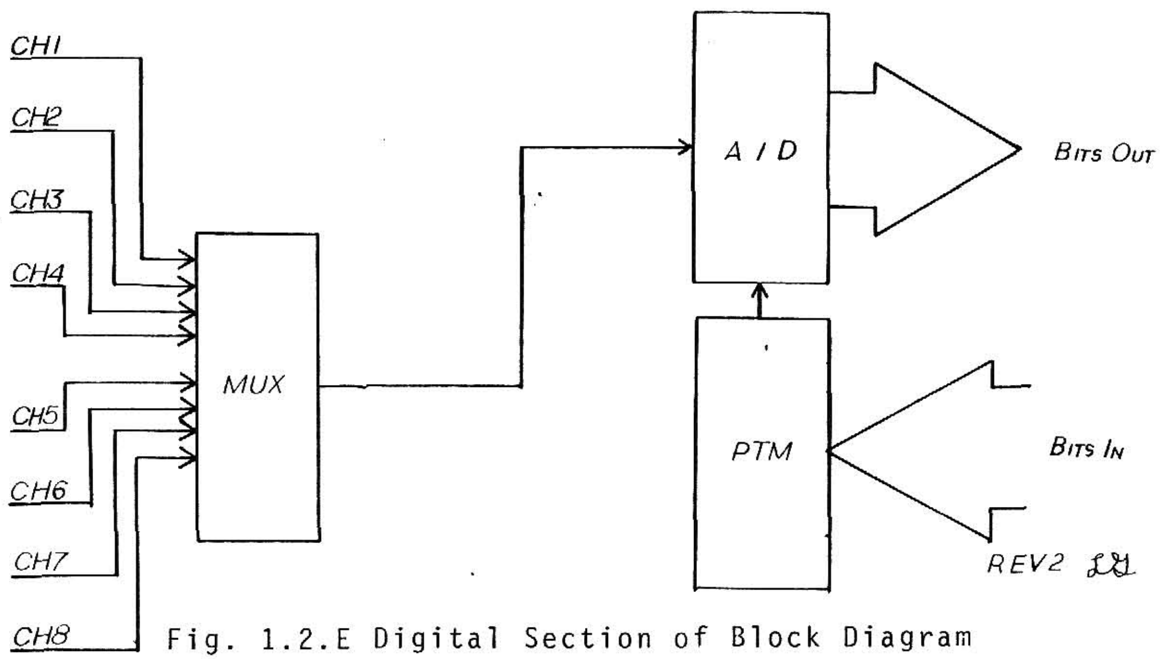

Fig. 1.2.E Digital Section of Block Diagram

II. DESIGN CONSIDERATIONS FOR CIRCUIT SUBSYSTEMS

In this chapter, the electronics for the block diagram in Fig. 1.2.D and 1.2.E will be developed. This includes an explanation of several different alternatives to the electronic problems and an explanation of why the selected alternative was used.

2.1 ANALOG SUBSYSTEMS

2.1.1 Amplifier Stage

The purpose of the AMP is threefold:

1. To improve S/N ratio.
2. To provide enough amplification to use the full 20 voltage range of the A/D.
3. To provide isolation between the peripherial device and the computer.

Two different types of amplifiers are readily available and will fulfill the purpose. The first is an Isolation Amplifier. Because of economical reasons this amplifier was not selected. The second is an AD521JD Instrumentation Amplifier (Fig. 2.1.A). This device has an excellent S/N ratio. Thus, it provides good isolation between the computer and the peripheral device. Also it is extremely simple to use for it only needs 2 external components, i.e., two resistors. One of the resistors can be made a variable resistor providing the required variable amplification as given by the following formulae:

$$R_{02}/R_{0} = \text{GAIN} \qquad (2.1)$$

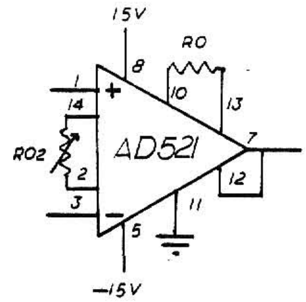

Fig. 2.1.A Instrumentation Amplifier Circuit

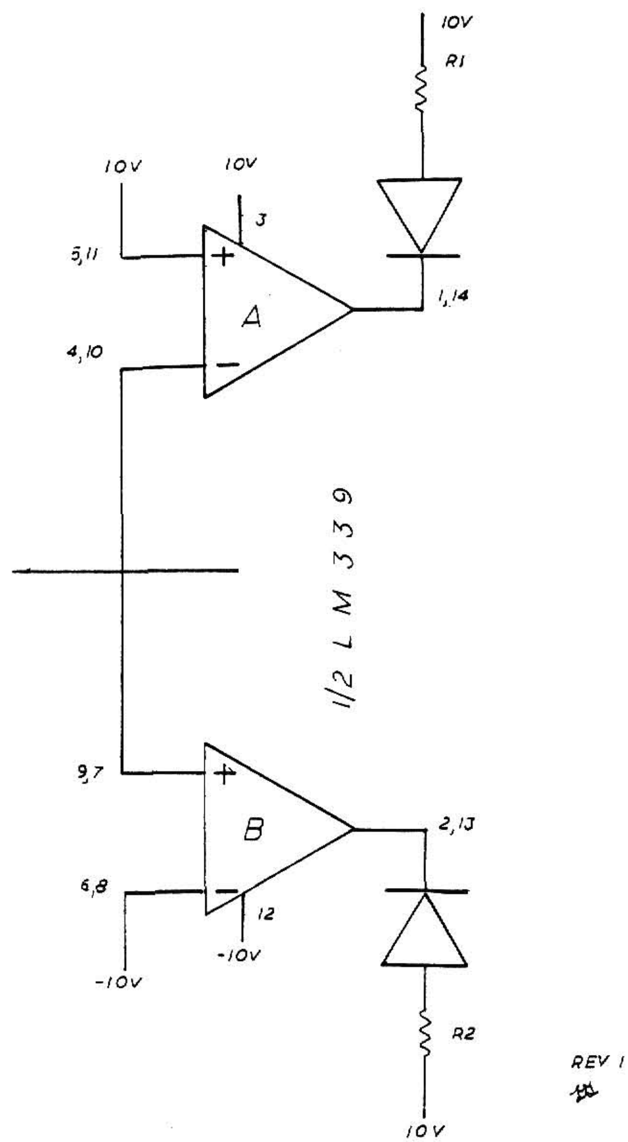

Fig. 2.1.B Peak Detector Circuit

2.1.2 Comparator Circuit (COM)

In this section the problem of obtaining the proper amplification in order to obtain a peak voltage of +10 and -10 V is addressed. The simplest way to detect +10 and -10 V is by the use of a comparator circuit.

The comparator used for this application is a high gain differential amplifier. Refer to Fig. 2.1.B. Because of the high gain of the comparator its output goes into positive saturation when the difference of the voltage at the positive terminal and the voltage of the negative terminal is positive. Again, because of the high gain of the comparator its output goes into negative saturation when the difference of the voltage at the positive terminal and the voltage of the negative terminal is negative. In order to detect when the output of the comparator goes into negative saturation an LED in series with a resistor is connected from +10 V to the output of the comparator. This is shown in Fig. 2.1.B. Also shown in Fig. 2.1.B is another comparator, Comparator A. This device detects when the signal goes above 10 V while comparator B detects when the signal goes below -10V. Thus, the voltage can be confined within the boundaries of +10 V and -10 V by controlling the gain of the AMP. When the circuit was tested the range of input values at which the output saturated was +9.8 and -9.8 V. Fortunately this was satisfactory for the application.

2.1.3 Active Filters

The problem of finding a suitable Band Pass Filter is addressed here. The purpose of the Band Pass Filter is to reduce the noise passed to the D/A. This improves the performance of the overall instrument.

In order to improve the S/N ratio it is necessary that the filter has a ripple signal less than 0.5 dB and that the signal has a fast roll-off rate at the cut-off frequency. Packaging flexibility is another consideration.

The first attempt to solve the above problem is shown in Fig. 2.1.C. This filter meets all of its requirements except for its flexibility requirements. Here eleven resistors have to be changed in order to change the filter's cut-off frequency. Also, both the low and the high cut-off frequencies have to be adjusted at the same time and not independently of each other. These two problems combined make the filter complex, inflexible and not desirable for the anticipated applications.

The second approach (see Fig. 2.1.D) proved to be satisfactory in all respects: simplicity, flexibility, and performance. One of the reasons for this circuit being quite acceptable is that it is divided into two sections, a High-Pass Filter and a Low-Pass Filter. This makes its high cut-off and its low cut-off frequencies completely divorced from each other.

The Op Amp at the very left of Fig. 2.1.D is the active component of the High-Pass Filter (HPF). R3 - R 5 and C1 - C3 are the passive components. This filter is a third order Multiple-Feedback High-Pass Filter with a .5 dB ripple. The transfer function of the circuit is the following:

$$\frac{V2}{V1} = \frac{S^3}{S^3 + A_2 S^2 + A_1 S + A_0} \qquad (2.2)$$

$$A_0 = \frac{1}{R_3 R_4 R_5} \qquad A_1 = \frac{2}{R_4 R_5} + \frac{2}{R_3 R_4} \qquad A_2 = \frac{3}{R_4} + \frac{1}{R_3}$$

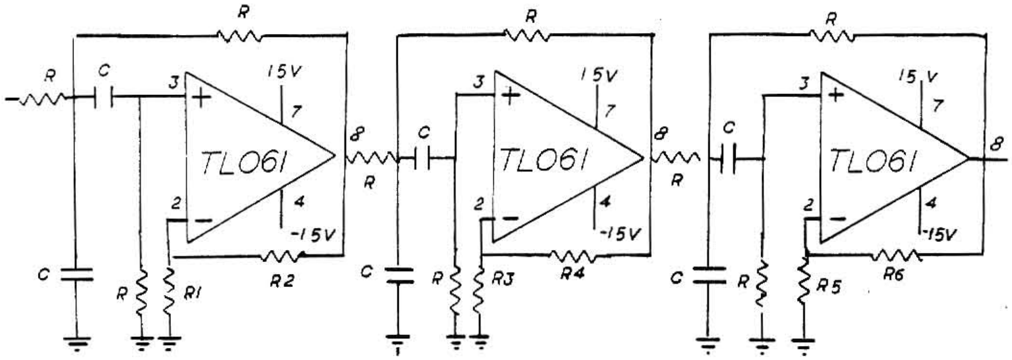

Fig. 2.1.C First Band-Pass Filter Circuit

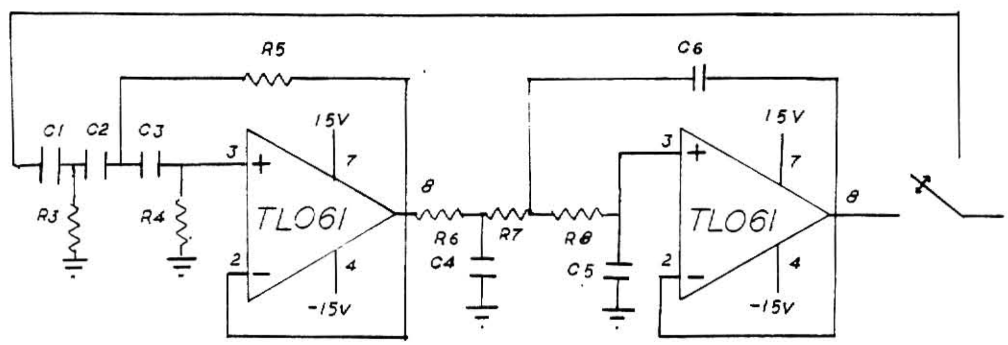

Fig. 2.1.D Second Band-Pass Filter Circuit

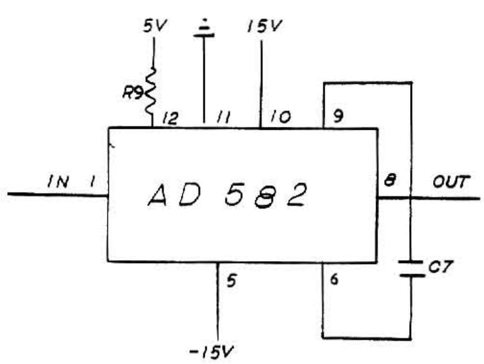

Fig. 2.1.E Sample/Hold Circuit

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where C_2, C_3, C_4 and the cut-off frequency have been normalized to one (1).

The remainder of the circuit in Fig. 2.1.D is part of the Low-Pass-Filter (LPF). This is another third order Multiple-Feedback filter with a .5 dB ripple. The Low-Pass Filter transfer function is (1)

$$\frac{V2}{V1} = \frac{GBO}{S^3 + B_2S^2 + B_1S + B_0} \qquad (2.3)$$

with

$$B_0 = \frac{1}{R_6R_7R_8C_6C_5} \qquad B_1 = \frac{R_7 + R_8}{C_6R_7R_8}\left[\frac{1}{R_6} + \frac{1}{R_7}\right] + \frac{C_4}{R_7R_8C_7C_6} - \frac{1}{R_7^2C_6}$$

$$B_2 = \frac{R_7 + R_8}{C_6R_7R_8} + \frac{1}{R_6} + \frac{1}{R_7}$$

Unfortunately, when the cut-off frequency is changed a total of three resistor values have to be changed. This feature created some instrumentation packaging problems as discussed in Section 2.4. Lastly, in order for the instrument to pass D.C. components it is necessary to by-pass the Band-Pass Filter. This was done by setting a single-pole double-throw switch at the output of the filter as shown in Fig. 2.1.D.

2.1.4 Sample and Hold Circuits

The last part of the analog section is a Sample-and Hold circuit (Fig. 2.1.E). This device functions in two states. In the sample state the S/H functions like a standard Op Amp. In the hold state the capacitor C7 holds the output at its last level, regardless of input voltage (2).

The purpose of this device is twofold:

1. To allow enough time for the A/D to do its conversion.
2. To sample all the channels at a particular time.

There are several chips readily available that will fulfill our purposes. The AD582JD was used because it is tailored to experimental requirements, it possesses superior performance and is of low cost. The AD582JD is configured as a non-inverting unity gain S/H (Fig. 2.1.E). In order to reduce voltage fluctuation it is necessary that capacitor C7, in Fig. 2.1.E, be a low leakage polystryrene capacitor. The performance of the AD532JD is also reduced if the proper capacitor value is not used. This value is 0.01 µf.

2.2 DIGITAL SUBSYSTEMS

2.2.1 Multiplexer

This device allows the controller to select any of the inputs as specified by the digital control [7]. The controller of the MUX is the computer system, HP9845. The digital levels are TTL levels. This requirement for TTL logic limits the section of analog multiplexers since most readily available analog multiplexers do not use TTL levels. As a consequence some external circuitry must be designed so that the HP9845 can control the MUX (Fig. 2.2.A).

The AD7503 is a MUX that can take 30 Vpp input voltage levels, with TTL digital control levels (see Fig. 2.2.B). This device allows for a reasonably simplistic design.

2.2.2 Analog-to-Digital Converter

This device converts the analog signal into a digital signal. There are several different A/D conversion techniques available, such as Parallel Encoder, Successive Approximation, Voltage-to-Frequency Converter, and Signal-Slope Integration. The successive approximation

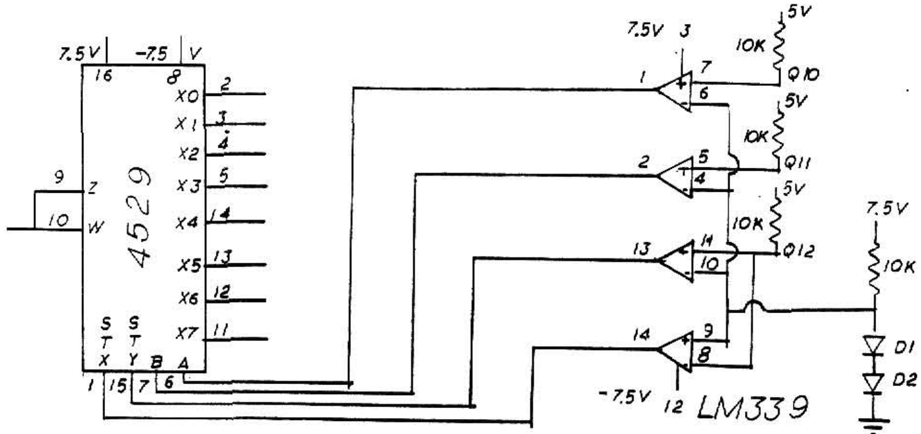

Fig. 2.2.A First Multiplexer Circuit

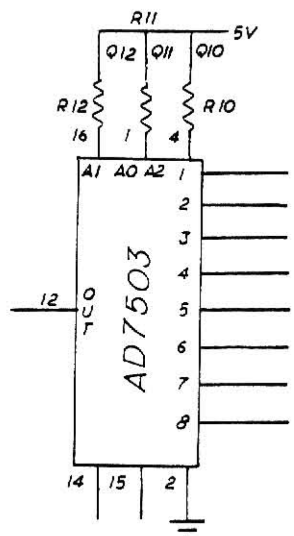

Fig. 2.2.B Second Multiplexer Circuit

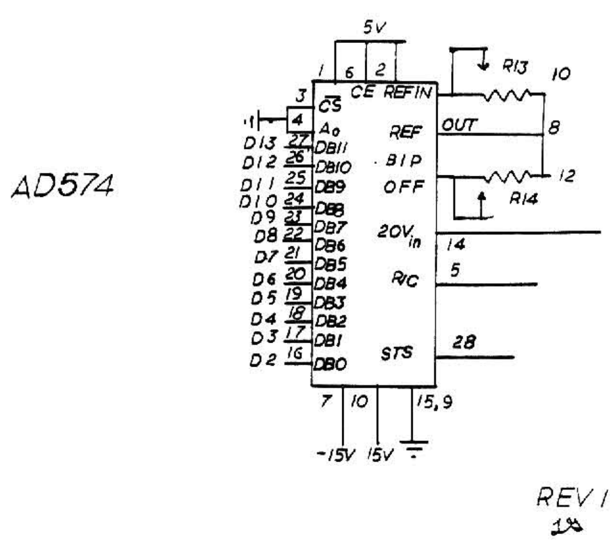

Fig. 2.2.C Analog-to-Digital Converter Circuit

technique is used because of its simplicity and accuracy. The AD574JD chip was selected from several successive approximation chips because of its fast convertion time, its accuracy, its simplicity and its low cost.

The successive approximation technique works by comparing the analog input signal with a counting digital signal by the use of a D/A converter. These signals are then compared until the digital signal is equal to the analog input. At this time, the STS bit in the AD574JD is reset (3).

2.2.3 Programmable Timer

The rate at which the A/D chip performs its conversion is controlled by a device known as a Programmable Timer (Fig. 2.2.E). This timer is, in turn, controlled by the HP9845. With this technique it is possible to make sure that the sampling frequency is proper for the particular application of the user.

The Programmable Timer has three different counters, each of which may be programmed by the HP9845 to divide the frequency of the input signal by two. For the anticipated application the input frequency is 1 MHz. The 500 KHz square wave signal is then fed into the input of the second counter. This counter is programmed to set pulses every t seconds with t being the sampling period. The sampling period should be greater than or equal to 1/5 sec. The Programmable Timer is controlled by the "Interface Circuit" (see left position of Fig. 2.2.E) which itself is controlled by the HP9845.

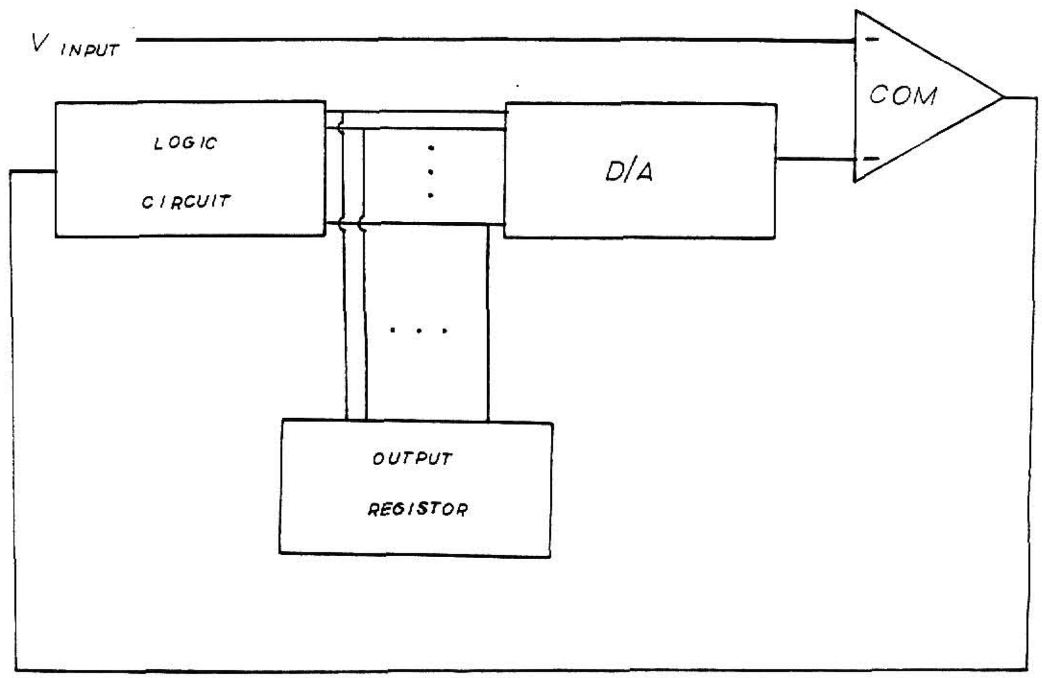

Fig. 2.2.D Block Diagram of Analog-to-Digital Converter

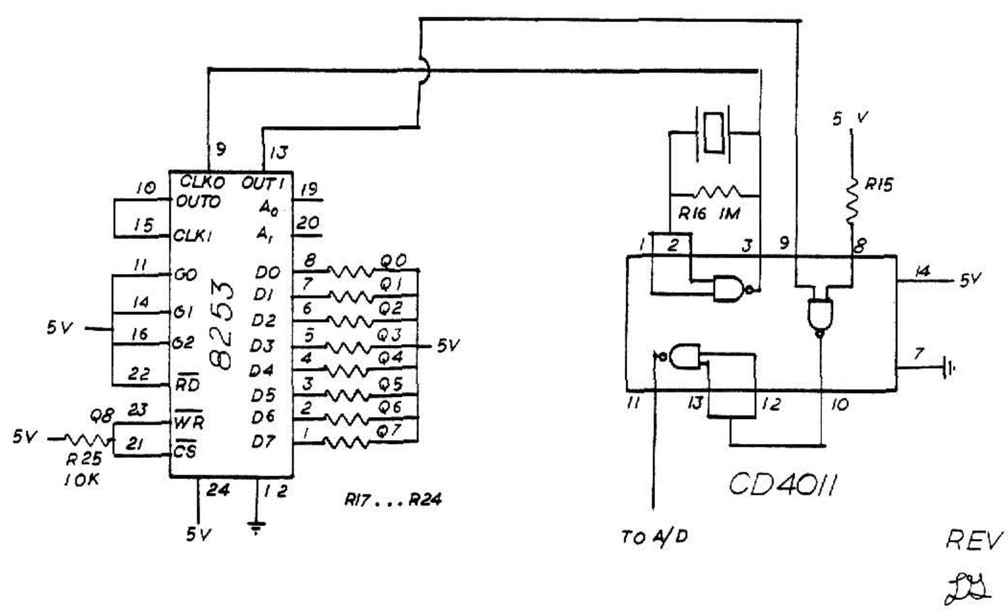

Fig. 2.2.E Programmable Timer Circuit

2.3 POWER SUPPLY

2.3.1 Design of Power Supply

The instrument is housed in a Tektronix TM Plug-in Module. The TM503 provides +33.5 Vdc, -33.5 Vdc and +11.5 Vdc. These voltages are not adequately regulated and are not the required values, +15, +10, +5, -15, and -10 Vdc.

The +11.5 Vdc can be properly regulated and the voltage dropped to 5 Vdc by simply using a MC7805. Capacitors 3C1 and 3C2 are used for stability (see Fig. 2.3.A). The 33.5 Vdc has to be dropped to approximately 20 Vdc. This is accomplished by a "Dropping Circuit" which consists of 1R1, 1D1, 1D2, 1R2, 1Q1 and 1Q2. The 20 Vdc is then regulated to +15 Vdc by a LM340 chip. This 15 Vdc is dropped to +10 Vdc by an adjustable voltage regulator LM317. Again, capacitor 1C2, 1C3 and 1C4 are used for stability. Using similar circuits, the required -15 Vdc and -10 Vdc are obtained from the -33.5 Vdc supply.

Components 1Q2 and 2Q2 are part of the TM503. In addition, these chips can supply the maximum current required by the DAM (See Table 2.3.1.A).

CHIP	VOLTAGE (V)	I(mA)	I MAX (A)
LM340	+15	370	1.5
MC7915C	-15	340	1.5
LM317K	+10	370	1.5
LM337T	-10	340	1.5
MC7805	+5	340	1.5

Table 2.3.1.A Current Requirement for DAM

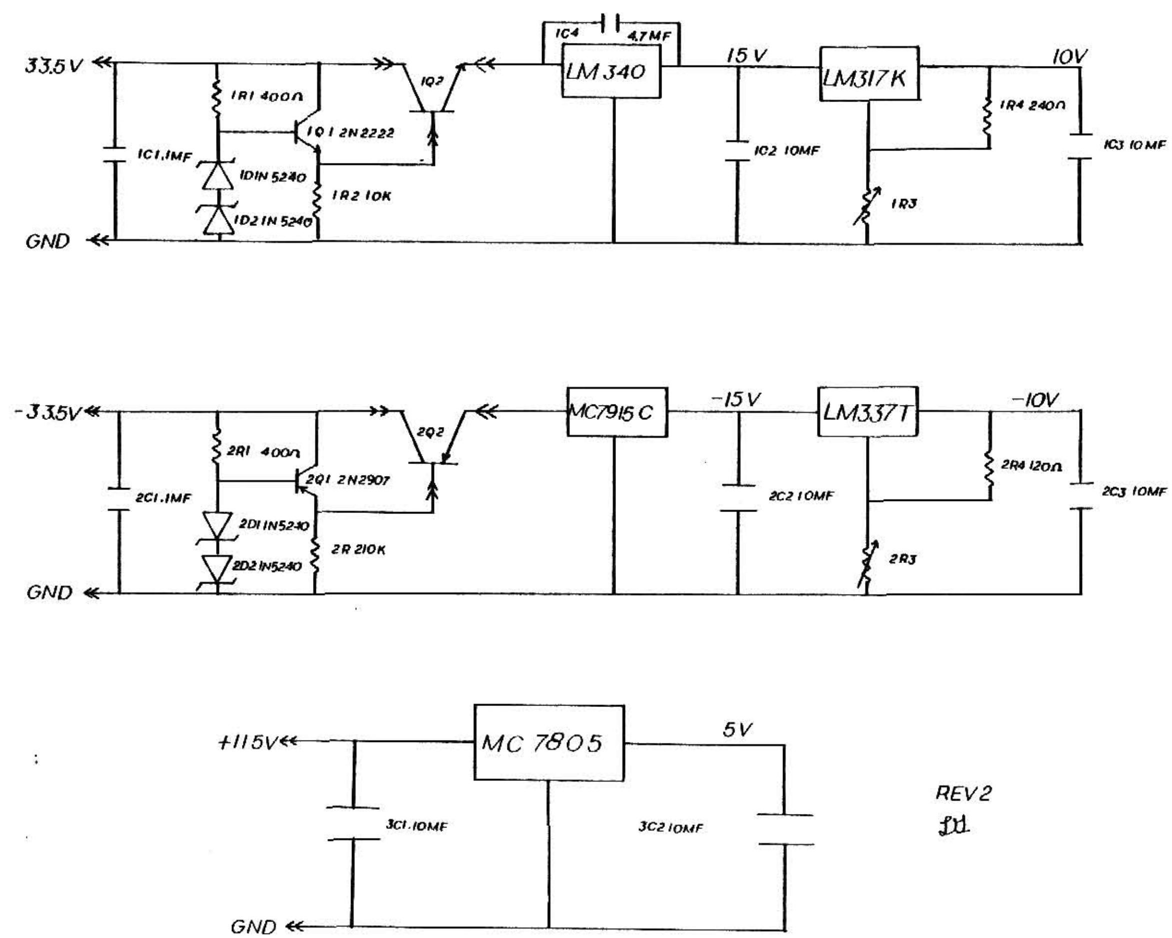

Fig. 2.3.A Power Supply Circuit

2.4 PACKAGING

2.4.1 Packaging Considerations

The DAM is packaged in a TM plug-in module. With the complexity of the electronics and the physical limitations of this plug-in module, the packaging of the instrument proved to be time consuming.

The first problem addressed was to determine the optimum number of different printed circuit boards to design. This was crucial because if too many boards had been designed then there would not have been enough space in the package. Consequently, if the boards are crowded, then the circuits might not work properly. Thus, after a period of trial and error, the optimum number of boards in the package was determined to be four.

The DAM circuit is now divided among the four boards in the following manner. Board one has the amplifier, the comparator and the filter for five channels. Board two has the amplifier, the comparator and the filter for the remaining three channels. Board three has the S/H of each channel plus the Multiplexer, the Programmable Timer and the A/D. Finally, Board Four has the power supply circuit. Power is delivered to the rest of the boards by interconnections between each respective board. There are also similar interconnections between boards 1 and 3, and between boards 2 and 3 in order to have continuity in the circuit.

Unfortunately, because of limited space in the front-panel (Fig. 2.4.A) not all the channels have the same flexibility, Channels A,B, C and D have a ten turn pot to change the gain of the amplifier, while channels E, F, G and H have a one turn pot. Also the filters in channels A, B and C have variable cut-off frequencies, whereas the rest of the channels have fixed cut-off frequencies.

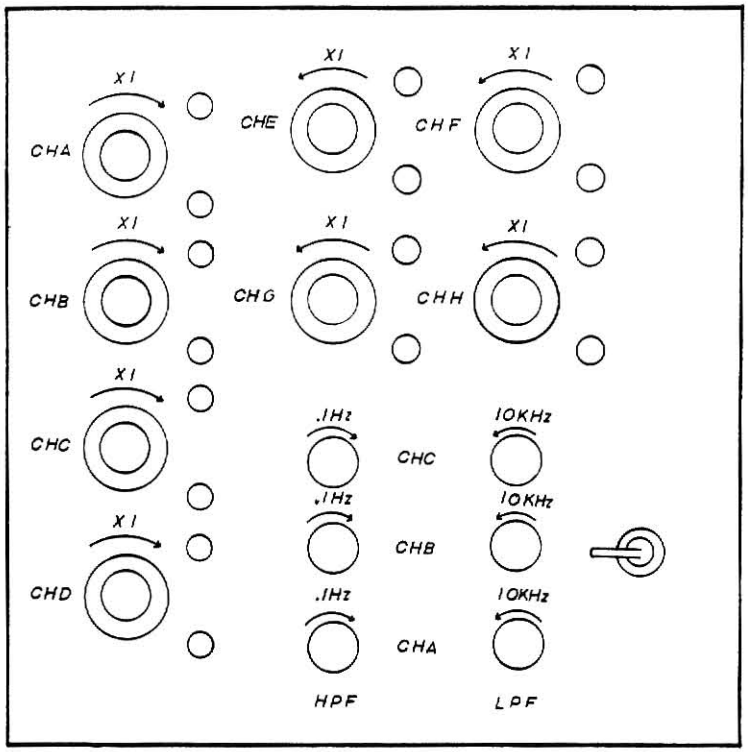

Fig. 2.4.A Front Panel of the DAM

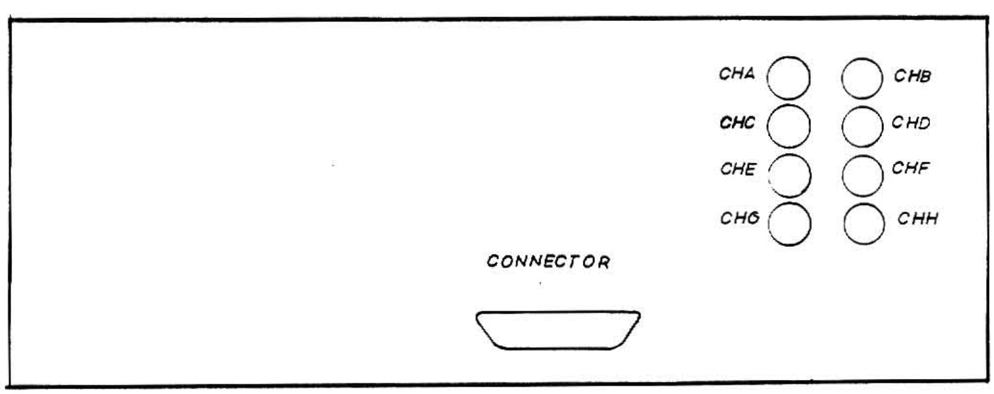

Fig. 2.4.B Back Panel of the DAM

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The Plug-in Module is used in conjunction with a TM503. Therefore, the DMA communicates with the computer and any peripheral device through connectors located on the back panel of the TM503 (see Fig. 2.4.B).

III. EVALUATION OF INSTRUMENT

In order to evaluate the performance of the instrument, one channel of the interfase was wired in a proto board (Fig. 3.1.A) and then each component was evaluated. Because of economical reasons, it was important that the circuit be well designed before making the printed circuit board.

3.1 ANALOG SUBSYSTEM

3.1.1 Evaluation of Analog Subsystem

The first device that was evaluated was the amplifier (AD 521). The input of the AMP was connected to the output of a completely divorced 503 Frequency Generator. While changing the gain of the AMP, the input and output of the device was compared on a 5403 oscilloscope. This signal comparison proved to be an excellent evaluation procedure.

The evaluation of the 9.8 V detector was accomplished as follows. The gain of the AMP was set to x10. The input to the AD521 was set to a voltage of 0.6 V peak-to-peak plus a dc offset voltage of 0.45 Vdc. The maximum voltage at the output of the AMP was 10.5 V. As expected, the LED detector was turned on. The evaluation of the -9.8 Vdc detector was accomplished in a similar fashion as for the 9.8 Vdc detector. Finally the overall performance of the comparator circuit was tested by injecting a 1.05 V peak voltage into the AMP. The frequency of the signal was changed from .3 Hz to 100 KHz. Both LED's were turned on at all frequencies. These LED's turned off when the peak voltages at the input of the comparator circuit was under 9.8 V and above -9.8 V. Also the signal was not distorted when it was within the +9.8 and -9.8 Vdc range.

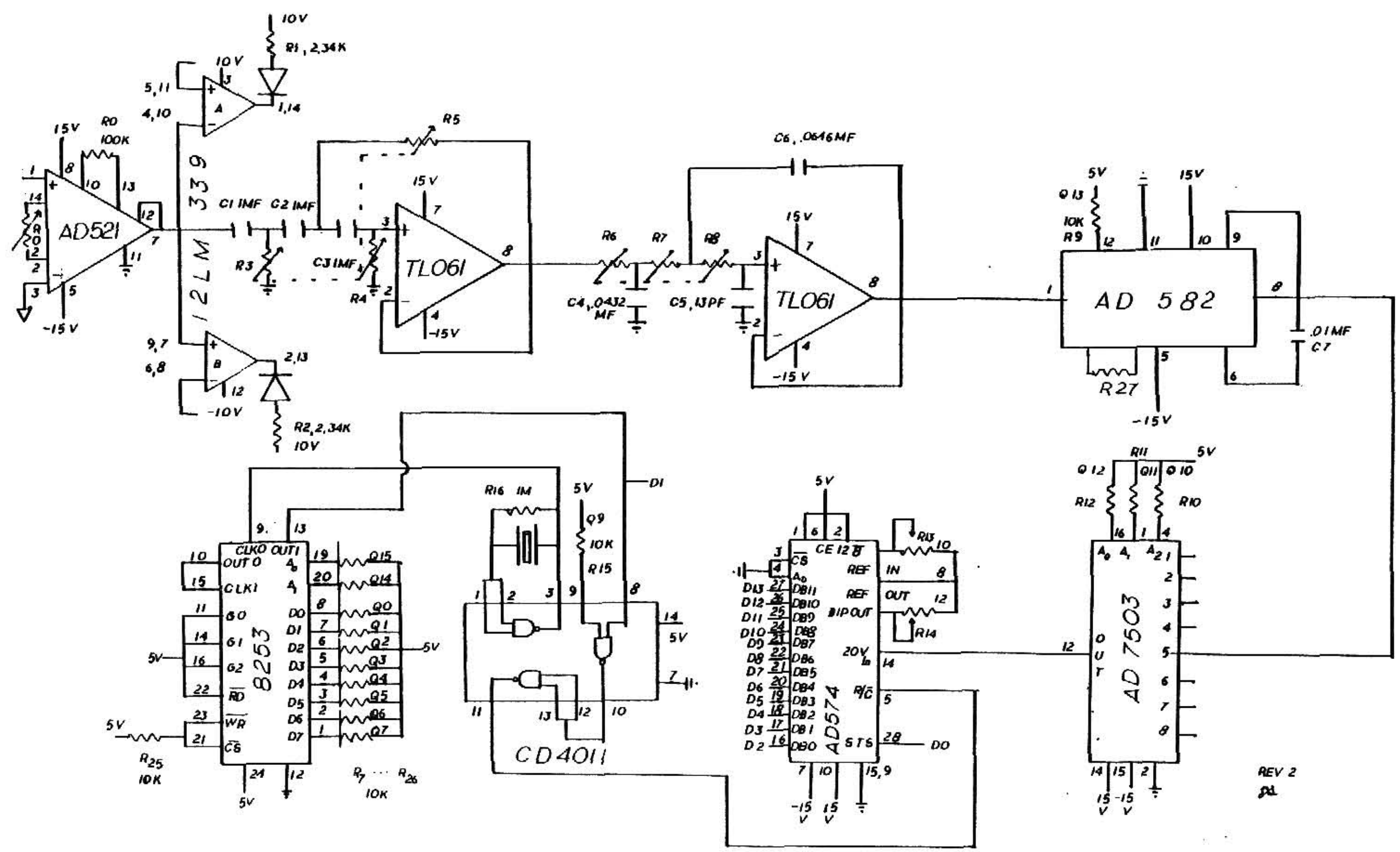

Fig. 3.1.A One Complete Channel of DAM

The filters were evaluated by two different methods. First, the AMP gain was set to one, and injected with a 4 V peak-to-peak signal into the input of the Instrumentation Amplifier using a HP3575 gain phase meter the cut-off frequencies were determined. The second procedure was identical to the first except that the cut-off frequencies were determined with a 5403 oscilloscope. The advantage of using the oscilloscope over the gain phase meter was that distortion, if any, was observable.

The final device which was evaluated was the Sample/Hold. A signal was injected into the input so as to compare the input and output with a 5403 oscilloscope. When in the sample state it was important to make sure that there was no distortion.

In the hold state, the output was checked with an oscilloscope and a digital voltmeter to assure that it was a D.C. voltage and that it stayed constant for a minimum of 2 seconds.

The results of the evaluation test were good, except for one important detail. When the voltage output from the AMP was not within the voltage range of +9.8 Vdc and -9.8 Vdc, the signal was distorted. This was not of much concern because the A/D can only work within the +10 Vdc and -10 Vdc range, and only .4 V are affected.

3.2 DIGITAL SUBSYSTEM

3.2.1 Evaluation of Digital Subsystem

In this section an evaluation of the digital section is described. The components in this section are controlled digitally; therefore, it is necessary to program the HP9845 to control the device. In this section no explanation of the program used will be offered. But, in Section 3.3 the programming will be explained.

The first device to be evaluated in this section is the MUX. This was done by first injecting a signal into its input. In order to detect any distortion in the signal the input and output signals were monitored with a oscilloscope. Again, the controls of the MUX were made by the HP9845. The Anlog-to-Digital converter was tested by putting a DC Voltage signal into the input. Then, controlling the chip with the minicomputer the A/D procedure was performed and the result was printed on the screen of the HP9845. The result was then compared with the actual value.

The last device to be assessed is the Programmable Timer. To evaluate the device the 8253 chip was programmed to set pulses at frequencies from 3 Hz to 500 Hz. The output of the 8253 was then connected to the A/D, in order to sample a 5 Vdc signal. The result of the conversion was compared to the 5 Vdc value satisfactorily. Again, the output of the A/D was printed on the CRT of the HP9845.

The performance of the individual devices was considered quite adequate. But, it is not possible to truly evaluate the instrument, until a program is developed that will allow the circuit (both digital and analog) to work as a unit. This will be described in Section 3.4.

3.3 POWER SUPPLY

3.3.1 Evaluation of Power Supply

The evaluation in this section consists of making certain that the power supply voltages are the required values, are properly regulated, and that the chips can deliver sufficient current.

In order to evaluate the circuit, Fig. 2.3.A was wired in a bread board and connected to the TM503. The output voltages of the power supply circuit were checked with a TM5403 oscilloscope. The predicted output voltages and ripple voltage agreed with the actual values. The final step was to determine if the chips could deliver enough current (see Table 2.3.1.A). This was demonstrated by connecting the proper resistor from each output of the regulators to ground. The resistor values were such that the current delivered was approximately .5 A for every chip. Because the chips could deliver .5 A for several hours it was assumed that they would deliver enough current to the instrument.

3.4 TEST EXAMPLE

3.4.1 Illustration of a General Test

As was explained in Section 3.3, in order to truly evaluate the instrument, it is necessary to develop a program that will control the instrument as a whole. In this section a program is described which will accomplish this.

Before explaining how the program operates it is necessary to understand the input and output word. The input word is illustrated in Table 3.4.A. The first 8 bits (Q0-Q7)

Q13	Q12	Q11	Q10	Q9	Q8	Q7	Q6	Q5	Q4	Q3	Q3	Q1	Q0
S/H	A0	A1	X	$R/\overline{C}$	CS	D7	D6	D5	D4	D3	D2	D1	D0
	MA2	MA1	MA0										

Table 3.4.A Control Input Word from the HP9845 Computer

are used to operate the 8253. In order to get the 8253 to function correctly the proper mode must be selected for the proper counters. Then the value to be counted must be loaded into the counter. Table 3.4.B illustrates the word format necessary to select the mode for each counter. The mode of operation for counter 0 is 3, the mode of operation for counter 1 is 2. For more detail in the operation of the operation of the 8253 see Ref. 4.

D7	D6	D5	D4	D3	D2	D1	D0
SC1	SC0	RL1	RL0	M2	M1	M0	BCD

Table 3.4.B Word Format for the 8253

Going back to the input word illustrated in Table 3.4.A, Q8 selects the 8253, while Q9 starts the conversion of the AD574JD. The function of bits Q11 and Q12 are two fold. First, with bit Q10, they select the channel to be analyzed. Secondly, in conjunction with bits Q8, Q7 and Q6, they select the counter to be programmed.

With the above information it is possible to understand how the HP9845 can talk to the instrument. In addition, it is also possible for the DAM to talk to the HP9845. This is done with the output word (Table 3.4.C). First D0 is connected to the 8253 output, in order to detect the pulse from the 8253. D1 is connected to the STS pin of the AD574JD. This is necessary to determine when the A/D has finished with its conversion. Finally, D2-D13 contain the digital information, where D2 is the least significant bit and D13 is the most significant bit.

D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
DB11	DB10	DB9	DB8	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	STS	CLK1

Table 3.4.C Control output word to the 9845

Once the input and output words have been explained it is possible to better understand the program. The program allows the user to choose among the following features:

1. Selection of channel to be sampled
2. Number of samples
3. Sampling Frequency
4. Request for Hard Copy
5. Request for plot of data

The program can be divided into two sections; namely, the Basic Language Section and the Assembly Language Section. In the Basic Language Section the user decides which features to use. The Basic Language section then programs the 8253. Next, the Assembly Language Section samples the signal and stores the information. The Basic Language rearranges the stored values. More details of the program are given in the flow chart (Fig. 3.4.A-3.4.G) or the program listing (Fig. 3.4.H-3.4.J).

An example of the output is shown in Table 3.4.D and Fig. 3.4. This represents the sampling of a respiratory signal, where Table 3.4.D contains the numerical values and Fig. 3.4. illustrates the plots of the numerical values. As can be seen from the tables the results are in close agreement.

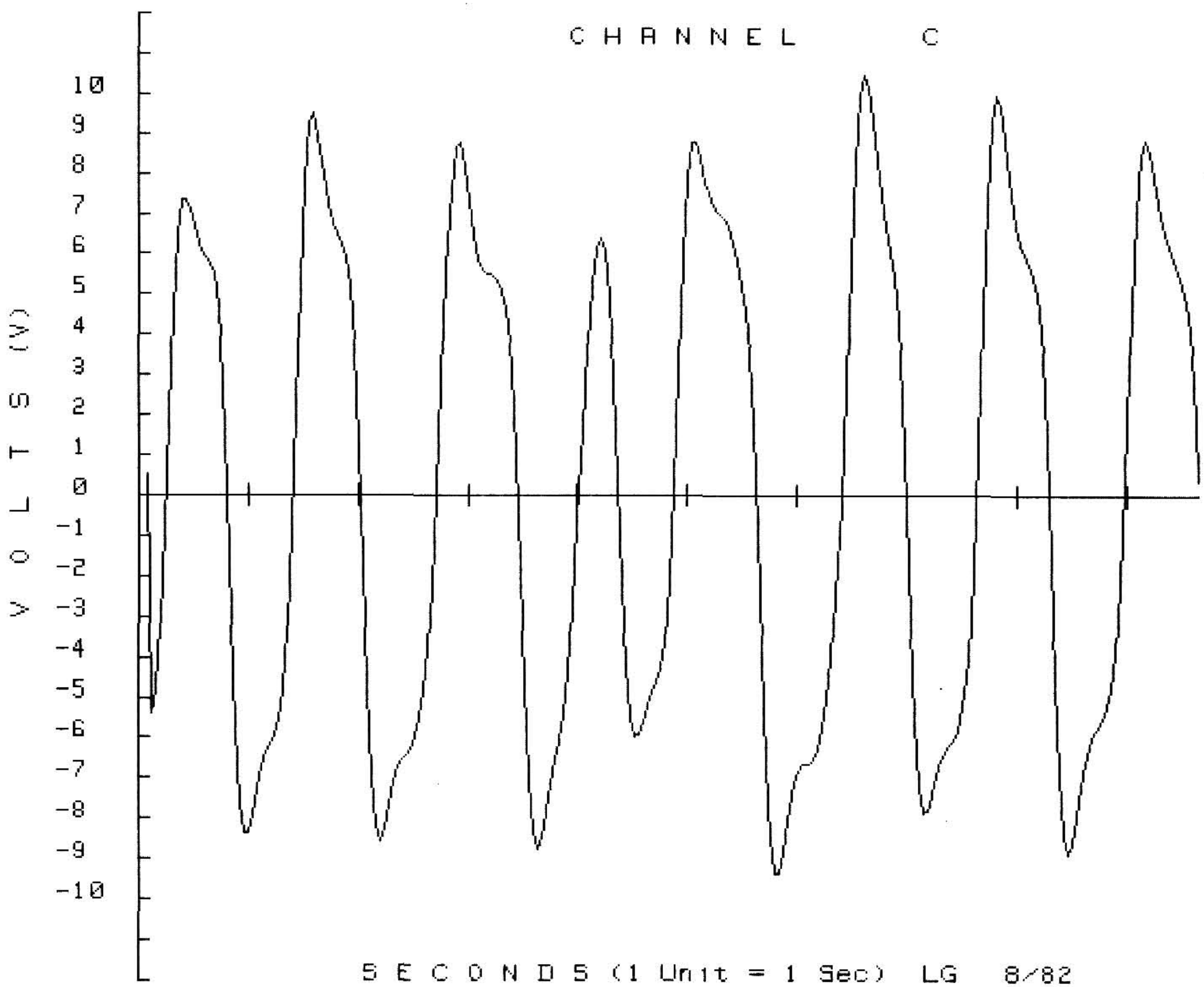

Fig. 3.4. Output Graph of Flow Signal (150 Samples/Channel, 50 Hz Sampling frequency)

******************************* VOLTS (V) *************************************

.53	-5.41	-4.78	-3.15	-.82	1.96	4.58	6.47	7.34	7.37	6.91	6.44
6.09	5.92	5.78	5.52	4.68	2.86	.07	-3.06	-5.78	-7.59	-8.37	
-8.35	-7.86	-7.25	-6.73	-6.37	-6.14	-5.92	-5.55	-4.79	-3.30	-.87	
2.18	5.30	7.82	9.25	9.51	8.90	8.00	7.23	6.77	6.48	6.24	
5.92	5.21	3.72	1.27	-1.79	-4.76	-6.97	-8.22	-8.55	-8.24	-7.66	
-7.09	-6.70	-6.54	-6.46	-6.31	-5.98	-5.48	-4.79	-3.80	-2.26	.03	
2.84	5.59	7.61	8.66	8.77	8.19	7.30	6.46	5.88	5.59	5.50	
5.48	5.41	5.22	4.87	4.30	3.16	1.02	-1.83	-4.72	-7.01	-8.36	
-8.78	-8.48	-7.84	-7.16	-6.58	-6.07	-5.41	-4.37	-2.77	-.64	1.64	
3.68	5.23	6.12	6.42	6.07	4.92	2.91	.32	-2.24	-4.25	-5.49	
-5.96	-5.92	-5.59	-5.19	-4.87	-4.61	-4.28	-3.60	-2.15	.22	3.19	
5.97	7.86	8.76	8.77	8.35	7.80	7.36	7.09	6.96	6.85	6.64	
6.30	5.81	5.23	4.54	3.52	1.74	-.90	-3.93	-6.64	-8.50	-9.35	
-9.34	-8.81	-8.06	-7.38	-6.91	-6.70	-6.65	-6.65	-6.55	-6.27	-5.77	
-5.03	-4.01	-2.48	-.19	2.73	5.79	8.31	9.92	10.47	10.15	9.31	
8.34	7.43	6.68	6.05	5.41	4.34	2.39	-.31	-3.18	-5.60	-7.19	
-7.87	-7.84	-7.41	-6.93	-6.56	-6.33	-6.21	-6.09	-5.83	-5.25	-4.06	
-1.89	1.18	4.51	7.36	9.24	9.96	9.69	8.84	7.86	7.01	6.44	
6.09	5.85	5.59	5.21	4.62	3.47	1.37	-1.51	-4.52	-6.94	-8.42	
-8.90	-8.62	-7.94	-7.21	-6.61	-6.21	-5.89	-5.63	-5.38	-5.01	-4.36	
-3.12	-1.00	1.81	4.70	7.03	8.44	8.83	8.53	7.92	7.26	6.74	
6.34	6.02	5.70	5.38	5.02	4.48	3.52	1.83	-.58	-3.23	-5.55	
-7.16	-7.96	-8.07	-7.75	-7.25	-6.76						

Table 3.4.D. Numerical Output of Flow Signal (250 samples at 25 Hz sampling frequency)

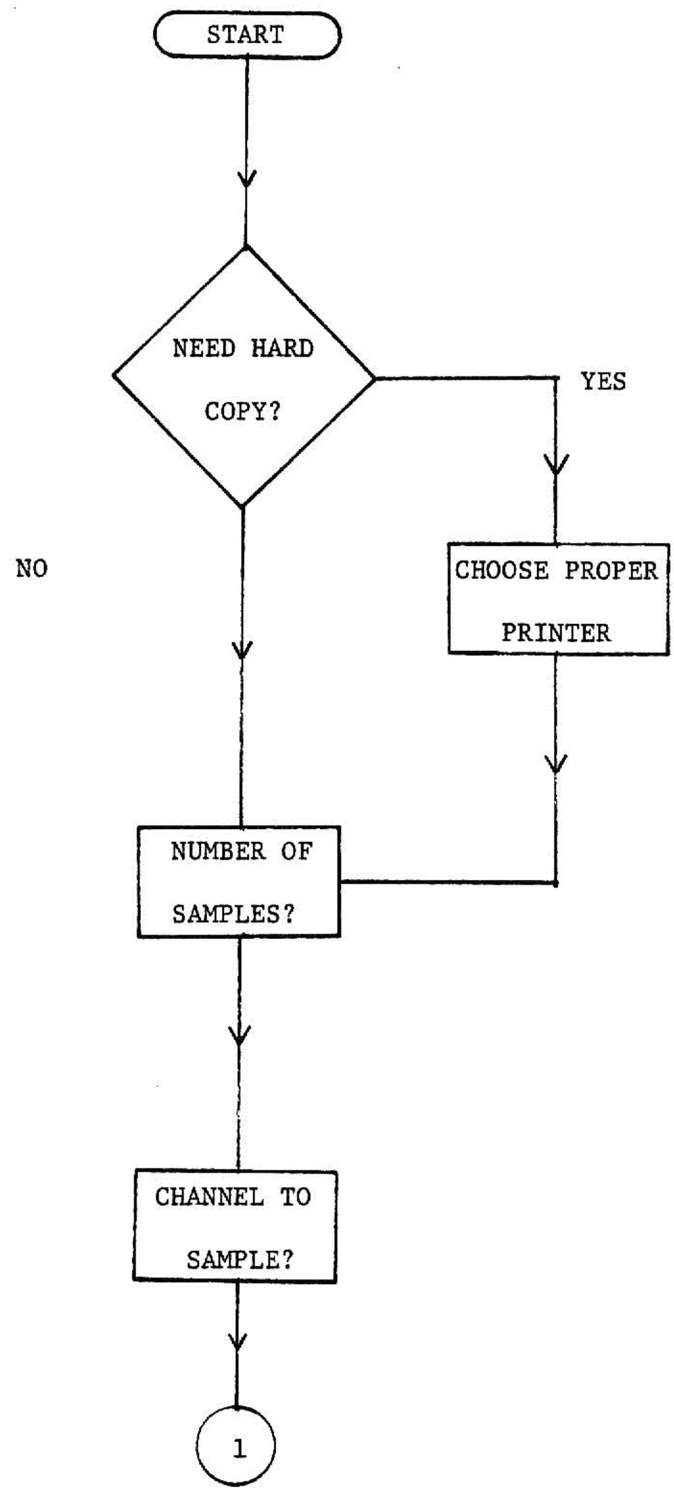

Fig. 3.4.A Basic Language Block Diagram Part I.

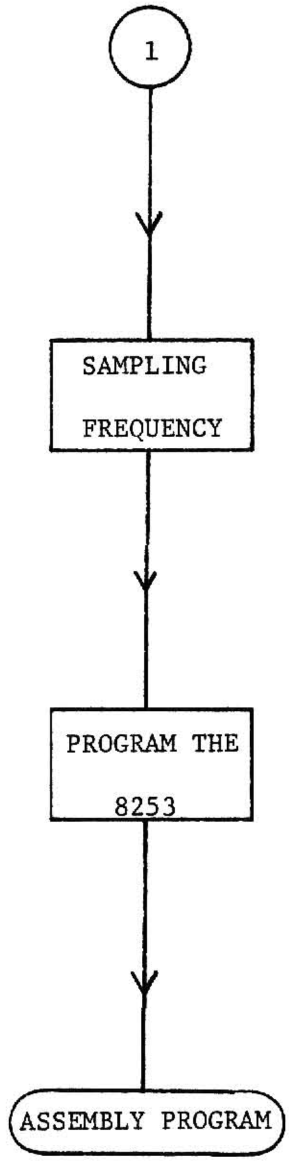

Fig. 3.4.B Basic Language Block Diagram Part II

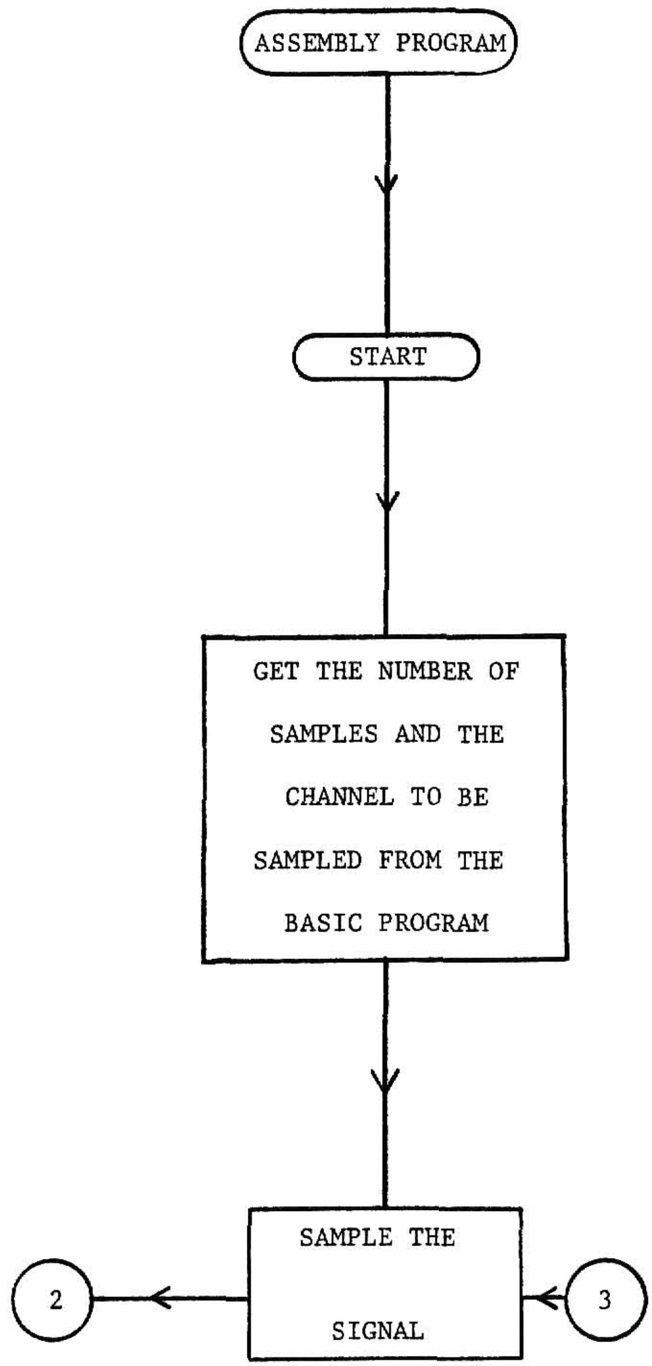

Fig. 3.4.C Assembly Language Block Diagram Part I.

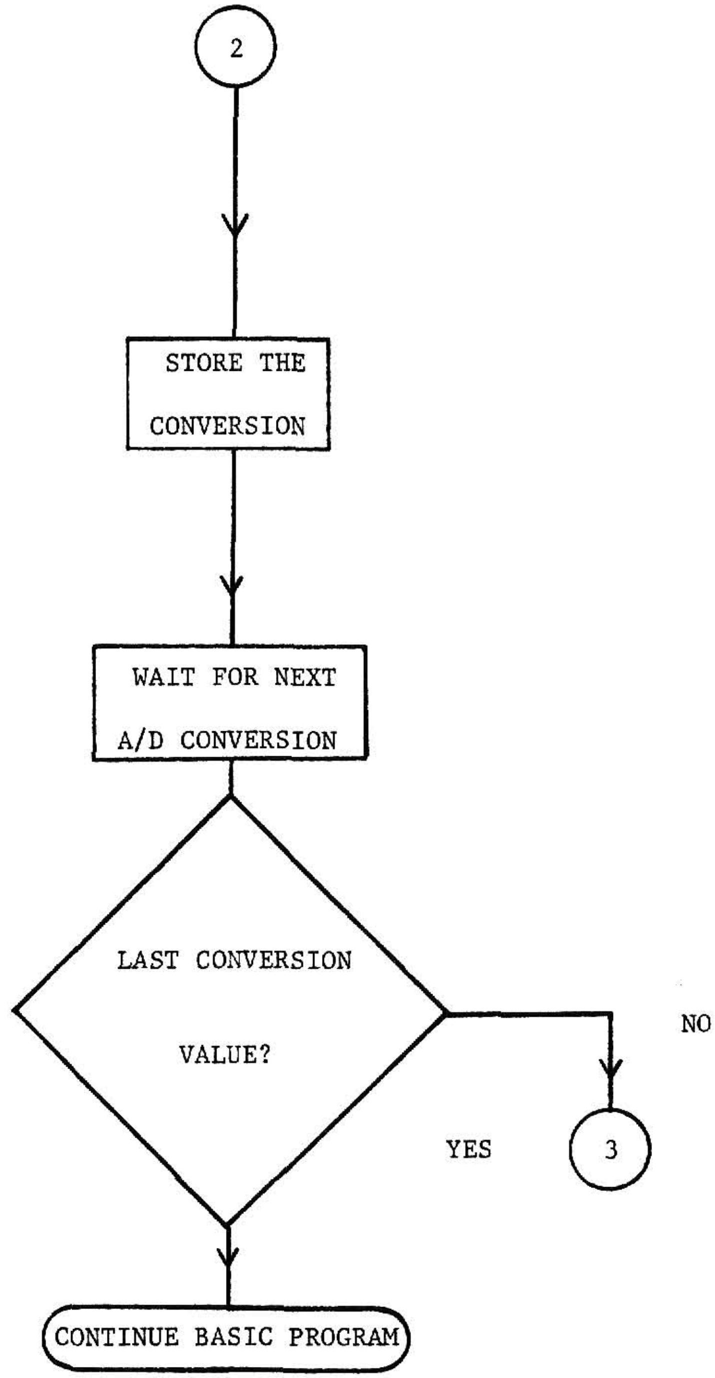

Fig. 3.4.D Assembly Language Block Diagram Part II.

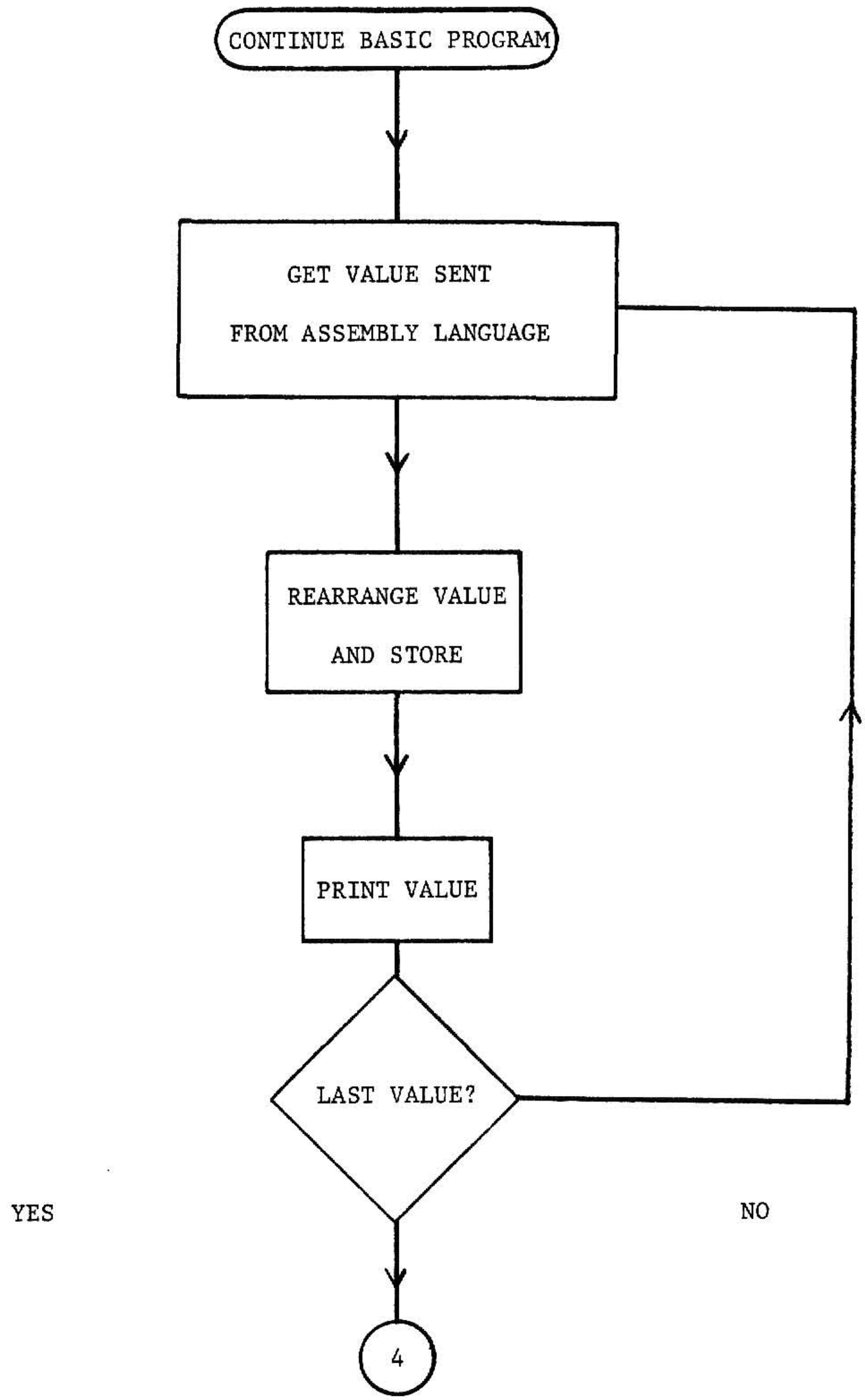

Fig. 3.4.E Basic Language Block Diagram Part III.

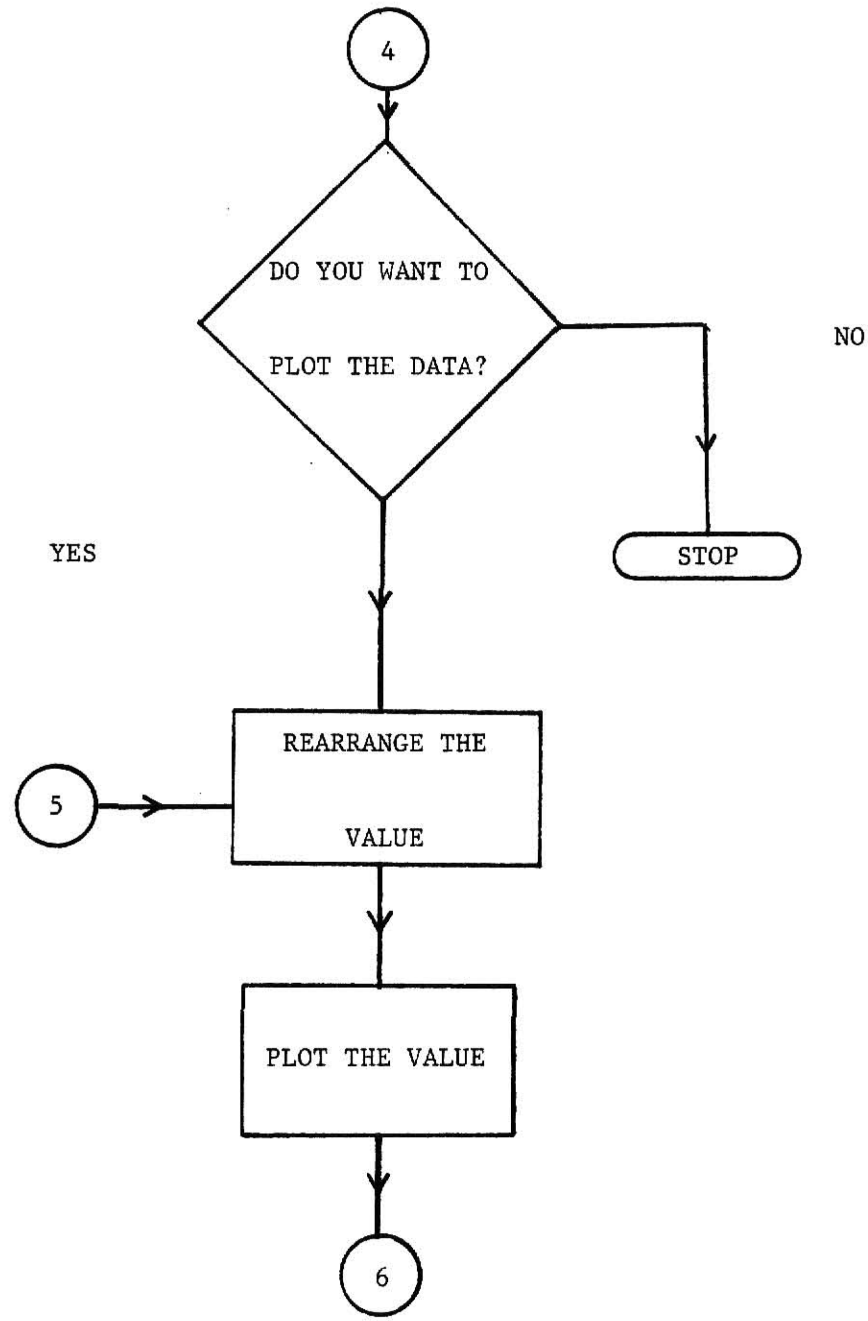

Fig. 3.4.F Basic Language Block Diagram Part IV.

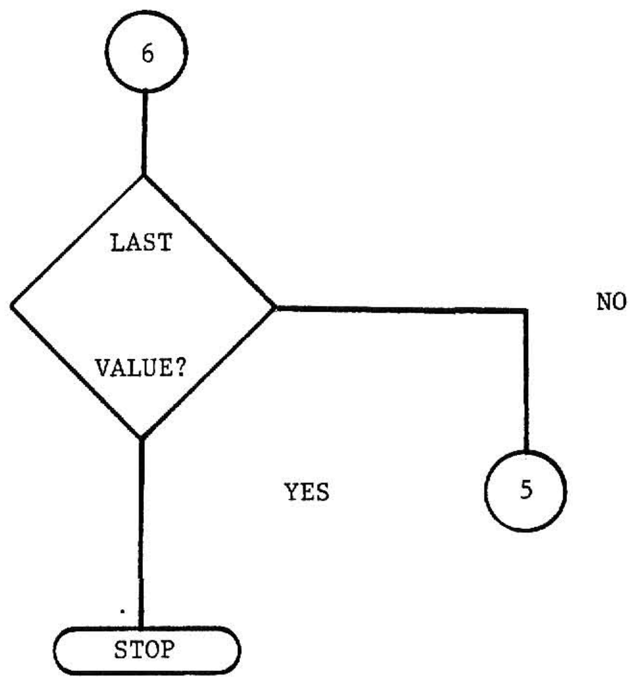

FIg. 3.4.G Basic Language Block Diagram Part V.

Program Cow

```
10   !  THIS PROGRAM ALLOWS TO CHECK THE DAM BUILT BY LG
20   !  THIS IS ONLY FOR ONE CHANNEL
30   !  THE PROGRAM LETS THE USER CHOOSE CHANNEL TO BE SAMPLED
40   !  OPERATOR CAN CHOOSE SAMPLING FREQUENCY
50   !  OPERATOR CAN ALSO CHOOSE THE NUMBER OF SAMPLES
60   !  BUT ALSO OPERATOR CAN GET A HARD COPY OF DATA
70   !  DATE 8/5/82
80   !  NAME COW
90   ICOM 600                        !Set space for memory
100  INPUT "DO YOU WANT HARD COPY (Y/N)?",Q$ !Do you need hard copy?
110  IF Q$="Y" THEN 140
120  PRINTER IS 16
130  GOTO 150
140  PRINTER IS 7,1
150  INTEGER Data1                   !Variable used for printing and plotting dat
160  INTEGER Sa                      !Variable containing number of samples
170  INTEGER Ch1                     !Variable containing channel to be sampled
180  Data1=1                         !Initialize location of first valid data
190  INTEGER Line1(1000)              !Array containig data
200  INPUT "ENTER NUMBER OFF SAMPLES",Sa !Choose the number of samples
210  INPUT "CHANNEL TO BE SAMPLED",Ch1$  !Choose channel to be sampled
220  IF Ch1$="A" THEN Ch1=15359       !Number that has the channel to be sampled
230  IF Ch1$="B" THEN Ch1=13311
240  IF Ch1$="C" THEN Ch1=11263
250  IF Ch1$="D" THEN Ch1=9215
260  IF Ch1$="E" THEN Ch1=14335
270  IF Ch1$="F" THEN Ch1=16383
280  IF Ch1$="G" THEN Ch1=10239
290  IF Ch1$="H" THEN Ch1=12287
300  INPUT "ENTER SAMPLING FREQUENCY (10 TO 500 HZ )",S
310  X=INT(500000/S)                 !Value to be entered in the 8253
320  IF X<256 THEN 360               !Is the number more than 8 bits long
330  Fm=INT(X/256)                   !Obtain the msb if value is more than 8 bits
340  Fl=X-256*Fm                     !Obtain the lsb if value is more than 8 bits
350  GOTO 380
360  Fm=0                            !Value is less than 8 bits long
370  Fl=X
380  IASSEMBLE Tester                !Name assembly program
390  WRITE IO 2,6;705                !11110100111110 Set counter 0 to mode 3
400  WRITE IO 2,6;961                !11110000111110 Allow s.s. to be reached
410  WRITE IO 2,6;713                !11110100110110 Allow s.s. to be reached
420  WRITE IO 2,6;643                !11110101111100 Set counter 1 to mode 2
430  WRITE IO 2,6;899                !11110001111100 Allow s.s.
440  WRITE IO 2,6;651                !11110101110100 Allow s.s.
450  WRITE IO 2,6;6909               !10010100000010 lsb of counter 0
460  WRITE IO 2,6;7165               !10010000000010 Allow s.s.
470  WRITE IO 2,6;6909               !10010100000000 Allow s.s.
480  WRITE IO 2,6;6911               !10010000000000 msb of counter 0
490  WRITE IO 2,6;7167               !10010000000000 Allow s.s.
500  WRITE IO 2,6;6911               !10010100000000 Allow s.s.
510  WRITE IO 2,6;16383-(13568+Fl) !11010100000000+Fl lsb of cnt.1 remmember 1'
complement
520  WRITE IO 2,6;16383-(13312+Fl) !11010000000000+FlAllow s.s.
530  WRITE IO 2,6;16383-(13568+Fl) !11010100000000+FlAllow s.s.
540  WRITE IO 2,6;16383-(13568+Fm) !11010100000000+Fm msb of cnt.1 remmember 1'
complement
550  WRITE IO 2,6;16383-(13312+Fm) !11010000000000+FmAllow s.s.
560  WRITE IO 2,6;16383-(13568+Fm) !11010100000000+FmAllow s.s.
570  IPAUSE ON                       !Allow to step in assembly language
580  ICALL Test(Line1(*),Sa,Ch1)     !Call assembly language program
```

Fig. 3.4.H Program Listing Part I

```
590  PRINT "*********************************************************************
************"                              !Set the heading for the data
600  PRINT "****************************** VOLTS (V) ***************************
************"
610  PRINT "*********************************************************************
************"
620  Data1=Data1+1
630  Line1(Data1)=Line1(Data1)+32768-16384      !Rearrenge value from a.p.
640  Volts=(2048-Line1(Data1))*10/1802*-1      !Change the value one final time
650  FIXED 2
660  PRINT Volts;SPA(1);                       !Print the data
670  IF Data1<Sa THEN 620                       !Get another value if not the last value
680  INPUT "DO YOU WANT TO PLOT THE DATA (Y/N)",P1$
690  IF P1$="N" THEN 1080
700  PLOTTER IS 13,"GRAPHICS"                    !Choose plotter to be used
710  ! GRAPHICS
720  LOCATE 15,127,0,100                        !Define area to be scaled
730  SCALE 0,Sa/S,-12,12                        !Scale the area defined above
740  LINE TYPE 1                               !Specify solid lines
750   CSIZE 3                                  !Size of the letters
760   AXES 1,1,0,0                             !Define axis parameters
770   SCALE 0,Sa,-12,12                        !Redefine scale
780  Data1=1                                   !Location of first valid value
790   FIXED 0
800  FOR I=1 TO Sa STEP 1                      !Loop to get value from array and to plot
                                                the value
810  Data1=Data1+1
820  Volts=(2048-Line1(Data1))*10/1802*-1
830  PLOT Data1,Volts                          !Plot the data
840  NEXT I
850  LOCATE 10,150,0,100                        !Relocate the pen
860  SCALE 0,1000,-12,12                       !Redefine scale
870  FOR I=-10 TO 10 STEP 1                    !Loop to label axis
880  MOVE -25,I
890  LABEL I
900  NEXT I
910  MOVE -47,-3                               !Move arm
920  LDIR PI/2                                 !Change direction at which pen is going
                                                to write
930  LABEL "V  O  L  T  S  (V)"                 !Label the units of y axis
940  MOVE 350,11.25                            !Move arm
950  LDIR 0                                    !Change direction at which pen is going
                                                to write
960  LABEL "C H A N N E L",Ch1$                 !Heading of the graph
970  MOVE 200,-12                              !Move arm
980  LDIR 0                                    !Change direction at which pen is going
                                                to write
990  LABEL "S E C O N D S (1 Unit = 1 Sec)"  !Label units of x axis
1000 MOVE 610,-12
1010 LABEL "LG"                                !Miscellaneous Labels
1020 MOVE 670,-12
1030 INPUT "Date?",D$
1040 LABEL D$
1050 MOVE 1000,12                              !Move arm
1060 WAIT 7000
1070 ! EXIT GRAPHICS
1080 END
1090 ! This section is the Machine Language Section
1100 ! ==========================================
1110 ISOURCE NAM Tester                        !Initialize a. p.
```

Fig. 3.4.I Program Listing Part II

```
1120 ISOURCE EXT Get_info,Put_element,Get_value
1130 ISOURCE LIT (40)
1140 ISOURCE Passa:BSS 2
1150 ISOURCE Counter:BSS 2
1160 ISOURCE Del: BSS 2
1170 ISOURCE Int: BSS 2
1180 ISOURCE Chna: BSS 4
1190 ISOURCE Controller:BSS 4
1200 ISOURCE Array_infoa: BSS 30
1210 ISOURCE Elementa:EQU Array_infoa+16
1220 ISOURCE SUB                          !Start a. p.
1230 ISOURCE Vala:INT (*)                  !Initialize variables from main program
1240 ISOURCE Sam:INT
1250 ISOURCE Chana:INT
1260 ISOURCE Test:LDA =Controller         !Get the necesary values from basic
1270 ISOURCE LDB =Sam
1280 ISOURCE JSM Get_value
1290 ISOURCE LDA =Chna
1300 ISOURCE LDB =Chana
1310 ISOURCE JSM Get_value
1320 ISOURCE LDA =2                       !Use a 16 bite input output
1330 ISOURCE STA Pa
1340 ISOURCE LDA =0                       !Reset counter1
1350 ISOURCE STA Counter
1360 ISOURCE Padre: LDA =15360            !0110111111111 Turn s/h on
1370 ISOURCE AND Chna                     !Choose appropiate channel
1380 ISOURCE STA R6
1390 ISOURCE LDA =15                      !Initialize a loop for a time delay
1400 ISOURCE STA Del
1410 ISOURCE Back:DSZ Del                 !Time delay for operational purposes
1420 ISOURCE JMP Back
1430 ISOURCE LDA =7680                    !1110011111111 Set pulse for conversion
1440 ISOURCE AND Chna                     !Choose appropiate channel
1450 ISOURCE STA R6
1460 ISOURCE LDA =7168                    !1110111111111 Return to normal position
1470 ISOURCE AND Chna                     !Choose appropiate channel
1480 ISOURCE STA R6
1490 ISOURCE LDA =Array_infoa             !Begin sending info back to basic
1500 ISOURCE LDB =Vala
1510 ISOURCE JSM Get_info
1520 ISOURCE ISZ Counter
1530 ISOURCE LDA Counter
1540 ISOURCE STA Elementa
1550 ISOURCE LDA R4                       !Get the value and rearenge the value
1560 ISOURCE SAR 2
1570 ISOURCE CMA
1580 ISOURCE STA Passa
1590 ISOURCE LDA =Passa
1600 ISOURCE LDB =Array_infoa
1610 ISOURCE JSM Put_element              !Send the value back to basic
1620 ISOURCE Puron:LDA R4                 !Wait for next pulse to appear
1630 ISOURCE SAR 1
1640 ISOURCE SLA Puron
1650 ISOURCE High:LDA R4
1660 ISOURCE SAR 1
1670 ISOURCE RLA High
1680 ISOURCE DSZ Controller               !Is this the last value
1690 ISOURCE JMP Padre
1700 ISOURCE RET 1                        !Back to main program
1710 ISOURCE END Tester
```

Fig. 3.4.J Program Listing Part III

IV. CONCLUSIONS AND SUGGESTED MODIFICATIONS OF INSTRUMENT

4.1 ANALOG SUBSYSTEMS

4.1.1 Results of Analog Subsystems

The performance of the Analog Subsystem proved to be satisfactory. There exist only two minor problems, neither of which affect the performance of the instrument. The first problem is concerned with the detector circuit. This device goes into saturation when the output of the AD521JD is not within the +9.8V and -9.8V range. The only way to eliminate this problem is by changing the power supply voltages delivered to the circuit from +10 V and -10V to +15 V and -15V. In order to accomplish this it is necessary to have more space on boards one and two. This could be accomplished by making the traces thinner on boards one and two. The second problem is concerned with the order of the devices. See Fig. 1.2.D. With this design, if noise, of an undesired frequency, happens to be of a greater magnitude than the input signal, the comparator circuit will be detecting the peak of the noise instead of the peak of the signal. If the filters were inserted in front of the comparator circuit, this problem would be avoided.

4.2 DIGITAL SUBSYSTEMS

4.2.1 Results of Digital Subsystems

Presently, the limiting factor of the total system is the HP9845 computer. The effect of this limitation can be minimized by making the instrument more automated and improving the speed and flexibility of the instrument. In order to make the instrument more automated it would be necessary to add a microprocessor and memory. This would allow for the controlling and storing of information in the same instrument, without depending on the HP9845.

V. BIBLIOGRAPHY

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VI. ACKNOWLEDGMENTS

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APPENDIX

A.1 USER'S GUIDE

A.1.1 System Description

The system is composed of three devices. The controller is the HP9845 computer which also has an internal printer used for plots. The data sets are printed through the HP2631B. In order to allow the system to communicate with the outside world a Data Acquisition Module (DAM) is used. In the following two sections a detailed explanation of how the DAM operates will be given.

A.1.2 Hardware Description

In this section a detailed explanation of the necessary hardware knowledge needed to properly operate the instrument is given.

The degree of flexibility of each channel is explained by the following table:

CHANNEL	CUT OFF FREQUENCY	AMPLIFICATION	S/H CAPABILITY
A	Variable	Fine	Yes
B	Variable	Fine	Yes
C	Variable	Fine	Yes
D	Fixed	Fine	Yes
E	Fixed	Normal	Yes
F	Fixed	Normal	No
G	Fixed	Normal	Yes
H	Fixed	Normal	Yes

Table A.1.2.A Channel Selection

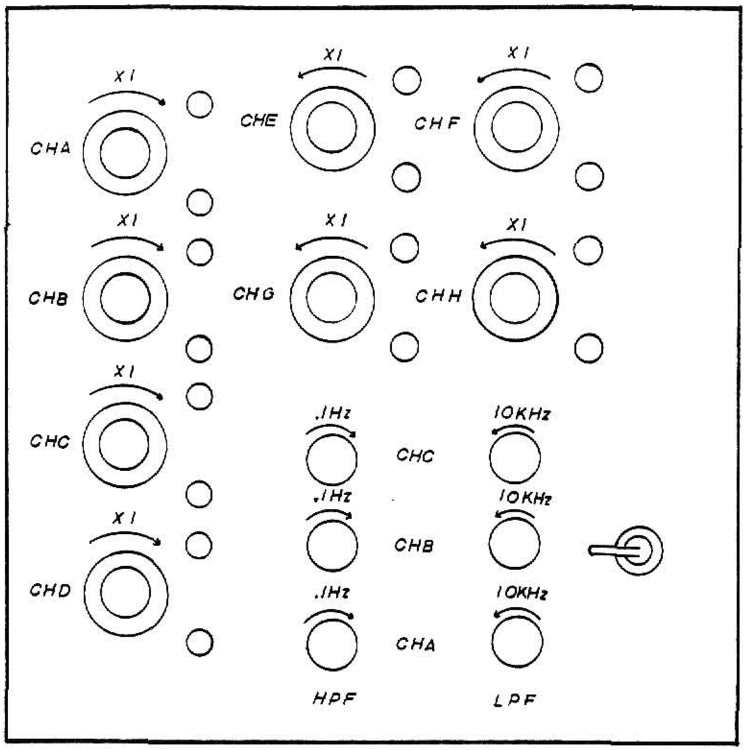

Fig. A.1.2.A Front Panel View

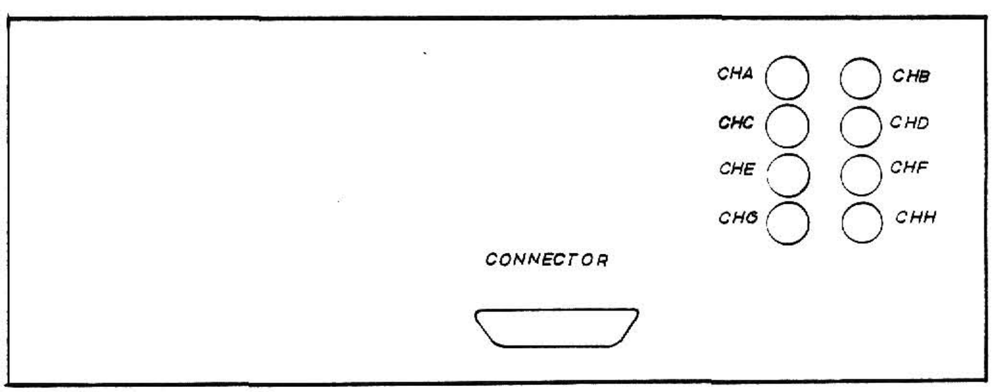

Fig. A.1.2.B Back Panel View

REV I

Two terms in Table A.1.2.A might be confusing. Fine amplification means that the amplification can be in very small steps, while normal amplification refers to larger increments in amplification.

The purpose of each control knob is as follows. Channel A amplification is changed by the ten turn pot labeled as Ch A in Fig. A.1.2. A gain of one is obtained by rotating the control knob to its extreme right. The two LED's in front of this knob turn on when the amplification has reached saturation. The control knobs at the lower center of the panel labeled as Ch A in Fig. A.1.2.A control the cut-off frequencies. The knob at the left controls the low cut-off frequencies (See Table A.1.2.C) while the knob at the right controls the high cut-off frequencies (See Table A.1.2.B). Channels B and C are organized in exactly the same way as channel A. In order for the instrument to pass

NUMBER OF NOTCHES FROM ITS EXTREME LEFT POSITION	CUT-OFF FREQUENCIES
0	10 K
1	3 K
2	1 K
3	300
4	100
5	30
6	10
7	3

Table A.1.2.B. High Cut-off Frequencies.

NUMBER OF NOTCHES FROM ITS EXTREME RIGHT POSITION	CUT-OFF FREQUENCIES
0	.1
1	.5
2	1.5
3	5.0
4	15
5	50
6	100
7	150

Table A.1.2.C. Low Cut-off Frequencies

D.C. values it was necessary to by-pass the Band-Pass Filter. This was done by the use of a switch. When in the right position the filter is bypassed and when in the left position the instrument filters out the D.C. components.

Channels D-H do not have variable cut-off filters but do have variable amplification. Channel D has a 10 turn pot. Channels E-H have a one turn pot. In order to obtain a gain of one for channels E-H the control pot should be turned to its extreme left.

The connections between the peripheral devices and the interface are made through the coaxial interconnections located in the upper right corner of the backpanel of the interface. See Fig. A.1.2.B. Finally, the connection between the computer and the interface are made through the fifty pin subminiature connector.

A.1.3. Software Description

In this section a detailed explanation of the necessary program knowledge needed to properly program the DAM is considered.

The first step is to understand the way the DAM communicates with the HP9845. This is accomplished through the input and output words. The input word is illustrated in Table A.1.3.A. The first eight bits (Q0-Q7) are used to operate the 8253. In order to get the 8253 to function correctly the proper mode must be selected for the proper counter. Then the value to be counted must be loaded into the counter.

Q13	Q12	Q11	Q10	Q9	Q8	Q7	Q6	Q5	Q4	Q3	Q2	Q1	Q0
S/H	A0	A1	X	R/$\bar{C}$	CS	D7	D6	D5	D4	D3	D2	D1	D0
	MA2	MA1	MA0										

Table A.1.3.A. Control input word from the HP9845.

Table A.1.3.A illustrates the word format necessary to select the mode for each counter. The mode of operation for counter 0 is three, the mode of operation for counter 1 is two. Counter 2 is not used. Details

D7	D6	D5	D4	D3	D2	D1	D0
SC1	SC0	RL1	RL0	M2	M1	M0	BCD

Table A.1.3.B Word Format for the 8253

for the operation of the 8253 is available in another source (4). Going back to the input word illustrated in Table A.1.3.A, Q8 selects the

8253, while Q9 starts the conversion of the AD574JD. The function of bits Q11 and Q12 are two fold. First, with bit Q10, they select the channel to be analyzed. Secondly, in conjunction with bits Q8, Q7 and Q6, they select the counter to be programmed.

In addition it is also possible for the DAM to talk to the HP9845. This is done with the output word (Table A.1.3.C). First D0 is connected to the 8253. D1 is connected to the STS pin of the AD574JD. This is necessary to determine when the A/D has finished with its conversion. Finally D2-D13 contain the digital information, where D2 is the least significant bit.

D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
DB11	DB10	DB9	DB8	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	STS	CLK1

Table A.1.3.C. Control Word to the HP9845.

With the DAM and HP9845 communication links established, programming of the HP9845 is addressed.

The first step is to select the printer, the number of samples, and the three channels to be sampled. See Fig. A.1.3.A and Fig. A.1.3.B. The next stage is to program the 8253 with the required sampling frequency. This is illustrated in Fig. A.1.3.B.

The Sample and Hold, Multiplexer, and the A/D are controlled through an Assembly Language Program (ALP) (Fig. A.1.3.E and Fig. A.1.3.F). Values are sent back and forth from the Basic to the Assembly Language programs through the ICALL statement shown in Fig. A.1.3.B. The conversion value is stored by an Assembly Language constant. It is necessary to send back the value to Basic through the ICALL statement. This value does not represent an actual voltage since -10 V is 0 and +10 V is 4095. Therefore, it is necessary for the Basic Program to rearrange the value in order to obtain the actual voltage. Once this is accomplished the value is plotted upon request (See Fig. A.1.3.C - Fig. A.1.3.E). A flow chart of the program is illustrated in Fig. A.1.3.E.

A.1.4 User Instructions

The instructions given below are for the particular application of the DAM. The DAM is used to monitor CO2, O2 and flow signals on a breath-by-breath basis from appropriate transducers properly instrumented on the subject, a calf exercising on a treadmill.

1 DAM

2 HP 9845B

3 Printer (HP 2631)

4 Plotter (HP 9845)

5 Mass Spectrometer, Perkin-Elmer Medical Gas Analyzer

6 Flowmeter

7 Treadmill

8 Subject

It is very strongly recommended that the user refer to the previous three sections prior to continuing with the user instructions.

1. Position the calf on the treadmill and properly instrument it with the transducer. Determine the proper and available outputs from the Mass Spectrometer (CO2 and O2 concentration) and the flowmeter.

Program Vaca

```
10   !  THIS PROGRAM ALLOWS TO CHECK THE DAM BUILT BY LG
20   !  THIS SAMPLES THREE CHANNELS IN ONE RUN
30   !  THE PROGRAM LETS THE USER CHOOSE CHANNELS TO BE SAMPLED
40   !  OPERATOR CAN CHOOSE SAMPLING FREQUENCY
50   !  OPERATOR CAN ALSO CHOOSE THE NUMBER OF SAMPLES
60   !  ALSO OPERATOR CAN GET A HARD COPY OF DATA IF HE WANTS
70   !  DATE 8/5/82
80   !  NAME VACA
90   !  NOTE:       CHANNEL 1 MEANS FIRST CHANNEL TO BE SAMPLED
100  !              CHANNEL 2 MEANS SECOND CHANNEL SAMPLED
110  !              CHANNEL 3 MEANS THIRD CHANNEL TO BE SAMPLED
120  ICOM 600                      !Set space for memory
130  INPUT "DO YOU WANT HARD COPY (Y/N)?",Q$ !Do you need hard copy?
140  IF Q$="Y" THEN 170
150  PRINTER IS 16
160  GOTO 180
170  PRINTER IS 7,1
180  INTEGER Data1                 !Variables used for printing and plotting dat
a                                    for channels
190  INTEGER Data2
200  INTEGER Data3
210  INTEGER Sa                    !Variable containing number of samples
220  INTEGER Ch1                   !Variables containing channel to be sampled
230  INTEGER Ch2
240  INTEGER Ch3
250  Data1=1                       !Initialize location of first valid data for
                                    channels 1,2 and 3
260  Data2=1
270  Data3=1
280  INTEGER Line1(1000)            !Array containig data for channels 1,2 and
290  INTEGER Line2(1000)
300  INTEGER Line3(1000)
310  INPUT "ENTER NUMBER OFF SAMPLES",Sa !Choose the number of samples
320  INPUT "CHANNEL TO BE SAMPLED",Ch1$  !Choose channel to be sampled for
                                         channel 1
330  IF Ch1$="A" THEN Ch1=15359      !Number that has the channel to be sampled
340  IF Ch1$="B" THEN Ch1=13311
350  IF Ch1$="C" THEN Ch1=11263
360  IF Ch1$="D" THEN Ch1=9215
370  IF Ch1$="E" THEN Ch1=14335
380  IF Ch1$="F" THEN Ch1=16383
390  IF Ch1$="G" THEN Ch1=10239
400  IF Ch1$="H" THEN Ch1=12287
410  INPUT "CHANNEL TO BE SAMPLED",Ch2$   !Choose channel to be sampled for
                                          channel 2
420  IF Ch2$="A" THEN Ch2=15359       !Number that has the channel to be sampled
430  IF Ch2$="B" THEN Ch2=13311
440  IF Ch2$="C" THEN Ch2=11263
450  IF Ch2$="D" THEN Ch2=9215
460  IF Ch2$="E" THEN Ch2=14335
470  IF Ch2$="F" THEN Ch2=16383
480  IF Ch2$="G" THEN Ch2=10239
490  IF Ch2$="H" THEN Ch2=12287
500  INPUT "CHANNEL TO BE SAMPLED",Ch3$   !Choose channel to be sampled for
                                          channel 3
510  IF Ch3$="A" THEN Ch3=15359
520  IF Ch3$="B" THEN Ch3=13311
530  IF Ch3$="C" THEN Ch3=11263
540  IF Ch3$="D" THEN Ch3=9215
550  IF Ch3$="E" THEN Ch3=14335
```

Fig. A.1.3.A Program VACA Part I

```
560  IF Ch3$="F" THEN Ch3=16383
570  IF Ch3$="G" THEN Ch3=10239
580  IF Ch3$="H" THEN Ch3=12287
590  INPUT "ENTER SAMPLING FREQUENCY (10 TO 500 HZ )",S
600  X=INT(500000/S)                  !Value to be entered in the 8253
610  IF X<256 THEN 650                !Is the number more than 8 bits long
620  Fm=INT(X/256)                    !Obtain the msb if value is more than 8 bits
630  Fl=X-256*Fm                      !Obtain the lsb if value is more than 8 bits
640  GOTO 670
650  Fm=0                             !Value is less than 8 bits long
660  Fl=X
670  IASSEMBLE Tester                 !Name assembly program
680  WRITE IO 2,6;705                 !11110100111110 Set counter 0 to mode 3
690  WRITE IO 2,6;961                 !11110000111110 Allow s.s. to be reached
700  WRITE IO 2,6;713                 !11110100110110 Allow s.s. to be reached
710  WRITE IO 2,6;643                 !11110101111100 Set counter 1 to mode 2
720  WRITE IO 2,6;899                 !11110001111100 Allow s.s.
730  WRITE IO 2,6;651                 !11110101110100 Allow s.s.
740  WRITE IO 2,6;6909                !10010100000010 lsb of counter 0
750  WRITE IO 2,6;7165                !10010000000010 Allow s.s.
760  WRITE IO 2,6;6909                !10010100000000 Allow s.s.
770  WRITE IO 2,6;6911                !10010000000000 msb of counter 0
780  WRITE IO 2,6;7167                !10010000000000 Allow s.s.
790  WRITE IO 2,6;6911                !10010100000000 Allow s.s.
800  WRITE IO 2,6;16383-(13568+Fl) !11010100000000+Fl lsb of cnt.1 remmember 1's
complement
810  WRITE IO 2,6;16383-(13312+Fl) !11010000000000+FlAllow s.s.
820  WRITE IO 2,6;16383-(13568+Fl) !11010100000000+FlAllow s.s.
830  WRITE IO 2,6;16383-(13568+Fm) !11010100000000+Fm msb of cnt.1 remmember 1's
complement
840  WRITE IO 2,6;16383-(13312+Fm) !11010000000000+FmAllow s.s.
850  WRITE IO 2,6;16383-(13568+Fm) !11010100000000+FmAllow s.s.
860  IPAUSE ON                        !Allow to step in assembly language
870  ICALL Test(Line1(*),Line2(*),Line3(*),Sa,Ch1,Ch2,Ch3)   !Call assembly lang
uage program
880  PRINT "***************************************************************************
************"                    !Set the heading for the data for channel 1
890  PRINT "************************ VOLTS (V) OF FIRST CHANNEL ***************
******"
900  PRINT "***************************************************************************
************"
910  Data1=Data1+1
920  Line1(Data1)=Line1(Data1)+32768-16384      !Rearenge value from a.p. chn 1
930  Volts=(2048-Line1(Data1))*10/1802*-1      !Change the value one final time
940  FIXED 2
950  PRINT Volts;SPA(1);                   !Print the data
960  IF Data1<Sa THEN 910                  !Get another value if not the last value
970  PRINT "***************************************************************************
************"                          !Set the heading for chn 2 output data
980  PRINT "************************ VOLTS (V) OF SECOND CHANNEL ************
************"
990  PRINT "***************************************************************************
************"
1000 Data2=Data2+1
1010 Line2(Data2)=Line2(Data2)+32768-16384      !Rearrange value from a.p. chn 2
1020 Volts1=(2048-Line2(Data2))*10/1802*-1     !Change the value one final time
1030  FIXED 2                                  !Print the data
1040  PRINT Volts1;SPA(1);                     !Print the data
1050  IF Data2<Sa THEN 1000               !Get another value if not the last value
1060  PRINT "**************************************************************************
```

Fig. A.1.3.B Program VACA Part II

```
*************"                    !Set the heading for the output of chn 3
1070  PRINT "************************ VOLTS (V) OF THIRD CHANNEL *************
*************"
1080  PRINT "*****************************************************************
*************"
1090  Data3=Data3+1
1100  Line3(Data3)=Line3(Data3)+32768-16384      !Rearrange value from a.p. chn 3
1110  Volts3=(2048-Line3(Data3))*10/1802*-1      !Change the value one final time
1120  FIXED 2
1130  PRINT Volts3;SPA(1);                        !Print the data
1140  IF Data3<Sa THEN 1090               !Get another value if not the last value
1150  INPUT "DO YOU WANT TO PLOT THE DATA (Y/N)",P1$
1160  IF P1$="N" THEN 2130
1170  PLOTTER IS 13,"GRAPHICS"            !Choose plotter to be used
1180  ! GRAPHICS
1190  ! *****************This section is for channel 1******************
1200  LOCATE 15,127,70,95                 !Define area to be scaled
1210  SCALE 0,Sa/S,-12,12                 !Scale the area defined above
1220  LINE TYPE 1                         !Specify solid lines
1230  CSIZE 3                             !Size of the letters
1240  AXES 1/4,1,0,0                        !Define axis parameters
1250  SCALE 0,Sa,-12,12                   !Redefine scale
1260  Data1=1                             !Location of first valid value
1270  FIXED 0
1280  FOR I=1 TO Sa STEP 1                !Loop to get value from array and to plot
                                           the value
1290  Data1=Data1+1
1300  Volts=(2048-Line1(Data1))*10/1802*-1
1310  PLOT Data1,Volts                    !Plot the data
1320  NEXT I
1330  LOCATE 10,150,70,95                 !Relocate the pen
1340  SCALE 0,1000,-12,12                 !Redefine scale
1350  FOR I=-10 TO 10 STEP 5              !Loop to lable axis
1360  MOVE -25,I
1370  LABEL I
1380  NEXT I
1390  MOVE -47,-6                         !Move arm
1400  LDIR PI/2                           !Change direction at which pen is going
                                           to write
1410  LABEL "VOLTS (V)"                   !Label the units of y axis
1420  MOVE 350,11.25                      !Move arm
1430  LDIR 0                              !Change direction at which pen is going
                                           to write
1440  LABEL "C H A N N E L",Ch1$          !Heading of the graph
1450  MOVE 200,-12                        !Move arm
1460  LDIR 0                              !Change direction at which pen is going
                                           to write
1470  LABEL "S E C O N D S (1 Unit = 1/4 Sec)" !Lable units of x axis
1480  ! ********************This section is for channel 2*****************
1490  ! ++++++++++++++++++++++++++++ NEXT CHANNEL ++++++++++++++++++++++++++
++++++++"
1500  LOCATE 15,127,35,60                 !Define area to be scaled
1510  SCALE 0,Sa/S,-12,12                 !Scale the area defined above
1520  LINE TYPE 1                         !Specify solid lines
1530  AXES 1/4,1,0,0                        !Define axis parameters
1540  CSIZE 3
1550  SCALE 0,Sa,-12,12                   !Redefine scale
1560  FIXED 0
1570  Data2=1
1580  FOR I=1 TO Sa STEP 1                !Loop to get value from array and to plot
```

Fig. A.1.3.C Program VACA Part III

```
                                             the value
1590  Data2=Data2+1
1600  Volts=(2048-Line2(Data2))*10/1802*-1
1610  PLOT Data2,Volts                       !Plot the data
1620  NEXT I
1630  LOCATE 10,150,35,60                    !Relocate the pen
1640  SCALE 0,1000,-12,12                    !Redefine scale
1650  FOR I=-10 TO 10 STEP 5                 !Loop lable axis
1660  MOVE -25,I
1670  LABEL I
1680  NEXT I
1690  MOVE -47,-6                            !Move arm
1700  LDIR PI/2                              !Change direction at which pen is going
                                              to write
1710  LABEL "VOLTS (V)"                      !Label the units of y axis
1720  MOVE 350,11.25                         !Move arm.
1730  LDIR 0                                 !Change direction at which pen is going
                                              to write
1740  LABEL "C H A N N E L",Ch2$             !Heading of the graph
1750  MOVE 200,-12                           !Move arm
1760  LDIR 0                                 !Change direction at which pen is going
                                              to write
1770  LABEL "S E C O N D S (1 Unit = 1/4 Sec)" !Label units of x axis
1780  ! ************************This section is for channel 3****************
1790  ! ++++++++++++++++++++++++++ NEXT CHANNEL ++++++++++++++++++++++++++++++++
++++++++"
1800  LOCATE 15,127,0,25                     !Define area to be scaled
1810  SCALE 0,Sa/S,-12,12                     !Scale the area defined above
1820  LINE TYPE 1                            !Specify solid lines
1830  CSIZE 3
1840  AXES 1/4,1,0,0                          !Define axis parameters
1850  SCALE 0,Sa,-12,12                      !Redefine scale
1860  FIXED 0
1870  Data3=1
1880  FOR I=1 TO Sa STEP 1                   !Loop to get value from array and to plot
                                              the value
1890  Data3=Data3+1
1900  Volts=(2048-Line3(Data3))*10/1802*-1
1910  PLOT Data3,Volts                       !Plot the data
1920  NEXT I
1930  LOCATE 10,150,0,25                     !Relocate the pen
1940  SCALE 0,1000,-12,12                    !Redefine scale
1950  FOR I=-10 TO 10 STEP 5                 !Loop label axis
1960  MOVE -25,I
1970  LABEL I
1980  NEXT I
1990  MOVE -47,-6                            !Move arm
2000  LDIR PI/2                              !Change direction at which pen is going
                                              to write
2010  LABEL "VOLTS (V)"
2020  MOVE 350,11.25
2030  LDIR 0
2040  LABEL "C H A N N E L",Ch3$             !Heading of the graph
2050  MOVE 200,-12                           !Move arm
2060  LDIR 0                                 !Change direction at which pen is going
                                              to write
2070  LABEL "S E C O N D S (1 Unit = 1/4 Sec)" !Label units of x axis
2080  MOVE 650,-12                           !Miscellaneous Labels
2090  LABEL "LG"                             !Miscellaneous Labels
2100  MOVE 700,-12
```

Fig. A.1.3.D Program VACA Part IV

```
2110  INPUT "Date?",D$
2120  LABEL D$
2130  END
2140  ! This section is the Machine Language Section
2150  ! ==========================================
2160  ISOURCE NAM Tester                 !Initialize a. p.
2170  ISOURCE EXT Get_info,Put_element,Get_value
2180  ISOURCE LIT (40)
2190  ISOURCE Passa:BSS 2
2200  ISOURCE Passb:BSS 2
2210  ISOURCE Passc:BSS 2
2220  ISOURCE Counter:BSS 2
2230  ISOURCE Del:BSS 2
2240  ISOURCE Int:BSS 2
2250  ISOURCE Chna:BSS 4
2260  ISOURCE Chnb:BSS 4
2270  ISOURCE Chnc:BSS 4
2280  ISOURCE Controller:BSS 4
2290  ISOURCE Array_infoa:BSS 30
2300  ISOURCE Array_infob:BSS 30
2310  ISOURCE Array_infoc:BSS 30
2320  ISOURCE Elementa:EQU Array_infoa+16
2330  ISOURCE Elementb:EQU Array_infob+16
2340  ISOURCE Elementc:EQU Array_infoc+16
2350  ISOURCE SUB                        !Start a. p.
2360  ISOURCE Vala:INT (*)                !Initialize variables from main program
2370  ISOURCE Valb:INT (*)
2380  ISOURCE Valc:INT (*)
2390  ISOURCE Sam:INT
2400  ISOURCE Chana:INT
2410  ISOURCE Chanb:INT
2420  ISOURCE Chanc:INT
2430  ISOURCE Test:LDA =Controller       !Get the necesary values from basic
2440  ISOURCE LDB =Sam                   !This is for channel 1
2450  ISOURCE JSM Get_value
2460  ISOURCE LDA =Chna
2470  ISOURCE LDB =Chana
2480  ISOURCE JSM Get_value              !This is for channel 2
2490  ISOURCE LDA =Chnb
2500  ISOURCE LDB =Chanb
2510  ISOURCE JSM Get_value              !This is for channel 3
2520  ISOURCE LDA =Chnc
2530  ISOURCE LDB =Chanc
2540  ISOURCE JSM Get_value
2550  ISOURCE LDA =2                     !Use a 16 bite input output
2560  ISOURCE STA Pa
2570  ISOURCE LDA =0                     !Reset counter1
2580  ISOURCE STA Counter
2590  ISOURCE Padre:LDA =15360           !01101111111111 Turn s/h on
2600  ISOURCE AND Chna                   !Choose appropriate channel
2610  ISOURCE STA R6
2620  ISOURCE LDA =15                    !Initialize a loop for a time delay
2630  ISOURCE STA Del
2640  ISOURCE Back:DSZ Del               !Time delay for operational purposes
2650  ISOURCE JMP Back
2660  ! **********************This section is for channel 1 ***************
2670  ISOURCE LDA =7680                  !11100111111111 Set pulse for conversion
2680  ISOURCE AND Chna                   !Choose appropriate chanel
2690  ISOURCE STA R6
2700  ISOURCE LDA =7168                  !11101111111111 Return to normal position
```

Fig. A.1.3.E Program VACA Part V

```
2710  ISOURCE AND Chna                !Choose appropriate chanel
2720  ISOURCE STA R6
2730  ISOURCE LDA =Array_infoa        !Begin sending info back to basic
2740  ISOURCE LDB =Vala
2750  ISOURCE JSM Get_info
2760  ISOURCE ISZ Counter
2770  ISOURCE LDA Counter
2780  ISOURCE STA Elementa
2790  ISOURCE LDA R4                  !Get the value and rearenge the value
2800  ISOURCE SAR 2
2810  ISOURCE CMA
2820  ISOURCE STA Passa
2830  ISOURCE LDA =Passa
2840  ISOURCE LDB =Array_infoa
2850  ISOURCE JSM Put_element         !Send the value back to basic
2860  ! ********************This section is for channel 2***************
2870  ISOURCE LDA =7168               !1110111111111 Return to normal position
2880  ISOURCE AND Chnb                !Choose appropriate channel
2890  ISOURCE STA R6
2900  ISOURCE LDA =7680               !11100111111111 Set pulse for conversion
2910  ISOURCE AND Chnb                !Choose appropriate channel
2920  ISOURCE STA R6
2930  ISOURCE LDA =7168               !1110111111111 Return to normal position
2940  ISOURCE AND Chnb                !Choose appropriate channel
2950  ISOURCE STA R6
2960  ISOURCE LDA =Array_infob        !Begin sending information back to basic
2970  ISOURCE LDB =Valb
2980  ISOURCE JSM Get_info
2990  ISOURCE LDA Counter
3000  ISOURCE STA Elementb
3010  ISOURCE LDA R4                  !Get the value and rearrange the value
3020  ISOURCE SAR 2
3030  ISOURCE CMA
3040  ISOURCE STA Passb
3050  ISOURCE LDA =Passb
3060  ISOURCE LDB =Array_infob
3070  ISOURCE JSM Put_element         !Send the value back to basic
3080  ! ********************This section is for channel 3***************
3090  ISOURCE LDA =7168               !1110111111111 Return to normal position
3100  ISOURCE AND Chnc                !Choose appropriate channel
3110  ISOURCE STA R6
3120  ISOURCE LDA =7680               !11100111111111 Set pulse for conversion
3130  ISOURCE AND Chnc                !Choose appropriate channel
3140  ISOURCE STA R6
3150  ISOURCE LDA =7168               !1110111111111 Return to normal position
3160  ISOURCE AND Chnc                !Choose appropriate channel
3170  ISOURCE STA R6
3180  ISOURCE LDA =Array_infoc        !Begin sending info back to basic
3190  ISOURCE LDB =Valc
3200  ISOURCE JSM Get_info
3210  ISOURCE LDA Counter
3220  ISOURCE STA Elementc
3230  ISOURCE LDA R4                  !Get the value and rearrange the value
3240  ISOURCE SAR 2
3250  ISOURCE CMA
3260  ISOURCE STA Passc
3270  ISOURCE LDA =Passc
3280  ISOURCE LDB =Array_infoc
3290  ISOURCE JSM Put_element         !Send the value back to basic
3300  ! ******************This section is for all three channels************
3310  ISOURCE Puron:LDA R4            !Wait for next pulse to appear
3320  ISOURCE SAR 1
3330  ISOURCE SLA Puron
3340  ISOURCE High:LDA R4
3350  ISOURCE SAR 1
3360  ISOURCE RLA High
3370  ISOURCE DSZ Controller          !Is this the last value
3380  ISOURCE JMP Padre
3390  ISOURCE RET 1                   !Back to main program
3400  ISOURCE END Tester
```

Fig. A.1.3.F Program VACA Part VI

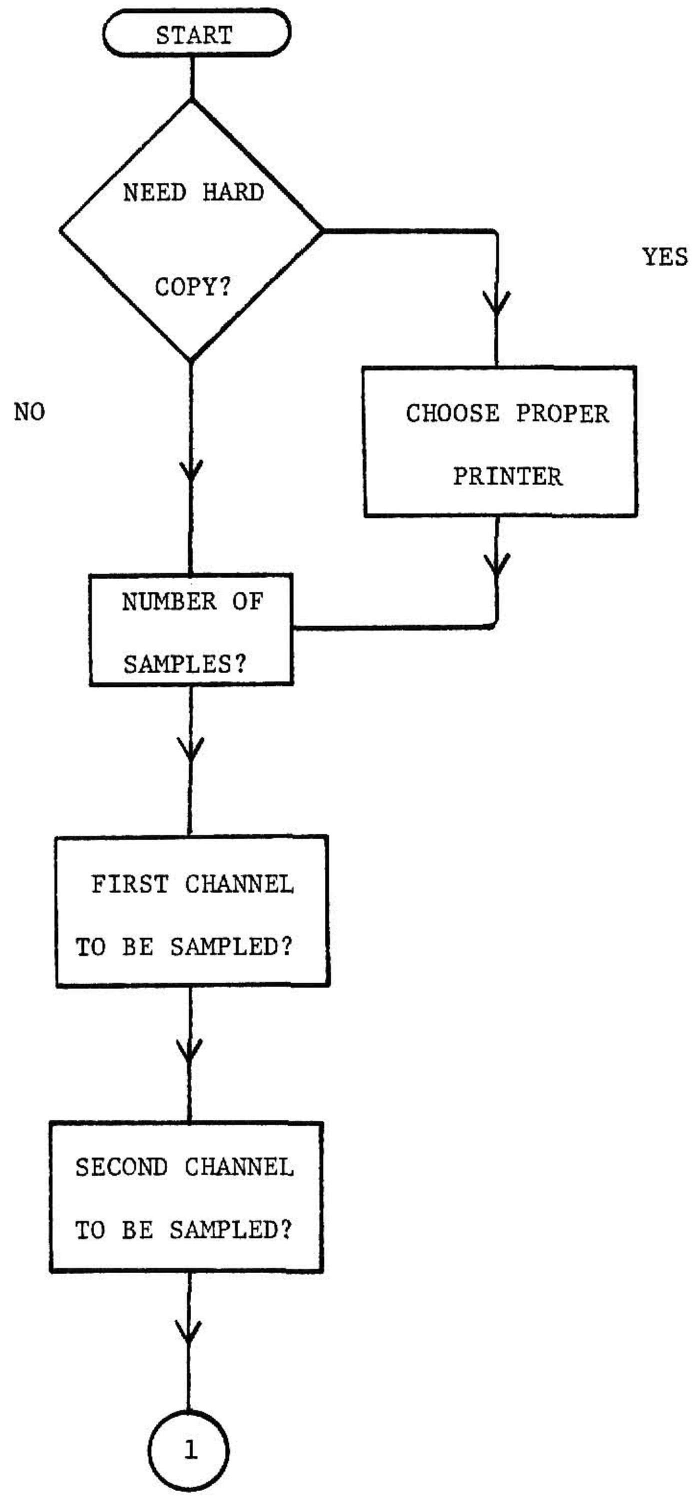

Fig. A.1.3.G VACA Flow Chart Part I.

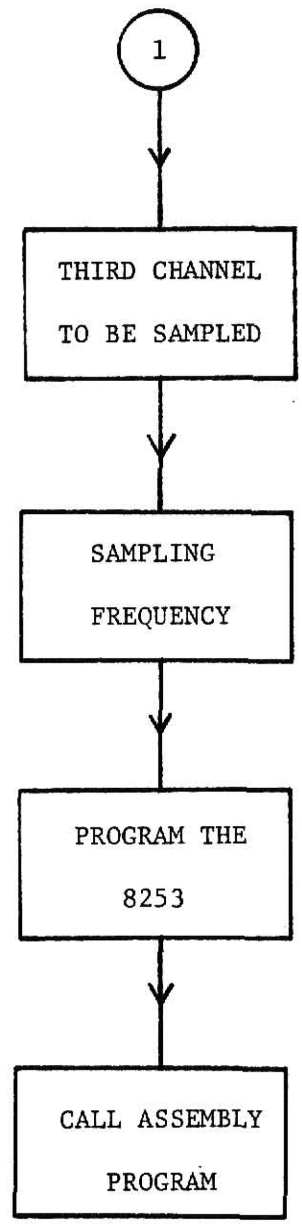

Fig. A.1.3.H VACA Flow Chart Part II.

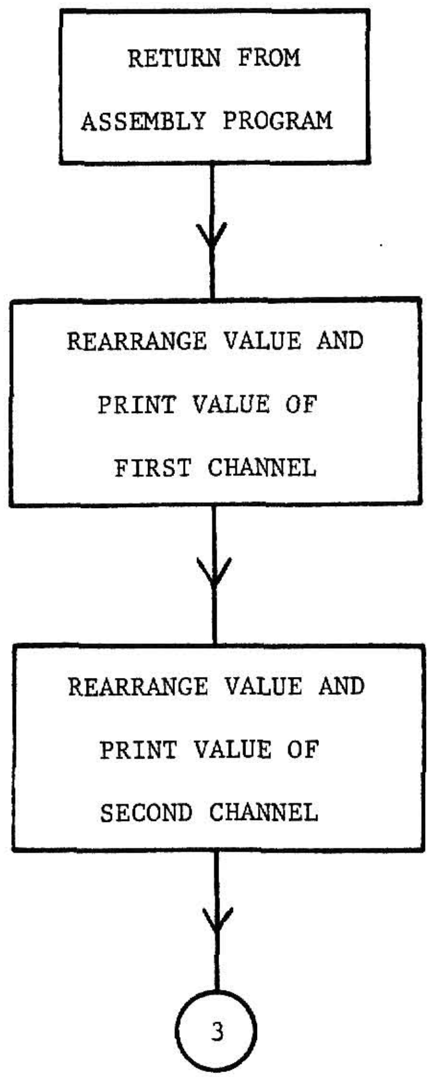

Fig. A.1.3.I VACA Flow Chart Part III.

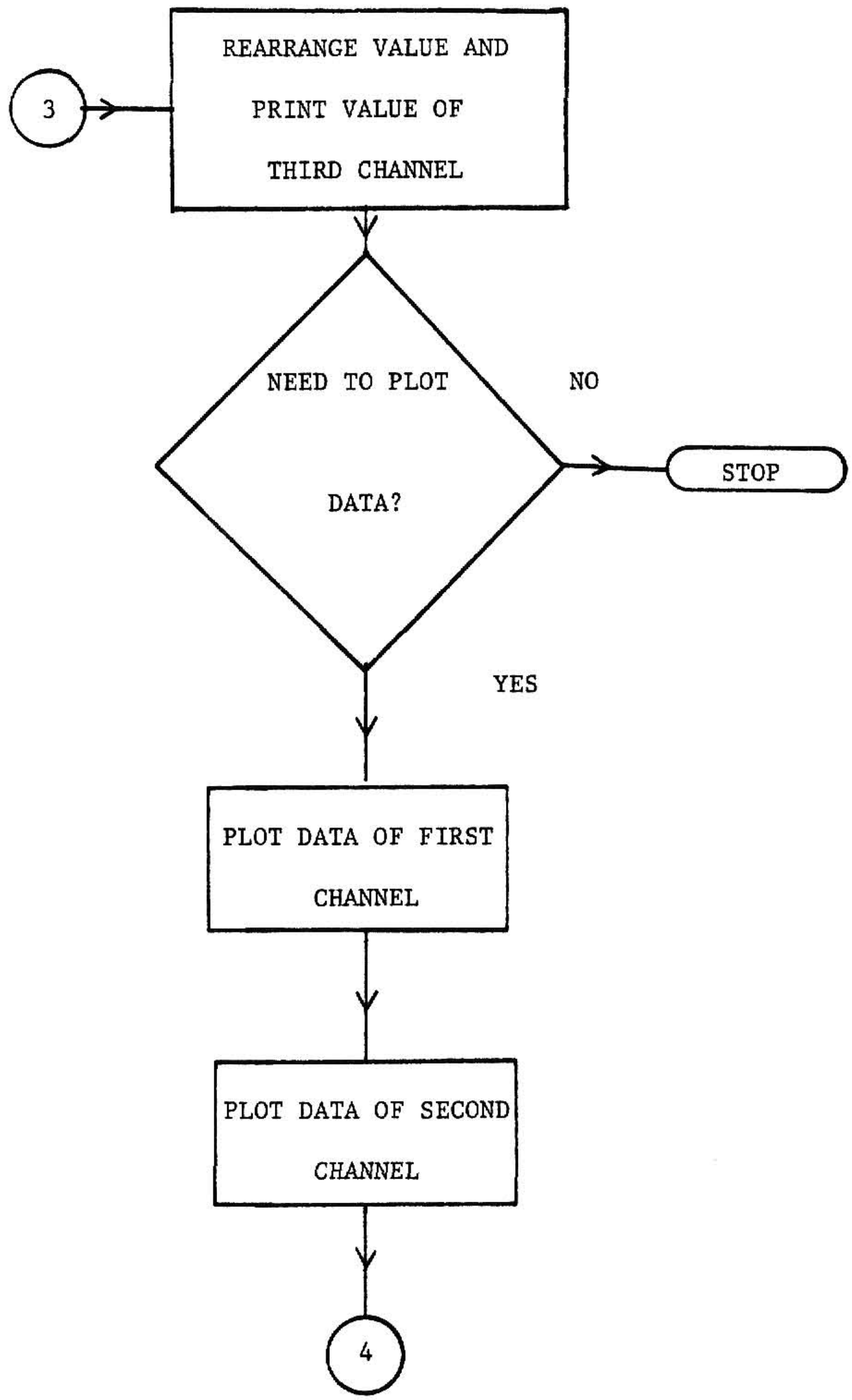

Fig. A.1.3.J VACA Flow Chart Part IV.

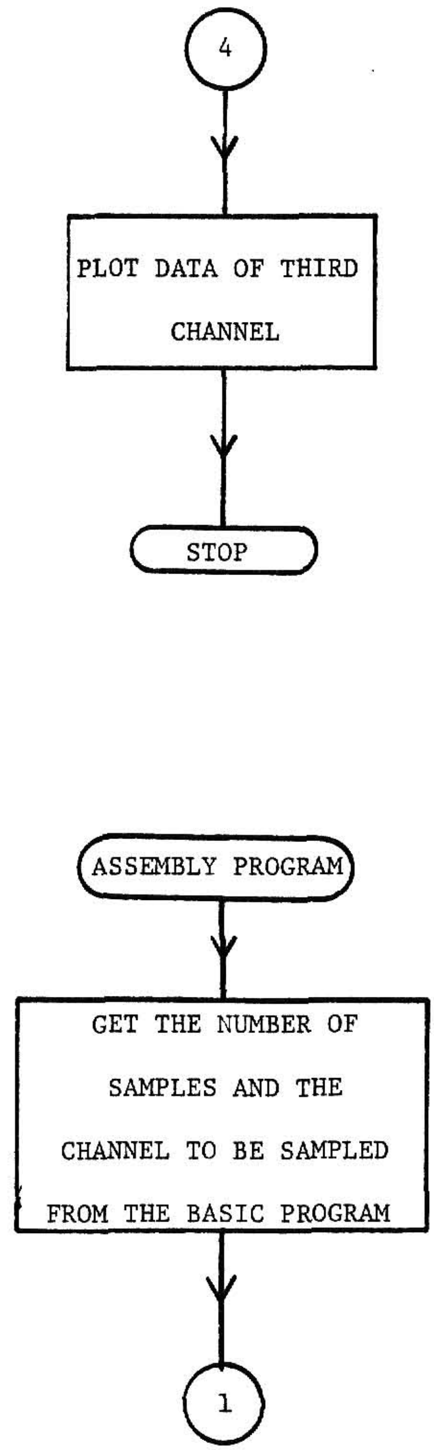

Fig. A.1.3.K VACA Flow Chart Part V.

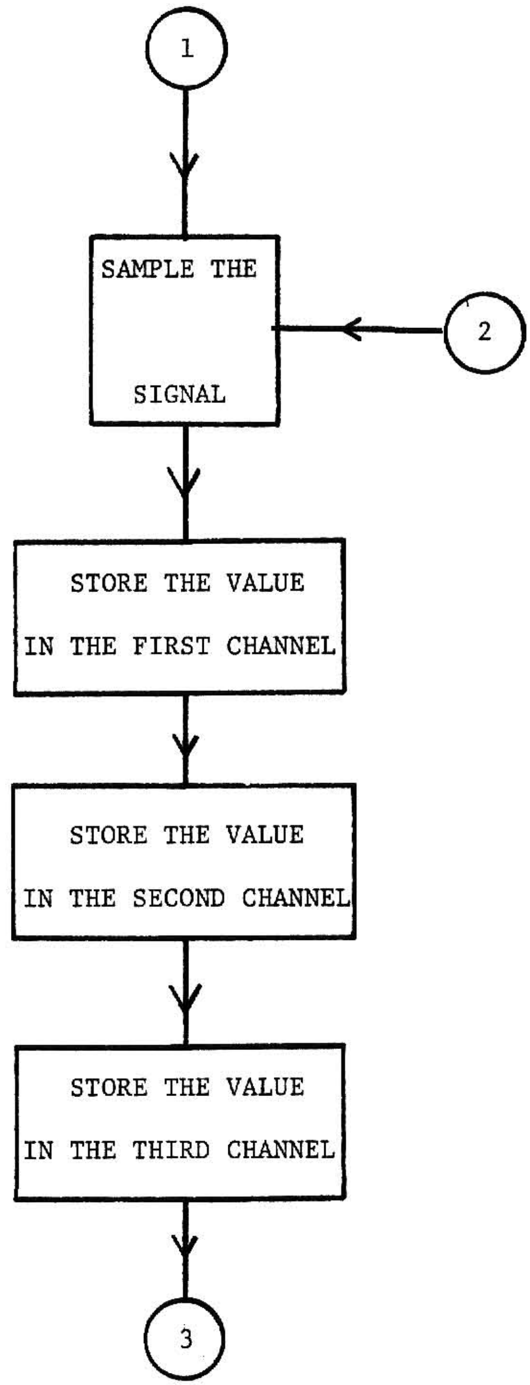

Fig. A.1.3.L VACA Flow Chart Part VI.

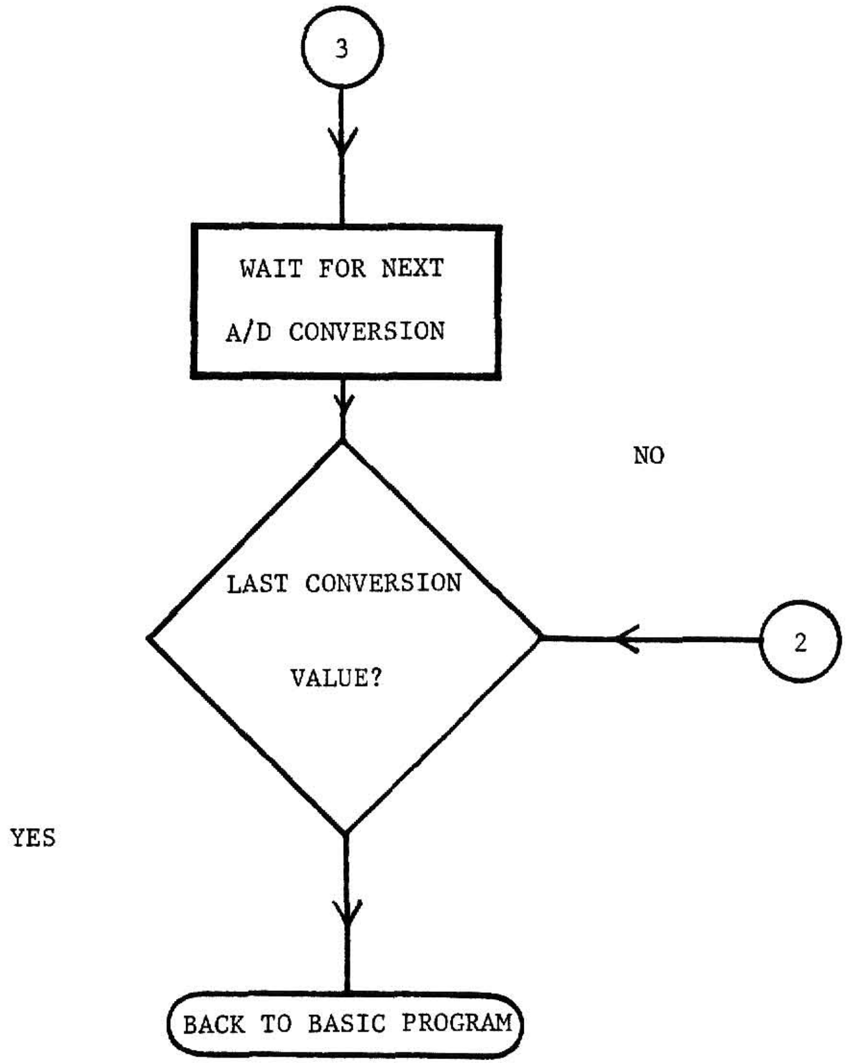

Fig. A.1.3.M VACA Flow Chart Part VII.

2. Connect the O2 channel to channel A input of the TM 503, the CO2 channel to channel B, and the flowmeter output to channel C. Make certain that the electronic plugs are properly connected on the remainder of the channels. If the plugs are not properly connected the instrument will saturate.

3. Power down the DAM and HP9845. Connect the 98032A interface from the HP9845 to the back panel of the DAM.

4. Power on the DAM with the on/off switch. This switch is black and located in the left most section of the DAM.

5. Turn amplification knobs for channels A-C to the far left (gain of one). Once this is done start turning knob A to the right until saturation is indicated by the LED's. When saturation is detected slowly turn the knob to the left until LED's turn off. Repeat this procedure for channels B and C. The other channels should not saturate if properly handled as described in Step 2.

6. If the D.C. component of the signal is not desirable turn the filters "on" by turning the switch to its most left position. Wait a few seconds for steady state to be reached.

7. Set the cut-off frequencies for the three channels to .1 and 3 Hz. This can be done by setting all the left cut-off frequency knobs to the extreme right and the right cut-off frequency knob to the extreme right.

8. If the D.C. component is required, turn the filter "off" by turning the switch to its most right position.

9. Load into the HP 9845 the program "VACA". This is done by inserting the tape cartridge into the T15 cartridge drive and typing GET "VACA". Then press EXECUTE.

10. Start the program by pressing RUN.

11. The first question to appear on the screen will be the following: Do you want hard copy (y/n)? If you do want a hard copy type Y and press CONT. If you do not want a hard copy press N and press CONT. Other software executed questions are answered in a similar manner. The user should type the response and press CONT.

12. An example of the output is shown in Fig. A.1.3.N and Table A.1.3.D.

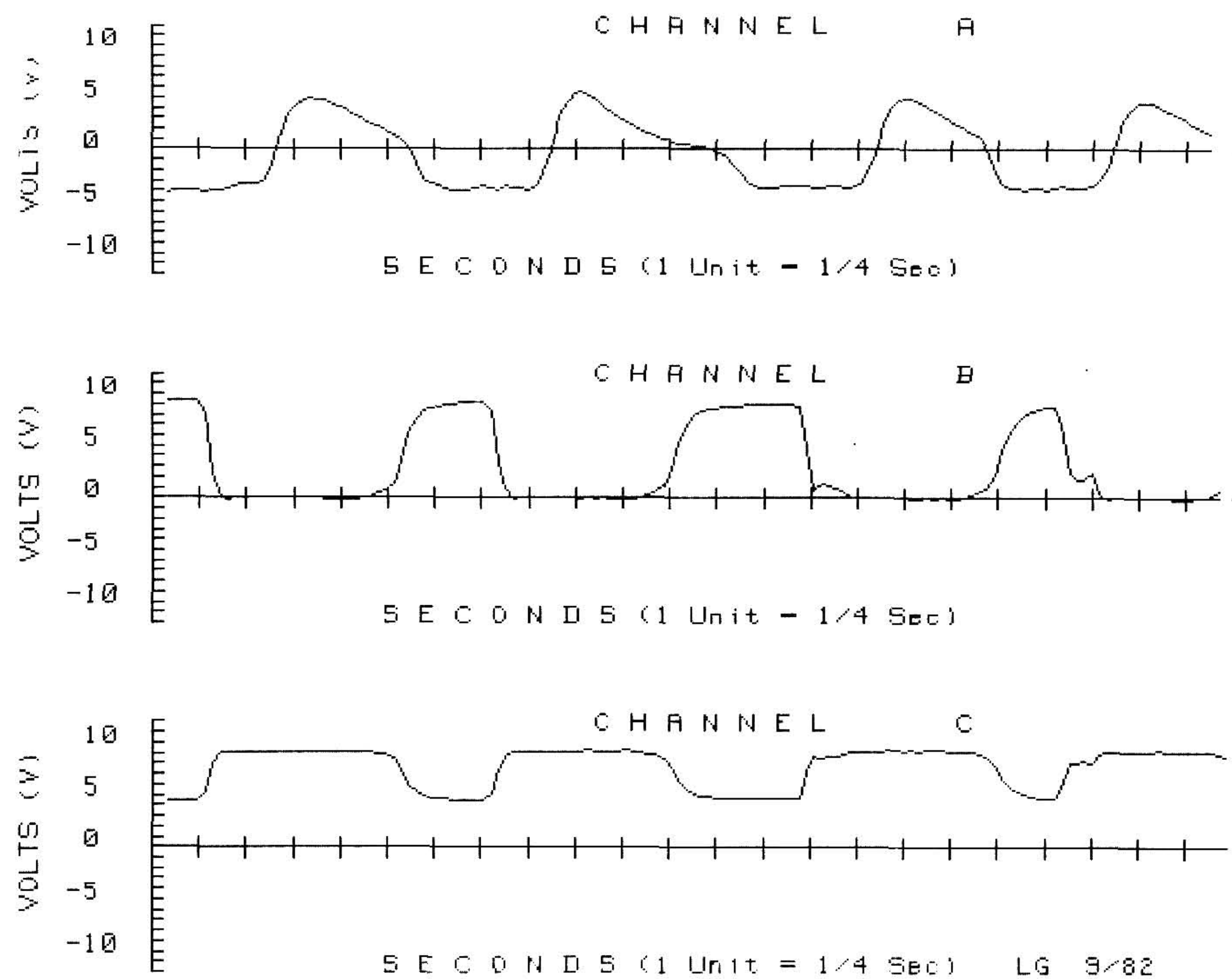

Fig. A.1.3.N Output Graph from VACA (150 Samples/Channel, 50 Hz Sampling) (Channel A is Flow signal, Channel B is CO_2 signal and Channel C is O_2 signal)

```
*****************************************************************************
************************* VOLTS (V) OF FIRST CHANNEL ********************
*****************************************************************************
-4.05  -3.95  -3.98  -4.02  -3.83  -4.03  -3.96  -3.82  -3.77  -3.45  -3.36
-3.36  -3.27  -2.87  -1.46   1.51   3.57   4.34   4.71   4.88   4.76   4.66
 4.37   4.08   3.76   3.37   2.90   2.46   2.13   1.70   1.28    .96    .28  -1.29
-2.84  -3.30  -3.47  -3.70  -3.82  -3.83  -3.93  -3.77  -3.58  -3.76  -3.84
-3.45  -3.69  -3.76  -3.82  -3.41  -2.31   -.11   3.21   4.63   5.37   5.51
 5.18   4.81   4.21   3.58   3.11   2.69   2.22   1.86   1.51   1.20    .93    .70
  .57    .45    .41    .24    .12   -.07   -.54  -1.38  -2.16  -2.99  -3.57  -3.63
-3.65  -3.68  -3.59  -3.54  -3.54  -3.56  -3.71  -3.75  -3.46  -3.53  -3.62
-3.61  -3.24  -2.18   -.26   2.56   3.96   4.72   4.99   4.97   4.60   4.13
 3.71   3.21   2.83   2.38   1.99   1.64   1.23    .14  -2.21  -3.27  -3.71
-3.71  -3.86  -3.80  -3.76  -3.87  -3.81  -3.49  -3.63  -3.75  -3.71  -3.43
-2.79  -1.50    .73   2.88   3.97   4.57   4.62   4.47   4.17   3.79   3.39
 2.99   2.52   2.26   1.83   1.45   1.32    .44  -1.81  -2.78  -3.35  -3.63
-3.71  -3.87  -3.72  ********************************************************
*********************
************************* VOLTS (V) OF SECOND CHANNEL ***********************
*****************************************************************************
 9.31   9.34   9.35   9.34   9.37   8.03   2.38    .01   -.06    .02    .01   -.01
 0.00    .01   -.01   -.01   -.02   -.02   -.03   -.02   -.03   -.04   -.04   -.04   -.06
 -.04   -.03    .11    .49    .69   1.31   3.46   6.22   7.48   8.26   8.56   8.70
 8.88   9.02   9.15   9.21   9.21   9.21   8.25   3.34    .90   -.03   -.01    .01
  .01   -.02   -.02   -.02   -.03   -.03   -.03   -.03   -.03   0.00   -.04   -.04   -.04
 -.03    .04    .34    .65   1.13   2.84   5.17   7.01   7.93   8.24   8.47   8.59
 8.72   8.78   8.83   8.88   8.90   8.91   8.92   8.93   8.95   8.92   8.77
 4.76    .69   1.30   1.17    .84    .39    .02   -.02   -.01   -.02   -.03   -.02   -.02
 -.02   -.03   -.03   -.03   -.03   -.03   -.04   -.03    .03    .37    .70    .97   2.28
 4.62   6.39   7.26   7.87   8.31   8.62   8.75   8.73   6.99   2.48   1.79
 1.86   2.43    .44   -.12    .03    .06   -.01   -.03   -.03   -.03   -.02   -.02   -.04
 -.04   -.05   -.02    .06    .29    .68    .93   1.40   3.04   5.08   6.60   7.72
 8.32   8.54   ***********************************************************
***************
************************* VOLTS (V) OF THIRD CHANNEL ***********************
*****************************************************************************
 4.40   4.42   4.40   4.40   4.41   5.33   8.15   9.08   9.20   9.23   9.22
 9.24   9.23   9.21   9.22   9.22   9.23   9.22   9.22   9.23   9.23   9.23
 9.21   9.18   9.18   9.22   9.23   9.12   8.95   8.89   8.46   7.27   5.90
 5.33   4.93   4.78   4.70   4.60   4.55   4.53   4.46   4.48   4.47   5.15
 7.56   8.73   9.18   9.21   9.20   9.23   9.21   9.23   9.22   9.23   9.23
 9.23   9.27   9.22   9.25   9.23   9.21   9.26   9.23   9.18   9.02   8.85
 8.61   7.62   6.39   5.55   5.17   4.98   4.86   4.79   4.76   4.72   4.70
 4.69   4.67   4.69   4.64   4.67   4.66   4.67   4.79   7.18   8.71   8.47
 8.70   8.80   9.00   9.21   9.25   9.23   9.15   9.23   9.26   9.26   9.23
 9.26   9.23   9.28   9.28   9.29   9.25   9.22   9.22   9.05   8.87   8.72
 7.89   6.70   5.84   5.39   5.09   4.86   4.72   4.67   4.68   5.68   8.01
 8.07   8.21   8.09   9.02   9.20   9.18   9.22   9.23   9.25   9.21   9.23
 9.26   9.22   9.23   9.21   9.23   9.23   9.17   9.06   8.84   8.77   8.47
 7.50   6.52   5.68   5.14   4.89   4.79
```

Table A.1.3.D. Hard Copy from VACA (150 Samples/Channel, 50 Hz sampling frequency)

A.2 TABLES

This appendix consists of tables with detailed information of the DAM

Theoretical Cut-Off Frequency (LPF)	Actual Cut-Off Frequency (LPF)	Theoretical Cut-Off Frequency (HPF)	Actual Cut-Off Frequency (HPF)
.1	.08	3	3
.5	.42	10	10.7
1.5	1.4	30	32
5	4.5	100	106
15	14	300	328
50	46	1 K	1.02 K
100	95.4	3 K	2.98 K
150	146.3	10 K	11.66 K

Table A.2.A. Cut-off Frequenicies of Channel A (values in Hz).

Theoretical Cut-Off Frequency (LPF)	Actual Cut-Off Frequency (LPF)	Theoretical Cut-Off Frequency (HPF)	Actual Cut-Off Frequency (HPF)
.1	.153	3	3.1
.5	.53	10	12
1.5	1.5	30	33.11
5	4.7	100	110
15	15	300	335
50	55	1 K	1.2 K
100	90	3 K	3.33 K
150	160	10 K	12.3 K

Table A.2.B. Cut-off Frequencies of Channel B (values in Hz).

Theoretical Cut-Off Frequency (LPF)	Actual Cut-Off Frequency (LPF)	Theoretical Cut-Off Frequency (HPF)	Actual Cut-Off Frequency (HPF)
.1	.1	3	3.1
.5	.5	10	10.8
1.5	1.5	30	32.2
5	4.7	100	111.3
15	13	300	340
50	44	1 K	1.11 K
100	95	3 K	3.26 K
150	150	10 K	12.4 K

Table A.2.C. Cut-off Frequencies of Channel C
(values in Hz).

Theoretical Bandwidth	Actual Bandwidth	Channel
.1 - 10 K	.1 - 12.9 K	D
.1 - 10 K	.07 - 10.5 K	E
.1 - 10 K	.083 - 10.5 K	F
.1 - 10 K	.1 - 10 K	G
.1 - 10 K	.07 - 10.5 K	H

Table A.2.D. Cut-off Frequencies for Channels D-H
(values in Hz).

Input to 9835		Output from 9835	
Pin #	Purpose	Pin #	Purpose
P_1	Examination of 8253 Output to interface circuit	P_{34}	Control Word Q_0
P_2	From A/D indicating end of conversion	P_{35}	Control Word Q_0
P_3	LSB bit from D/A	P_{36}	Control Word Q_0
P_4	bit from D/A	P_{37}	Control Word Q_0
P_5	bit from D/A	P_{38}	Control Word Q_0
P_6	bit from D/A	P_{39}	Control Word Q_0
P_7	bit from D/A	P_{40}	Control Word Q_0
P_8	bit from D/A	P_{41}	Control Word Q_0
P_9	bit from D/A	P_{42}	$\overline{WR}$
P_{10}	bit from D/A	P_{43}	$R/\overline{C}$ [AD 574]
P_{11}	bit from D/A	P_{44}	A_0 [MX]
P_{12}	bit from D/A	P_{45}	A_1 [MX] A_1 [8253]
P_{13}	bit from D/A	P_{46}	A_2 [MX] A_0 [8253]
P_{14}	MSB bit from D/A	P_{47}	S/H
P_{15}	GND	P_{48}	Nothing
P_{16}	GND	P_{49}	Nothing

Table A.2.E. Pin Connection for HP9845

Pin Num.	Description
28	GND of Ch B
27	GND of Ch H
26	GND of Ch C
25	GND of Ch G
24	GND of Ch D
22	A_1(8253) A_1(MX)
20	A_0(MX)
16	STS(AD574)
$\overline{F}$	Ch B
$\overline{E}$	Ch H
$\overline{D}$	Ch C
$\overline{C}$	Ch G
$\overline{B}$	Ch D
z	S/H
x	A_0(8253) A_2(MX)
w	Ch A
u	Ch F
R	Ch E
N	+33.5 Vdc
M	B(PNP)
L	E(PNP)
K	GND
J	-33.5 Vdc
H	E(NPN)
F	B(NPN)
B	+11.5 Vdc

Table A.2.F. Board # 1 Edge Connector.

Pin Num	Decription
22	CH 8 Output Signal
20	CH 7 Output Signal
19	CH 6 Output Signal
9	GND
3	CH 8 Input Signal
2	CH 7 Input Signal
1	CH 6 Input Signal
S	CH 6 Input GND
K	CH 7 Input GND
J	CH 8 Input GND
H	-15
C	+15
B	+10
A	-10

Table A.2.G. Board # 2 Edge Connector.

Pin Num.	Description
28	DB0 (LSB From D/A)
27	DB1 (Bit From D/A)
26	DB2 (Bit From D/A)
25	DB3 (Bit From D/A)
24	DB4 (Bit From D/A)
23	DB5 (Bit From D/A)
22	DB6 (Bit From D/A)
21	DB7 (Bit From D/A)
20	DB8 (Bit From D/A)
19	DB9 (Bit From D/A)
18	A_0 (8253)
17	$\overline{CS}$ (8253)
16	A_1 (8253)
15	D7 (8253)
14	D6 (8253)
$\overline{F}$	Output of 8253
Z	DB10 bit from D/A
Y	DB11 MSB bit from D/A
X	STS (A/D)
W	D_0 (8253)
V	D_1 (8253)
U	D_2 (8253)
T	D_3 (8253)
S	D_4 (8253)
R	D_5 (8253)

Table A.2.H. Board # 3 Edge Connector.

Pin Num.	Description
A	Emitter NPN
B	Base NPN
C	+33.5 V (in)
D	GND
E	No Connection
F	Emitter PNP
H	Base PNP
J	No Connection
K	-33.5 V (in)
L	-14.92 V (out)
M	-10.02 V (out)
N	+11.5 V (in)
P	+5.07 V (out)
R	+9.95 V (out)
S	+15.19 V (out)

Table A.2.I. Board #4 Edge Connector.

Pin Num.	Description
$\overline{F}$	Ch B
$\overline{E}$	Ch H
$\overline{D}$	Ch C
$\overline{C}$	Ch G
$\overline{B}$	Ch D
W	Ch A
U	Ch F
R	Ch E
D	Connect to +33.5 V Common
28	GND Ch B
27	GND Ch H
26	GND Ch C
25	GND Ch G
24	GND Ch D
11	Connect to -33.5 Vdc
7	Connect to +33.5 Vdc

Table A.2.J. TM 503 Changes on the left most edge connector [see Ref 5].

Pin Number	50 Pin Subminiature Pin Number
$\overline{F}$	3
$\overline{E}$	4
$\overline{D}$	5
$\overline{C}$	6
$\overline{B}$	7
$\overline{A}$	8
Z	9
Y	10
X	11
W	12
V	46
U	42
T	45
S	34
R	35
28	1
22	13
21	14
20	2
19	36
18	37
17	38
16	39
15	40
14	41

Table A.2.K. TM 503 Changes on the middle connector [see Ref 5].

A.3 PARTS LIST

Chips

Quantity	Part Number	Board Number	Description
8	AD521	U1 - 7U1	Inst. Amp.
5	LM339	U2 - 4U2	Comparators
16	TL061	U3-7U3, U4-7U4	FET Input OpAmp
7	AD582	U5-5U5 and 7U5	Sample and Hold
1	AD7503	U6	MUX
1	AD574	U7	A/D
1	CD4011	U8	Quad NAND Gates
1	8253	U9	Programmable Timer
1	LM340	1U1	+15 V Voltage Regulator
1	LM317	1U2	Positive Variable Voltage Regulator
1	MC7915C	2U1	-15 V Voltage Regulator
1	LM337T	2U2	Negative Variable Voltage Regulator
1	MC7805	3U1	+5 V Voltage Regulator

Transistor

Quantity	Part Number	Circuit Number	Board Number
1	2N2222	1Q1	1Q1
1	151-0349-00	1Q2	1Q2
1	2N2907	2Q1	2Q1
1	151-0373-00	2Q2	2Q2

LED's

Quantity
16

Diodes

Quantity	Part Number	Circuit Number	Board Number
4	1N5240	1D1, 1D2, 2D1, 2D2	1D1, 1D2, 2D1, 2D2

Capacitors

Quantity	Value	Circuit Number	Board Number
24	1µF ±5%	C_1, C_2, C_3	4C1, 4C2, 4C3 CR2, 1CR2, 2CR2, 2C1-2C3
8	0.432µF ±5%	C_4	CR1, 1CR1, 2CR1, 2C4, 4C4
8	13 pF ±5%	C_5	CR1, 1CR1, 2CR1, 2C5, 4C5
8	0.646 µF ±5%	C_6	CR1, 1CR1, 2CR1, 2C6 4C6
7	.01 µF ±5%	C_7	C7 - 5C7, 7C7
3	.1 µF ±5%	$1C_1$, $2C_1$, $3C_1$	1C1, 2C1, 3C1
1	4.7 µF ±5%	1C4	1C4
5	10 µF ±5%	1C2, 1C3, 2C2 2C3, 3C2	1C3, 1C5, 2C3 2C4, 3C2

Resistors

Quantity	Value	Circuit Number	Board Number
8	100 K ± 5%	R0	R1, R2, R3, R4 R5, R6, R7, R8
16	2.34 K ± 5%	R1, R2	SR1, SR12
8	20 M ± 5%	R3	CR2,1CR2,2CR2,3CR2,4CR2, SR2,SR21,SR22
3	4 M ± 5%		SR2,SR21,SR22
3	1.4 M ± 5%		SR2,SR21,SR22
3	417 K ± 5%		SR2,SR21,SR22
3	139 K ± 5%		SR2,SR21,SR22
3	41 K ± 5%		SR2,SR21,SR22
3	20 K ± 5%		SR2,SR21,SR22
3	13 K ± 5%		SR2,SR21,SR22
8	166 K ± 5%	R4	CR2,1CR2,2CR2,3CR3,4CR2, SR3,SR31,SR32
3	33 K ± 5%		SR3,SR31,SR32
3	11 K ± 5%		SR3,SR31,SR32
3	3 K ± 5%		SR3,SR31,SR32
3	1 K ± 5%		SR3,SR31,SR32
3	332 ± 5%		SR3,SR31,SR32
3	166 ± 5%		SR3,SR31,SR32
3	110 ± 5%		SR3,SR31,SR32
8	831 K ± 5%	R5	CR2,1CR2,2CR2,3CR2,4CR2, SR4,SR41,SR42
3	166 K ± 5%		SR4,SR41,SR42
3	55 K ± 5%		SR4,SR41,SR42
3	16 K ± 5%		SR4,SR41,SR42
3	5.5 K ± 5%		SR4,SR41,SR42
3	1.7 K ± 5%		SR4,SR41,SR42
3	831 ± 5%		SR4,SR41,SR42
3	550 ± 5%		SR4,SR41,SR42

Quantity	Value	Circuit Number	Board Number
8	591 ± 5%	R_6	CR1,1CR1,2CR1,3CR1,4CR1, SR5,SR51,SR52
3	2 K ± 5%		SR5,SR51,SR52
3	6 K ± 5%		SR5,SR51,SR52
3	20 K ± 5%		SR5,SR51,SR52
3	59 K ± 5%		SR5,SR51,SR52
3	197 K ± 5%		SR5,SR51,SR52
3	591 K ± 5%		SR5,SR51,SR52
3	2 M ± 5%		SR5,SR51,SR52
8	5.5 K ± 5%	R_7	CR1,1CR1,2CR1,3CR1,4CR1, SR6,SR61,SR62
3	18.5 K ± 5%		SR6,SR61,SR62
3	55.5 K ± 5%		SR6,SR61,SR62
3	185 K ± 5%		SR6,SR61,SR62
3	555 K ± 5%		SR6,SR61,SR62
3	1.85 M ± 5%		SR6,SR61,SR62
3	5.55 M ± 5%		SR6,SR61,SR62
3	18.5 M ± 5%		SR6,SR61,SR62
3	473 ± 5%	R_8	CR1,1CR1,2CR1,3CR1,4CR1, SR7,SR71,SR72
3	1.6 K ± 5%		SR7,SR71,SR72
3	4.7 K ± 5%		SR7,SR71,SR72
3	16 K ± 5%		SR7,SR71,SR72
3	47 K ± 5%		SR7,SR71,SR72
3	157 K ± 5%		SR7,SR71,SR72
3	472 K ± 5%		SR7,SR71,SR72
3	1.6 M ± 5%		SR7,SR71,SR72
22	10 K ± 5%	R_9-R_{12},R_{28},R_{17}-R_{26}	SR11
1	1 M ± 10%	R_{16}	SR10
2	400 Ω	1R1,2R2	1R1,2R2
2	10 K	1R2,2R2	1R2,2R2
1	240 Ω	1R4	1R4
1	120 Ω	2R4	2R4

<u>Variable Resistor</u>

Quantity	Value	Circuit Number	Description
2	0-5 K	1R3,2R3	
3	0-100 K	R02	10 Turn Pot
5	0-100 K	R02	1 Turn Pot
2	0-100	R13,R14	
7	0-10 K	R27	

DESIGN OF VERSATILE, MULTI-CHANNELED, DATA ACQUISITION MODULE

by

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Electrical Engineering

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1982

ABSTRACT

A versatile Data Acquisition Model (DAM) was designed and built for use in multi-signaled experimental respiratory research. It possesses the potential of receiving eight channels of analog input signals with maximum inputs of 19.6 volts peak-to-peak and with a maximum sampling frequency of 1 MHz. Three of the eight channels have variable low and high cut-off frequencies. The instrument automatically indicates to the operator channel saturation and signal overloads. The DAM is computer-controlled and provides digital output for on-line data processing or for mass storage of data.