INSTRUMENTATION OF A SAVONIUS WIND TURBINE

by

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1. INTRODUCTION

Instrumentation of the Kansas State University (KSU) Savonius wind turbine was needed to develop a method of measuring turbine performance in free air. In the past, tests were performed on scale models in wind tunnels. These tests and results are difficult, if not impossible, to extrapolate in order to predict full scale performance. At the KSU Wind Laboratory we wanted to measure wind speeds and power output from the turbine in the proper way to determine wind turbine characteristics without the need of a full scale wind tunnel.

The power output of a turbine and the wind speed measured at the same time do not exhibit a one-to-one correlation. It is necessary to take large quantities of data to determine wind turbine performance by statistical methods.

The simple scheme of collecting wind data sequentially does not give good results. Poor results arise from the fact that there is a large amount of scatter or variation in the data. This scatter is attributed to the phenomenon that the effective instantaneous wind speed over the surface of the turbine is not equal to the instantaneous wind speed at the anemometer. In most cases, data taken sequentially are of little use due to this scattering. The method developed here for taking reasonable data is called the Method of Bins.

The Method of Bins assumes that statistically the wind speeds over the surface of the turbine and at an anemometer placed at the median height of that turbine are the same. In other words, if the wind speeds are sampled for a long enough period of time the mean and the variance of the wind speed will be the same for both locations. With the Method of Bins, data are typically collected several times a second and the bin corresponding to each sampled value is incremented by one. When a bin becomes full, all bin contents are dumped to bulk storage.

The type of data taken by the Bin Method is illustrated in Figure 1.1-1. This is a histogram of actual wind speeds at about 10 m above the ground during a 4 minute period on March 31, 1978 at Manhattan, Kansas. Each bin represents a range of wind speed of 0.13 m/s. Bin 70 includes wind speeds between 10.13 and 10.26 m/s, for example. The wind speed was in this range 8 times during this particular test. The average wind speed for this period was 12.17 m/s (27.22 mph), somewhat above average but not uncommon for Kansas. The minimum wind speed measured was 10 m/s while the maximum was 15.37 m/s.

The KSU Savonius wind turbine shown in Figure 1.1-2 was completed in May 1977. This turbine was designed to deliver 5 kilowatts of three-phase electrical power to a load in an 11 meter per second wind speed. The turbine was built to study open air testing of wind machines. The major project goal was to develop a system by which any wind machine could be tested and analyzed. The Savonius tests, however, have turned out to be quite encouraging. Initial field testing in March 1978 indicated a peak coefficient of performance about equal to those of the Darrieus or large two-bladed propeller type wind turbines.

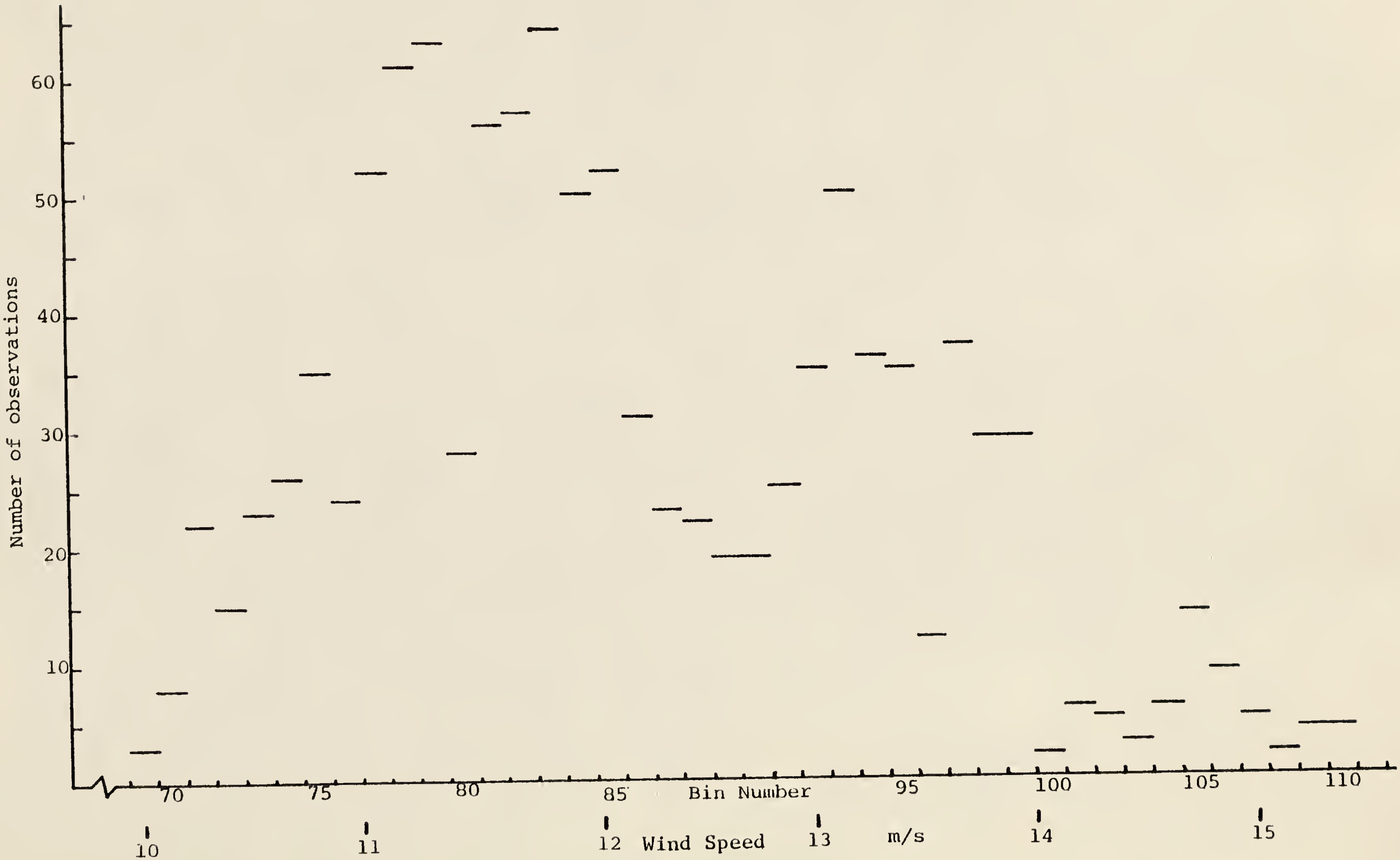


Fig. 1.1-1. Wind Speed Histogram.

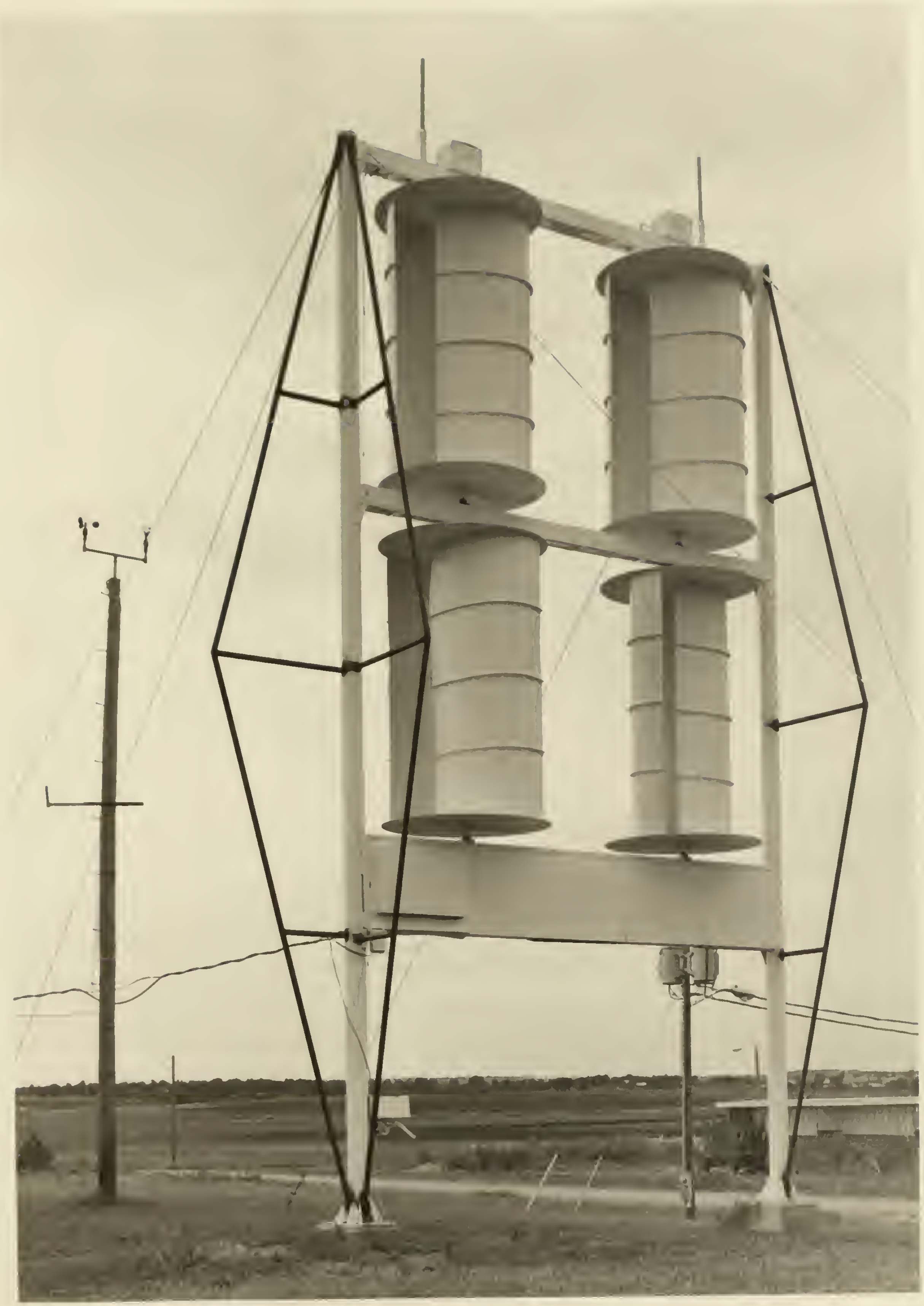


Fig. 1.1-2. The Kansas State University Savonius Wind Turbine.

2. SYSTEM HARDWARE

2.1 Introduction

The instrumentation necessary for the data acquisition from the Savonius wind turbine was a natural place for a microcomputer and a high quality analog to digital (A/D) converter. A block diagram of the data collection system is shown in Figure 2.1-1. The KSU Wind Laboratory instrumentation consists of a microcomputer, a paper tape punch, a variety of analog transducers, an angular velocity digital transducer and a digital anemometer. The microcomputer is a MOS Technology KIM-1 with an extra 4k of Random Access Memory (RAM) and a Burr-Brown analog to digital microperipheral. The A/D microperipheral has eight selectable differential inputs which are all connected to the transducers through RC filters for the reduction of high frequency noise. The microcomputer system utilizing a multiplexer board has an 8-bit digital Input-Output (I/O) port and two pulse rate inputs. These pulse rate inputs are connected to the digital anemometer and angular velocity transducer. Included on the multiplexer board is a paper tape punch digital interface for data output.

The instrumentation is powered by +8 Vdc regulated to +5 Vdc for the microcomputer, the digital portion of the A/D, the multiplexer-counter board, and the 4k RAM card. ±15 Vdc is needed for the A/D and +12 Vdc for the audio cassette interface. However, the cassette interface only needs +12 Vdc in the read mode and can remain disconnected at all other times.

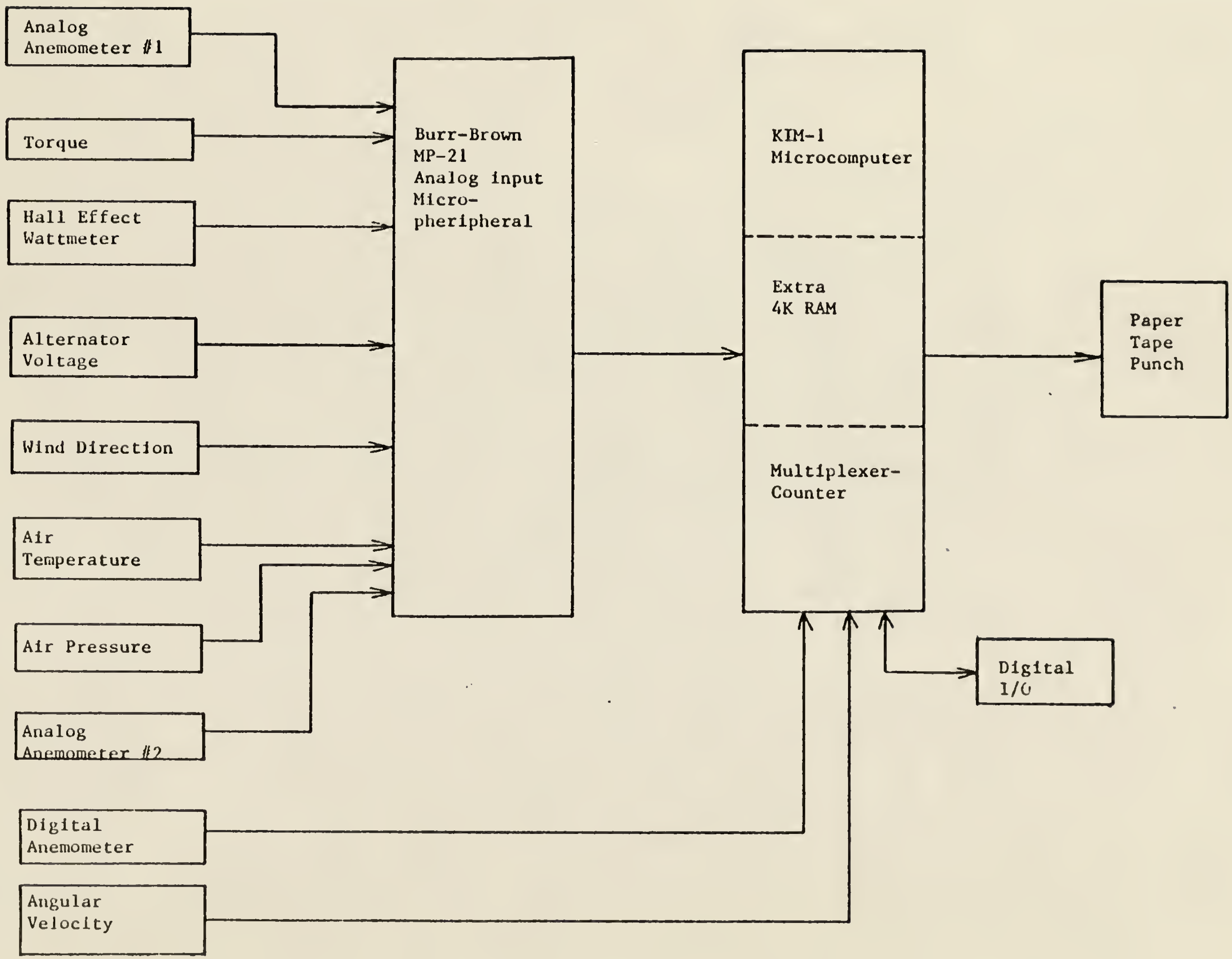


Fig. 2.1-1. Block Diagram of the KSU Wind Laboratory Data Acquisition System.

2.2 Microcomputer

The MOS Technology KIM-1 is a single board machine with a monitor residing in Read Only Memory (ROM) and with 1K bytes of RAM available for the user. The microcomputer employs a MCS6502 (6502) microprocessor as the Central Processing Unit (CPU). The 6502 is an 8-bit machine (8-bit bi-directional data bus) with a 16-bit program counter (16-bit address bus). Details of the 6502 can be found in the MOS Technology 6502 Hardware manual [1]. Internal registers in the CPU include one 8-bit accumulator, two 8-bit index registers--X and Y, an 8-bit stack pointer confined to page one, an 8-bit processor status register and a 16-bit program counter. Programming the 6502 is much the same as any present day 8-bit microprocessor with the exception of the zero page and zero page indexed address capabilities. This addressing ability allows for extended table programming operations to be done with ease. Details of the addressing can be found in the MOS Technology 6502 Hardware and Programming Manual [2].

One feature of the KIM-1 is its on board interfaces for TTY and audio cassette. The I/O ports, interrupt timer and hexadecimal display are also useful features. The TTY interface is a 4 wire 20 ma current loop configuration allowing a serial teleprinter to be connected directly to the KIM-1. The signal connections between the KIM-1 and TTY are given in Table 2.2-1.

The primary function of the TTY is to load cross-assembled programs from paper tape into the data acquisition system. By using the cross-assembly method for programming and receiving a paper tape, a hard copy of the system program can be on file at all times. The teleprinter may also be used for hard copy of data recorded by the system. This feature,

TABLE 2.2-1

TTY - KIM-1 Connections

KIM-1 Application Connector	KSU Standard Cinch Jones 8-pin Connector	
R	3	Keyboard Return
S	1	Printer Return
T	4	Keyboard
U	2	Printer

though not exploited by current software, could easily be added using routines in the KIM-1 monitor.

The audio cassette interface on the KIM-1 employs a frequency shifted signal to encode program information on cassettes. Audio quality cassettes can be recorded or read by routines in the KIM-1 monitor. Details of the audio interface are given in the KIM-1 user manual [3]. The audio cassette feature is used to load the system program into RAM. The system is powered on and reset from the keyboard. After reset the data collection program is loaded from audio cassette. This method allows user adjustable software to reside in RAM while keeping a semipermanent record of the program on tape. User adjusted software can be rerecorded on tape to save any user changes or adjustments. It can be useful to keep an extra copy of the program on tape in case of programming problems. This extra tape is not essential because of the availability of the hard copy paper tape received from the cross-assembler.

The I/O ports on the KIM-1 allow 15-bits of input and/or output partitioned as 8-bits from port A and 7-bits from port B. On the wind laboratory system, port A is multiplexed (1 to 4) to give 4 inputs and/or outputs. Two of these multiplexed ports are connected to pulse rate counters, one to the paper tape punch and one left for digital expansion. Port B is used to control the port A multiplexer, the paper tape punch, and receive interrupts from the timer on bit 7.

The interrupt timer is located on board in the MCS6530-002. This timer generates an interrupt upon count-out. It can be set at count-out or any other time by a write to the proper address. Details of the timer address are given in the KIM-1 User manual Appendix H and in the MOS Technology MCS6502 Hardware Manual. Bit 7 of port B is switched to interrupt request (IRQ) on the KIM-1 Expansion Connector to allow use of both the timer and interrupts in software debugging.

The KIM-1 has a built-in display which allows information to be entered or passed to the user. This display has 6 digits of display and is normally operated as 4 digits of hexadecimal address and 2 digits of hexadecimal data. This display along with the KIM-1 hexadecimal keyboard is used to make user modifications to the program. During operation the display is used to exhibit currently sampled data. It may also display any channel or data value recorded by the microcomputer. The ability to display this information gives the user some type of feedback and reassurance that they system is operating properly.

2.3 4k RAM Expansion

The Wind Laboratory microcomputer memory was expanded by 4k bytes with the use of an S.D. Sales 4k Low Power Ram Board [4]. This board is plug compatible with the S-100 bus and includes 4096 8-bit memory words with buffered outputs and on board power regulation. 21L02 memory chips are used, each having a capacity of one bit at each of 1024 addresses.

The 4k board decoding must be modified for use with the KIM-1. Modification is accomplished by following the step by step procedure given in Appendix A after normal assembly of the board. Also provided in Appendix A is a memory march test for testing the RAM.

The intention of the modification is to provide memory in the K1, K2, K3 and K4 positions of the already decoded locations of the KIM-1.

See Figure 2.3-1. Modification is accomplished by disabling the S-D decoding and providing the proper decoding for the KIM-1. The modification can best be understood by referring to the logic diagram in Appendix A. IC 39 (7400) on the S-D board is altered from an active high NAND gate to an active low OR gate which is true when K1, K2, K3 and K4 are low. See KIM-1 User Manual.

2.4 Multiplexer-Counter

The KIM-1 microcomputer is interfaced to the digital anemometer, angular velocity transducer and the paper tape punch by the multiplexer-counter board. The board employs 4 CMOS 4052's for multiplexing port A of the KIM-1 to the 4 digital I/O ports. The 4052's are analog multiplexers and therefore care must be taken to set port A to an input before selecting input signals with the multiplexer, so that two outputs are not tied together. The multiplexer is controlled by bits CØ and C1. These control bits correspond to port B bit 4 and 5 respectively. Anyone of the four ports or devices can be selected by the appropriate bit pattern at port B. See Table 2.4-1. A block diagram of the multiplexer-counter board is shown in Figure 2.4-1. The paper tape punch is wired with a solid state relay for power control. The punch powers-on when selected, that is, when CØ and C1 are both zero. Details of the multiplexer, punch connections, multiplexer-counter card connections, angular velocity counter and digital anemometer counter are given in Appendix B.

2.5 Angular Velocity Transducers

The angular velocity of the wind turbine is measured by a magnetic pick-up from a 60 tooth gear enclosed in the Lebow torque transducer. See

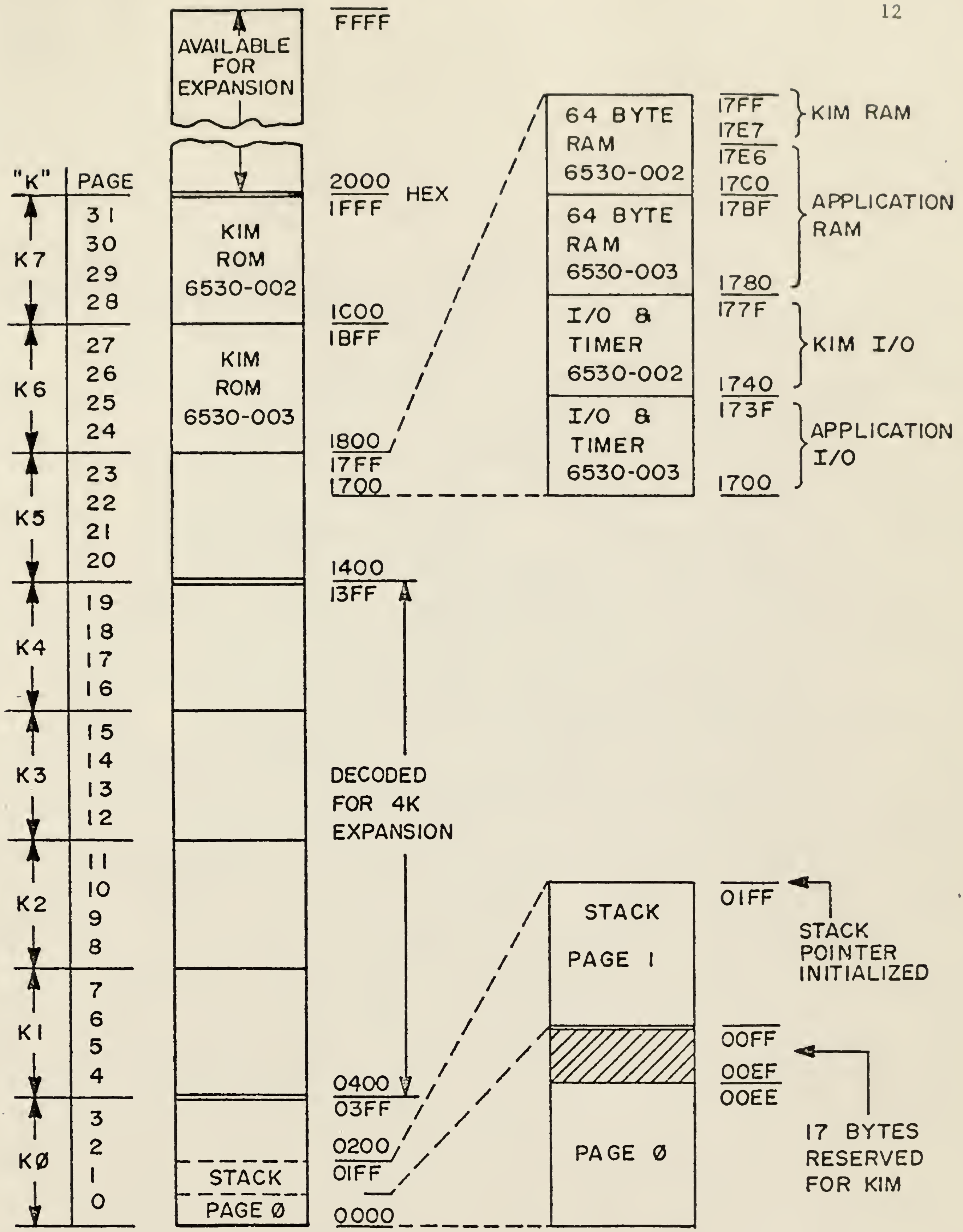


Fig. 2.3-1. KIM-1 Memory Map.

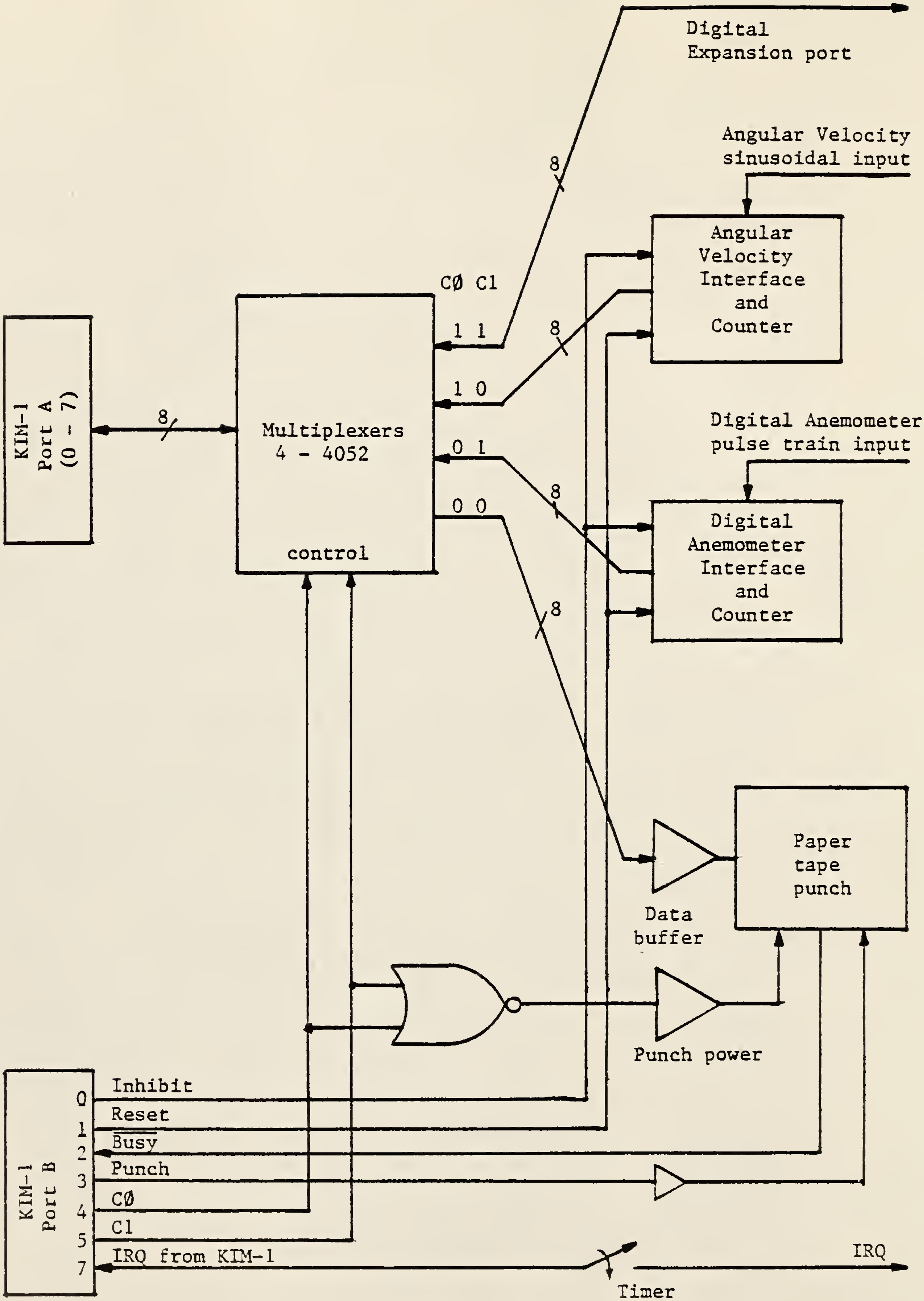


Fig. 2.4-1. Block Diagram of the Multiplexer - Counter Board and Interfacing.

Table 2.4-1. KIM-1 Port B Bit Patterns for Peripheral Control.

Bit		
7	input	IRQ
6	Not available	
5	output	C1
4	output	CØ
3	output	Punch Command
2	input	Busy (punch)
1	output	Reset Counters
Ø	output	Inhibit Counters

Bit # Port B	7	6	5	4	3	2	1	Ø	
	X		Ø	Ø	Ø	1	Ø	Ø	Punch select
	X		Ø	Ø	1	Ø	Ø	Ø	Punch command, Punch busy
	X		Ø	1	Ø	1	Ø	Ø	Angular velocity counter
	X		Ø	1	Ø	1	Ø	1	Inhibit counter
	X		1	Ø	Ø	1	Ø	1	Digital Anemometer counter selected and inhibited
	X		X	X	Ø	1	1	Ø*	Reset counter and release inhibit
	X		X	X	Ø	1	Ø	Ø*	Release reset
	X		1	1	Ø	1	Ø	Ø	Select digital expansion port

*Don't cares (X) in bits 4 and 5 must not be both Ø. This condition will select the punch and power it on.

Figure 2.5-1. The signal from the magnetic pick-up is fed by shielded cable to the input of the multiplexer-counter board. The input is protected against high voltage transients with a gas discharge tube (NE-2), a 1.3kΩ resistor and a 6.8V silicon voltage suppressor (Transzorb [5]). The 1.3kΩ resistor is also used in conjunction with a 0.1 μf capacitor to form a low pass filter. The filtered signal is amplified and shaped by a CA3140 [6] operational amplifier and CMOS 4093 Schmitt trigger. The signal is also gated by the 4093 using bit Ø of port B (inhibit). The angular velocity counter is read by writing a 1 to bit 4 and a Ø to bit 5 of the KIM-1 I/O port B. This condition connects port A to the angular velocity counter through the 4052 multiplexer on the multiplexer-counter board. The counter is inhibited, to reduce glitches, by writing a 1 to bit Ø of port B. After the counter is inhibited a read of port A will yield the contents of the counter. Writing a 1 to bit 1 of port B will reset the counter and a Ø written to bit Ø of port B will release the inhibit. The counter will then count until the next inhibit, read and reset. With the Wind Laboratory system, the angular velocity signal is counted for one-sixth of a second and the angular velocity recorded from these results. The location of the angular velocity transducer in the KSU Savonius wind turbine power shaft yields an output of 423.5 pulses per turbine revolution which produces a count of 1.18 in one sixth of a second per turbine rpm.

2.6 Digital Anemometer

A digital anemometer was developed to overcome problems and errors associated with 'Weather Bureau' type of anemometers. 'Weather Bureau' anemometers are generally analog permanent magnet generators with a

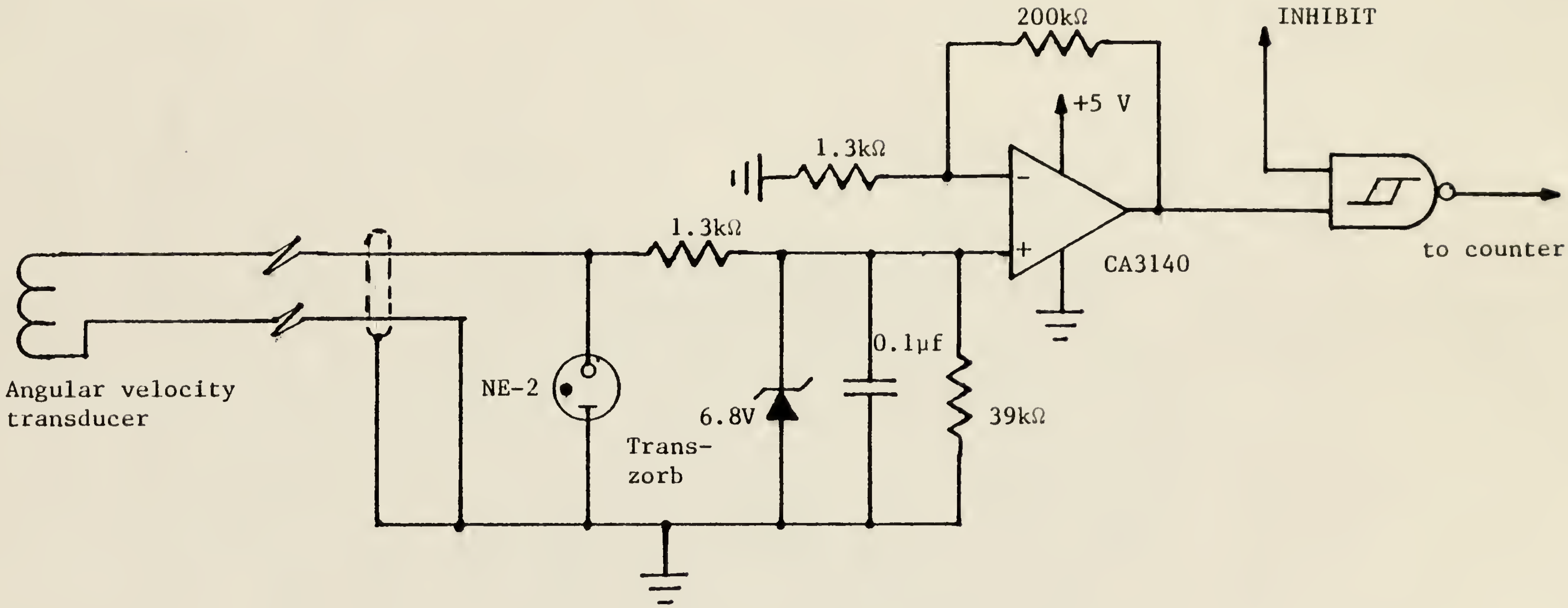


Fig. 2.5-1. Angular Velocity Transducer and Interface. Electronics are located on the Multiplexer - Counter board. Transducer outputs 423.53 pulse per turbine revolution.

cup-wheel assembly. Large errors can arise from the use of these anemometers because of their inherent design. 'Weather Bureau' analog anemometers have a cup-wheel driven armature with a commutator and brush assembly. If the bearings, commutator, or brushes become worn or dirty the output of the anemometer will be lower at equivalent wind speeds. Another problem stems from the fact that all anemometers are averaging devices which act as non-linear low pass filters. The velocity of the anemometer approaches the speed of the wind at the beginning of a wind gust, but due to its mass it overruns and is traveling faster at the end of the gust than the wind. To overcome this second problem, the mass of the anemometer must be reduced. This is done with a pulse rate encoded digital anemometer. The digital anemometer uses a cup-wheel assembly identical to the analog anemometer but reduces the mass of the rotor by eliminating the armature. The cup-wheel assembly on the digital device drives a photo chopper arrangement which outputs a pulse rate proportional to wind speed. The mass of the chopper wheel is small compared to the analog anemometer armature reducing its inertial effects. The first problem is also diminished with the photo chopper arrangement because there are fewer moving parts to get dirty or worn.

The cost of the analog anemometer is also higher than that of the digital anemometer, attributable to its wire-wound armature, brushes and commutator. In contrast, the digital device has a chopper wheel, a light emitting diode, and a photo-transistor or photodiode. This reduces the cost to mainly the cup-wheel assembly and housing. Some problems did arise with the KSU prototype digital anemometer built by Bootman [7]. The major problem with the anemometer was the bearings used on the cup-wheel shaft.

These bearings were standard industrial type sealed ball bearings. Drag factor introduced by these types of bearings were so high that in one case the anemometer did not register until wind speeds reached 3 m/s. Also after prolonged use, the bearing performance deteriorates, making the anemometer unusable for instrumentation purposes.

Improved performance could be obtained by a better choice of bearings similar to the ones used by Electric Speed Indicator Company [8] in their model F420-C wind speed transmitter. These bearings are New Departure SS-7034 and SS-7R4, stainless steel types or equivalents. They are lubricated with a mixture of 2/3 Dow Corning DC-33 silicon grease fluid consistency and 1/3 Hamilton Oil T-3358. Other bearings, especially synthetic ones, might exhibit better results but further development was beyond the scope of this research.

The KSU prototype digital anemometer did produce a 0.4 volt peak to peak sinusoidal signal. This signal was sent by shielded cable to a remote amplifier and counter. However, due to noise and signal level, the system was modified to amplify the signal within the anemometer and send a 0-5 V pulse train to the counter. The 0.4 volt signal produced by the LED-photodiode pair is compared with a 0.2 volt reference by a LM311 voltage comparator. The output of the LM311, pulled to ± 5 Vdc with a 21 kΩ resistor, is connected to the input of the multiplexer-counter board via shielded cable. See Figure 2.6-1. The terminating end of the cable at the input to the board is pulled high with another 21 kΩ resistor and protected against lightning by an 8 kΩ resistor-6.8 volt Transzorb pair. The signal is shaped and gated by a CMOS 4093 Schmitt trigger NAND Gate. The pulse train is counted by a 4520 (Dual 4 bit binary counter). See Figure 2.6-2.

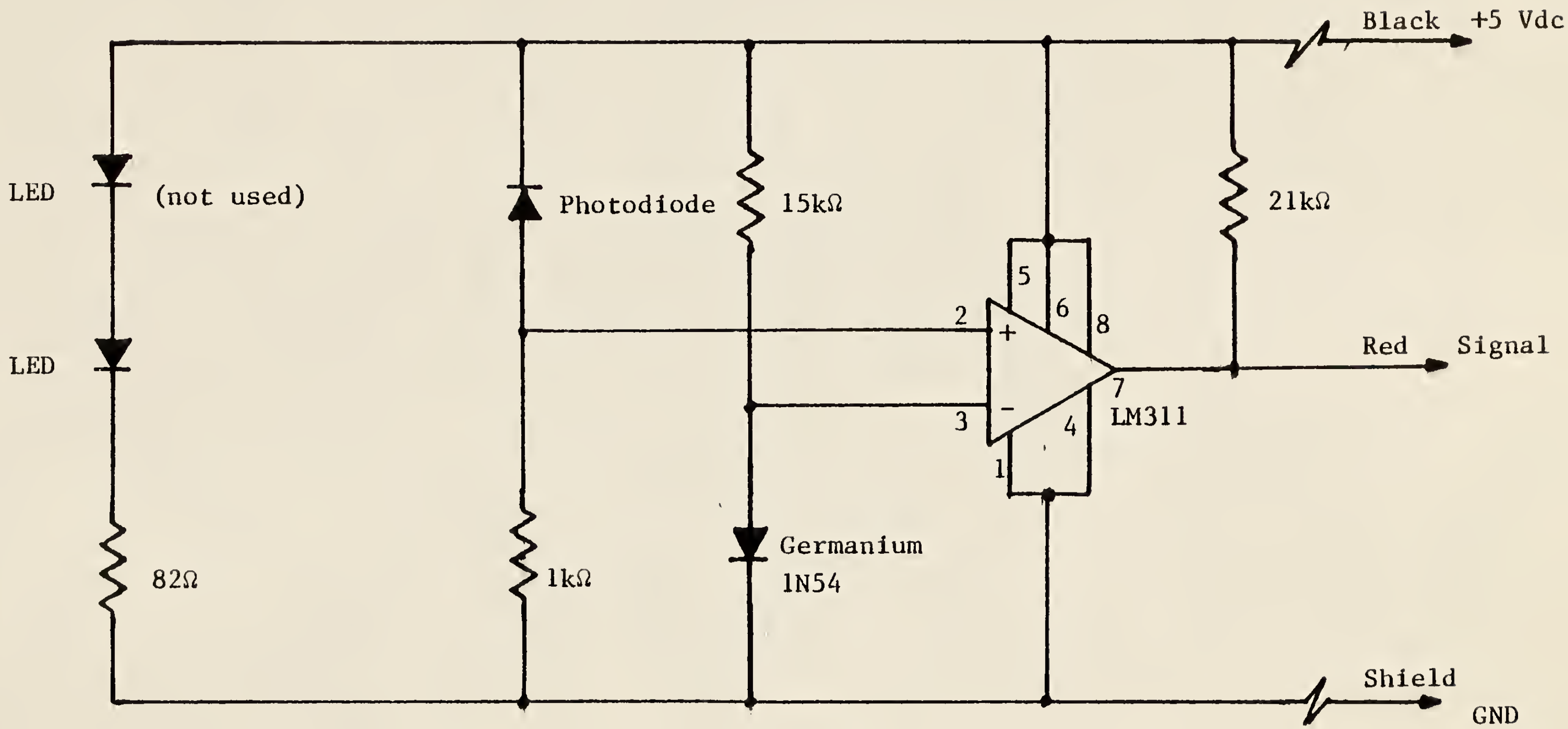


Fig. 2.6-1. Digital Anemometer Photochopper and Voltage Comparator. Components are located in the anemometer housing.

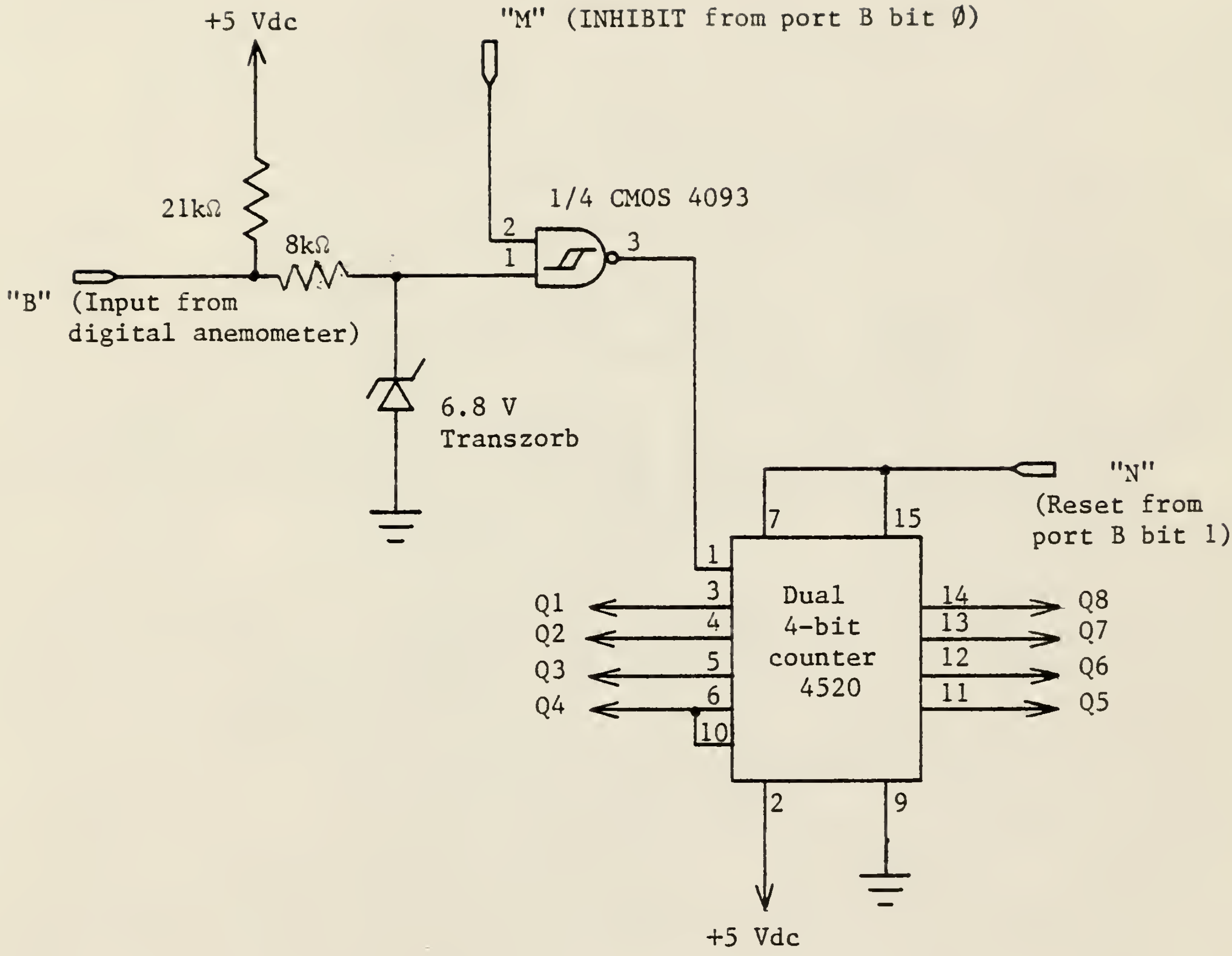


Fig. 2.6-2. Diagram of the KSU Prototype Digital Anemometer Signal Conditioning, Gating and Pulse Rate Counter. Components are located on the multiplexer - counter board.

The digital anemometer counter is read by writing a Ø to bit 4 of port B and a 1 to bit 5. This write connects port A through the multiplexer to the anemometer counter. The counter is inhibited by writing a Ø to bit Ø of port B and the counter contents read by fetching port A. The counter is then reset by a 1 written to bit 1 of port B. Note that both the digital anemometer counter and the angular velocity counter are inhibited and reset by bits Ø and 1 of port B.

2.7 Analog Anemometer

Analog anemometers used at the KSU Wind Laboratory are Electric Speed Indicator Company type F420-C wind speed transmitters. These devices are direct current permanent magnet generators which are self-contained and require no external source of electrical power. With the Wind Laboratory instrumentation system, the fact that the anemometers are self-powered is of little concern, but with a battery powered system, this is of major importance. The output of the anemometer is loaded with a 430Ω resistor, passed through a lightning protection network and fed to the A/D. The input range of the A/D is 0 to 3 volts allowing wind speeds from 0 to 34 m/s (0 to 77 mph). See equation 2.7-1.

Calibration of the anemometer is achieved by driving the armature of the anemometer with a synchronous electric motor and setting the output by adjusting the commutator. With the calibration system used at the KSU Wind Laboratory, the anemometers are driven at 525 RPM with a synchronous motor and the output of the anemometer adjusted to 2.1 volts. With the errors measured during calibration of six anemometers, it is likely that many previous wind records are in error. For example, the output of one anemometer in use for two years was off by a factor of two.

Errors arise from dirty commutator brushes or dragging bearings. The method of calibration given above is quite adequate if the bearings in the anemometer are good. However, if any drag develops from the bearings, the calibration results will be correct, but the field results will be in error. The errors arise from the fact that the driving motor develops enough torque to overcome the bearing effects. Drag related errors are impossible to detect with this calibration method. It would be desirable to have a device to determine the rolling resistance of the bearings. This type of test could be performed in many different ways, but it would be preferable to define one method as a standard. It is suggested to lubricate the bearings once a season and if they are untestable to replace them at the same time. The method of bearing removal and proper lubricants can be found in the Electric Speed Indicator Company F420-C manual.

The six anemometers were tested after calibration for linearity and deviation with the use of the USDA Wind Erosion Laboratory wind tunnel at Manhattan, Kansas. The anemometers were tested with one cup assembly to reduce data variation. The output of each anemometer was loaded with a 430Ω resistor and connected to an A/D input on a Hewlett-Packard Data Acquisition system (Model 2114). The A/D computer system sampled the anemometer and pitot tube assembly 100 times per second and averaged the values over 10 seconds. The test results were quite good with an approximate 1% non-linearity measurement between 2 m/s (4.5 mph) and 13 m/s (29 mph). The absolute error of wind speed at 1 volt output is within 1% and the standard deviation of the anemometers was equal to 0.06 at the 1 volt output level. Another test was performed comparing the output of the anemometers with different cup assemblies. Cup assemblies, 3 new and one pitted were tested on the same anemometer. The output of the anemometer with the three new assemblies was virtually the same. The pitted assembly, however, had an approximate 2% reduction in output at 10 m/s wind speed.

Data given by the Electric Speed Indicator Company and verified by tests performed in the USDA wind tunnel demonstrated that the voltage across the 430Ω load resistor is described by the following equation:

$$V_0 = \frac{u - 2.3}{25} \tag{2.7-1}$$

where u = wind speed in mph

V_0 = output in volts

Electric Speed Indicator Company also gave data for a relationship between wind speed and angular velocity of the anemometer which can be found to be

$$n = 10(u) - 23 \tag{2.7-2}$$

where n = angular velocity in rpm

Solving equation 2.7-2 for wind speed and substituting it into equation 2.7-1, yields:

$$V_0 = \frac{n}{250} \tag{2.7-3}$$

Equation 2.7-1 is used to compute the wind velocity after data collection and equation 2.7-3 is used for calibration purposes.

2.8 Pressure Transducer

A National Semiconductor Model LX1602A [9] pressure transducer is used to measure atmospheric pressure. This transducer is a hybrid device and is easily interfaced to the A/D microperipheral. See Figure 2.8-1. The device has an overall span accuracy of ±3% with better than ±0.5% repeatability over the rated pressure span. The pressure transducer is limited to a range of absolute pressure between 0 and 103 kPa (0-15 psia).

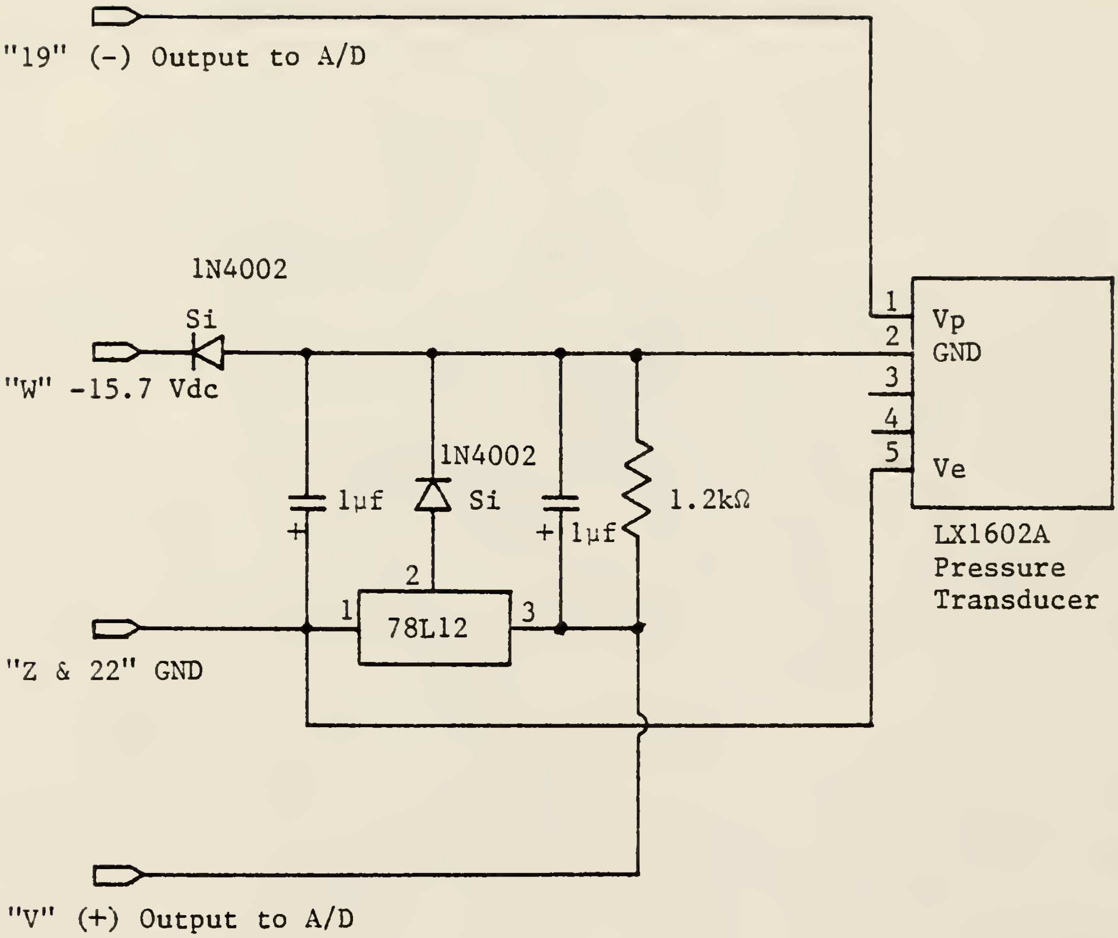


Fig. 2.8-1. National LX1602A Pressure Transducer and Interface Block Diagram.

Another choice of transducer would probably be better in this application because of the transducer's operation close to the uoper end of tis pressure range. This results from the fact that the mean pressure at Manhattan, Kansas, is 98 kPa (14.2 psia).

2.9 Temperature Transducer

A Westinghouse model VT2-841 temperature transducer [10] is used because of its availability and simplicity. This transducer uses a bridge circuit to convert the resistance of a copper detection coil into a voltage. The detection coil resistance is linearly proportional to its temperature over the range of interest. The temperature transducer output is low pass filtered, amplified, and connected to the A/D. See Figure 2.9-1. The accuracy of the transducer is within 2% between 9 and 100°C.

2.10 Wind Direction Transducer

The wind direction is measured by an Electric Speed Indicator [11] model F420-CR2 wind direction transmitter. This transducer is equivalent to a 206Ω potentiometer with the wiper driven by the direction vane. The ends of the resistor are connected to a 3 volt regulated power source. The regulated power supply is necesary because not all direction indicators have the same internal resistance. Regulation is achieved by the use of a transistor, operational amplifier pair as shown in Figure 2.10-1. Shown in Figure 2.10-2 are the connections to the direction indicator and Figure 2.10-3 shows the 5 Vdc reference for the 3 Vdc regulator.

The wind direction indicator arrangement equates both zero and three volts to North. See Figure 2.10-4. The absolute accuracy of the wind direction transmitter is dependent on the linearity of the potentiometer element and was never checked.

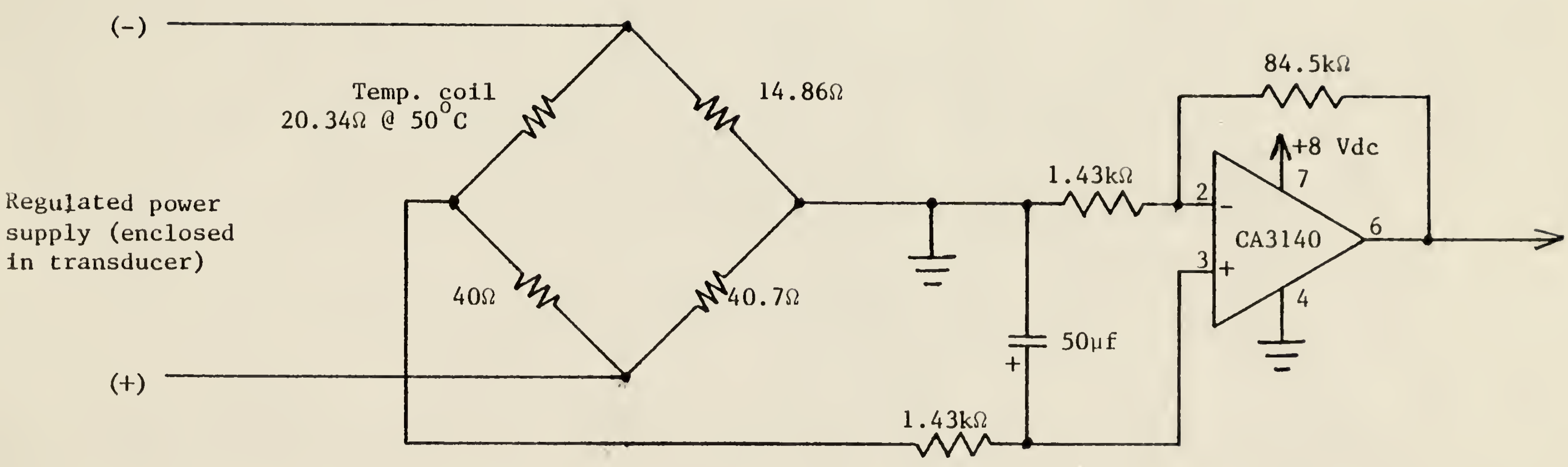


Fig. 2.9-1. Westinghouse Temperature Transducer, Filter and Amplifier Block Diagram. Amplifier is non-inverting with a gain of approximately 60.

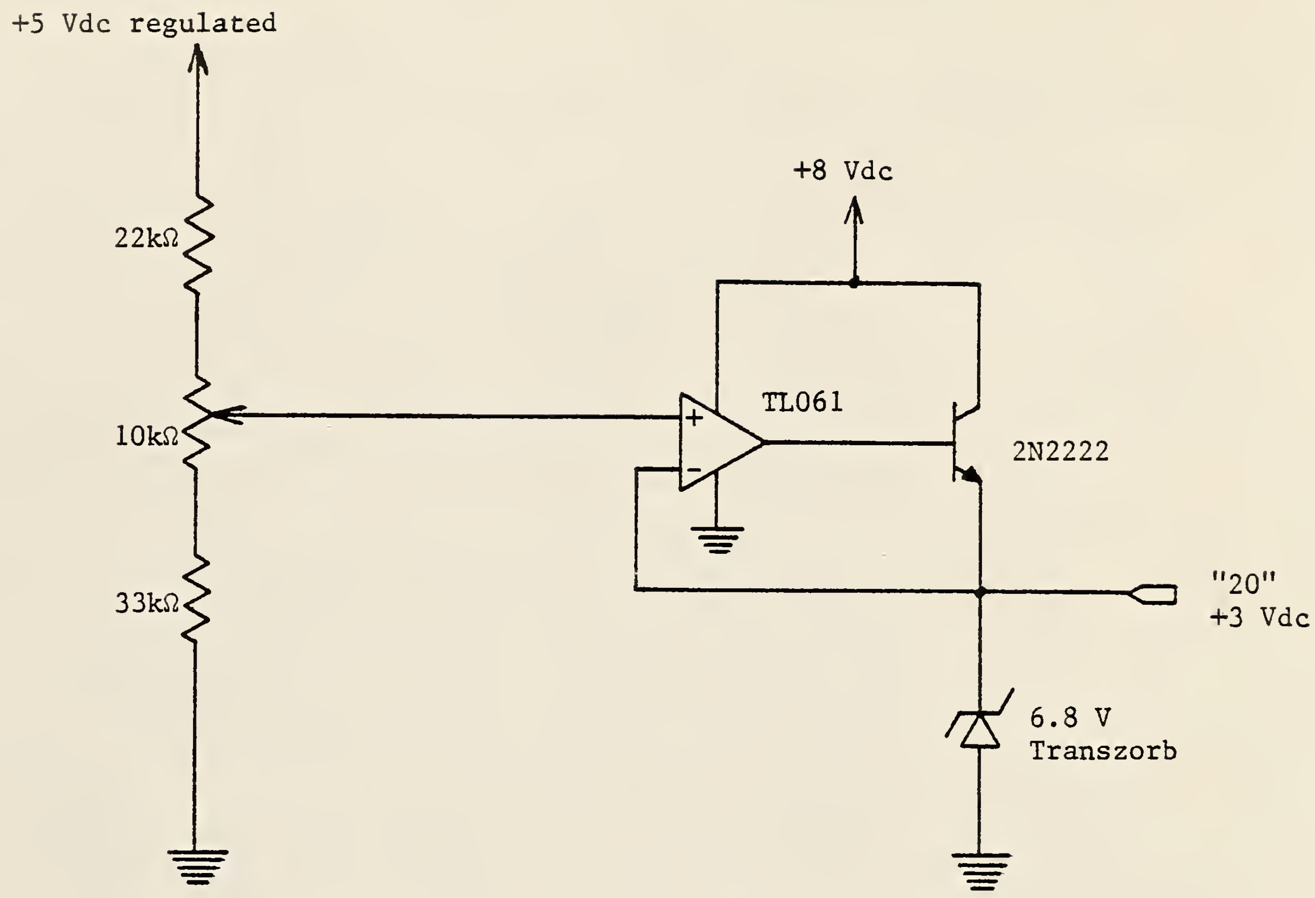


Fig. 2.10-1. +3 Vdc Regulator for Wind Direction Indicator.

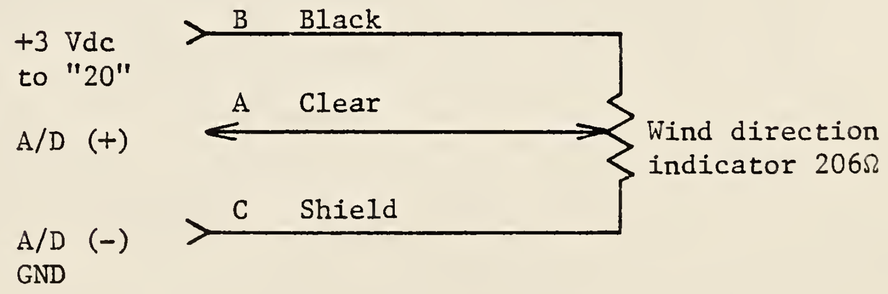


Fig. 2.10-2. Wind Direction Indicator Connections.

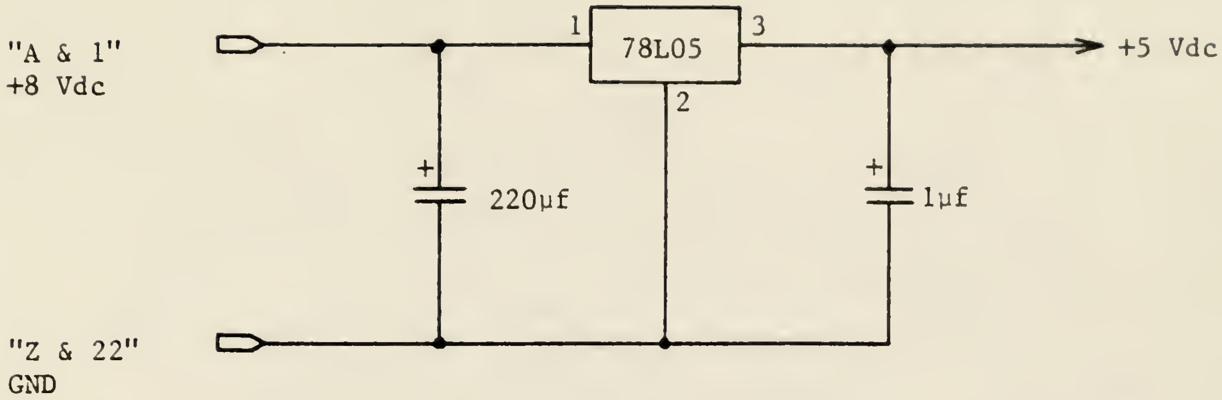


Fig. 2.10-3. +5 Vdc Regulator for Air Pressure - Wind Direction Card.

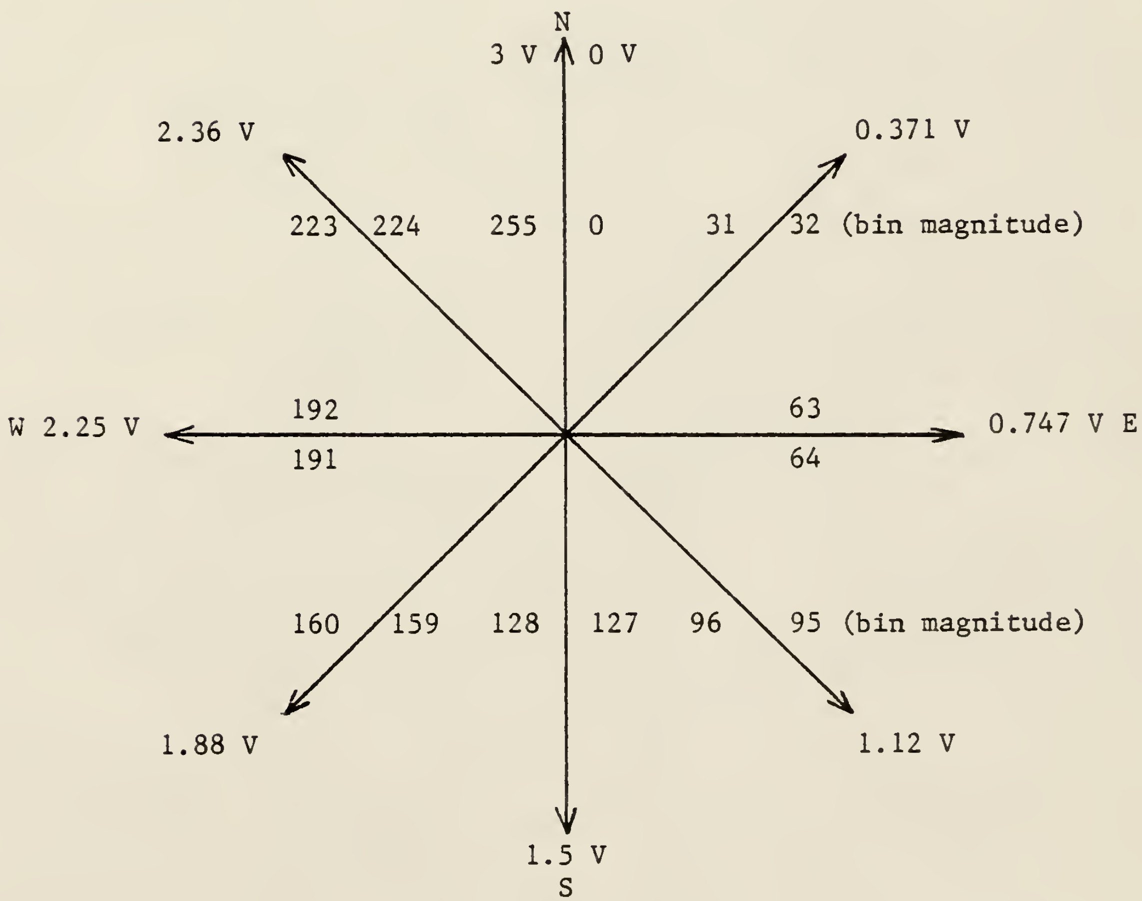


Fig. 2.10-4. Wind Direction Indicator Rose. Output voltage and bin magnitude given.

2.11 Torque Transducer

A Lebow [12] model 1604-1k torque sensor is used for torque sensing in the wind turbine power output shaft. This device employs a power shaft that deforms linearly and in a repeatable manner under a load torque. An array of strain gages are bonded to the power shaft in a Wheatstone bridge configuration. Wheatstone bridge strain gage arrangments inherently compensate for temperature and variations in loading. The strain gage bridge is connected to the secondary of a rotary transformer with the primary of the transformer driven by a Lebow [13] model 7535 strain gage indicator. This indicator generates a 3.2 kHz carrier to excite the sensor rotary transformer. In turn, the sensor modulates the carrier with torque information and returns the modulated carrier to the indicator. The indicator demodulates and filters the signal with a cutoff frequency of 5 Hz. The signal is then amplified and fed to the A/D microperipheral card.

The Lebow strain gage indicator has adjustable gain and the output is set to 3 volts at 1000 in-lb of torque. The torque sensor location in the turbine power shaft is shown in Figure 2.11-1. Torque relationships between the sensor turbine rotor and the sensor alternator, neglecting gear and sprocket losses, are as follows:

$$Tr = \frac{120}{17} Ts$$

$$Ta = \frac{17}{42} Ts$$

Tr = rotor torque

Ts = sensor torque

Ta = alternator torque

With the Wind Laboratory system, the strain gage indicator output is sampled and a bin incremented corresponding to the sampled value. Results of this operation are given in Section 4.4.

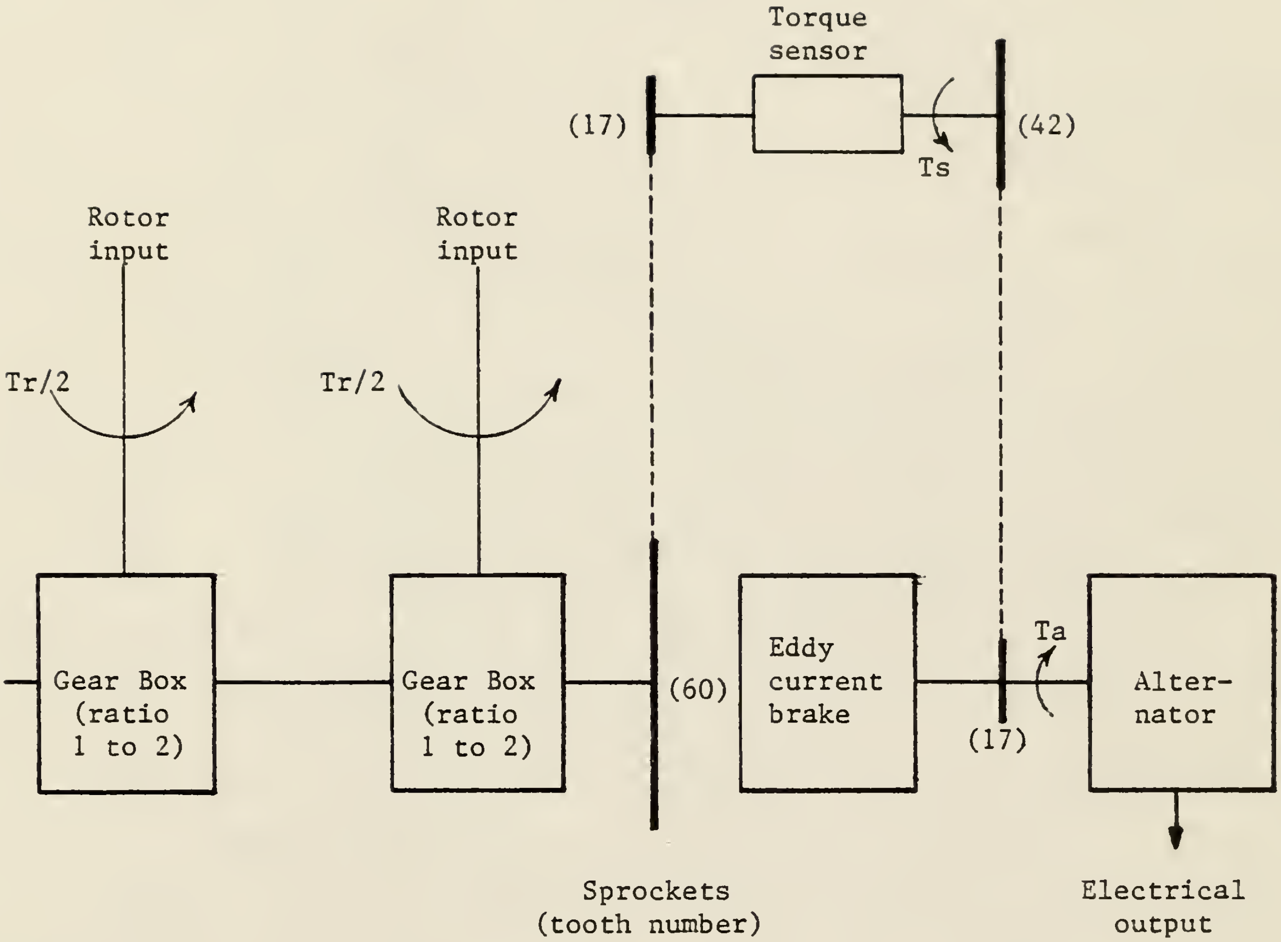


Fig. 2.11-1. Block Diagram of the KSU Savonius Wind Turbine Power Shaft.

2.12 Electrical Power Transducer

The electrical power produced by the Wind turbine is measured with an F.W. Bell [14] model PR-2401SX three-phase watt transducer. This transducer is a 4 wire, balanced voltage device that provides a direct current output proportional to three-phase power. Isolation and the dc output are achieved by use of the Hall-effect. The output of the transducer is 1.0 ma at rated power into a load resistor between 0 and 10 kΩ. A resistor value of 1.78 kΩ was used on the Wind Laboratory system giving a 3 Vdc signal at 6754 watts with the potential and current transformers used. See Figure 2.12-1. With this transducer, accurate measurements of real power to within 0.5% with linearity to within $\pm 0.2\%$ of rated output are attainable. Accuracy deviated as input frequency and voltage varied but was within 1% between 20 Hz and 70 Hz. Below 20 Hz this watt meter was not tested but similar Hall effect transducers were accurate to within 1% as frequency varied to a few Hertz if voltage varied with frequency.

2.13 Alternator Voltage Transducer

A signal proportional to the wind turbine alternator output is obtainable by a three-phase halfwave rectifier circuit. The rectified output is reduced by a resistor voltage divider and fed to the A/D microperipheral card where it is filtered. See Figure 2.13-1. The voltage divider network is an 18.2 kΩ resistor and a 430Ω resistor to give an output of 3 V at 130 V rectified input.

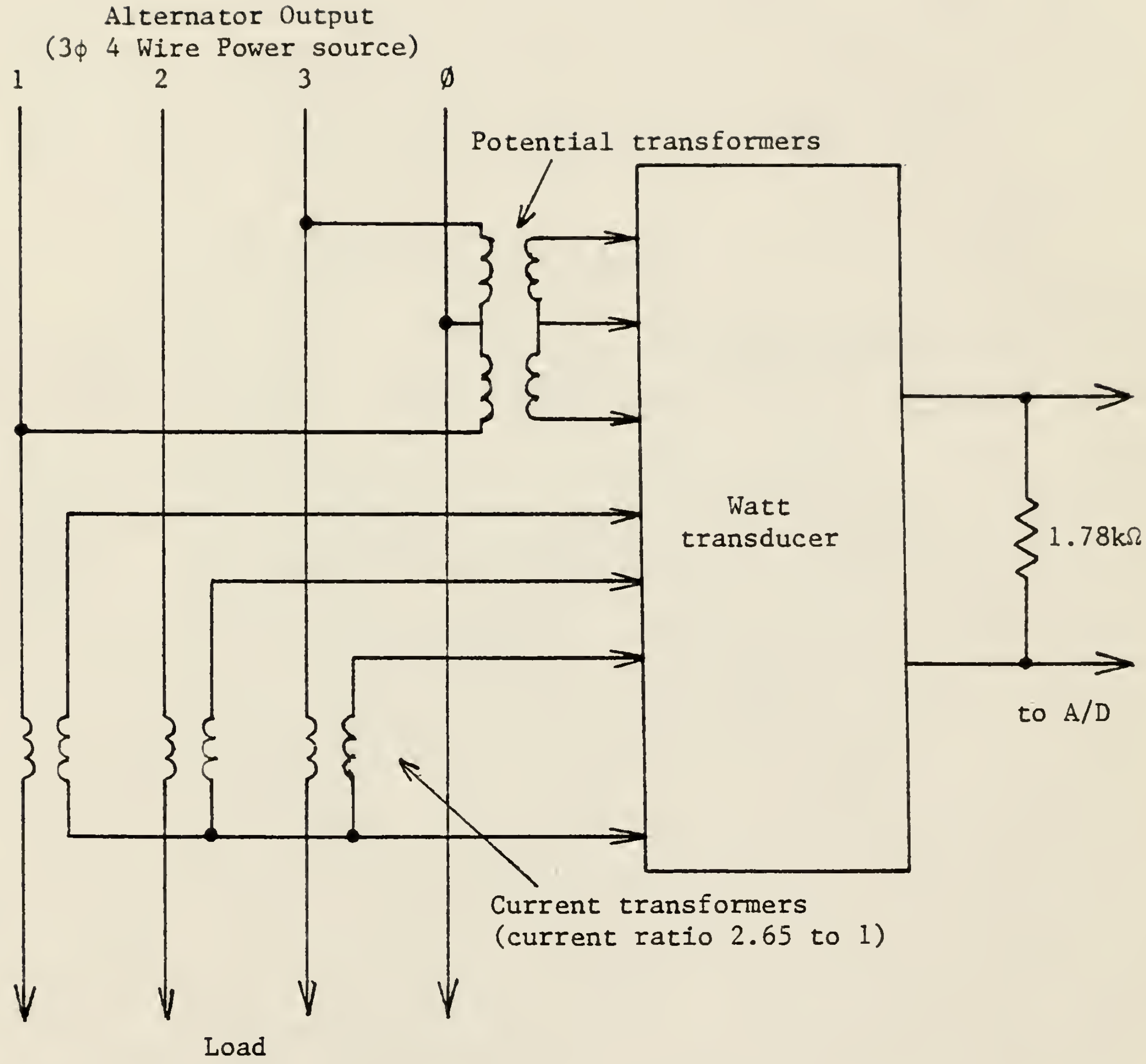


Fig. 2.12-1. Electrical Power Transducer Block Diagram.

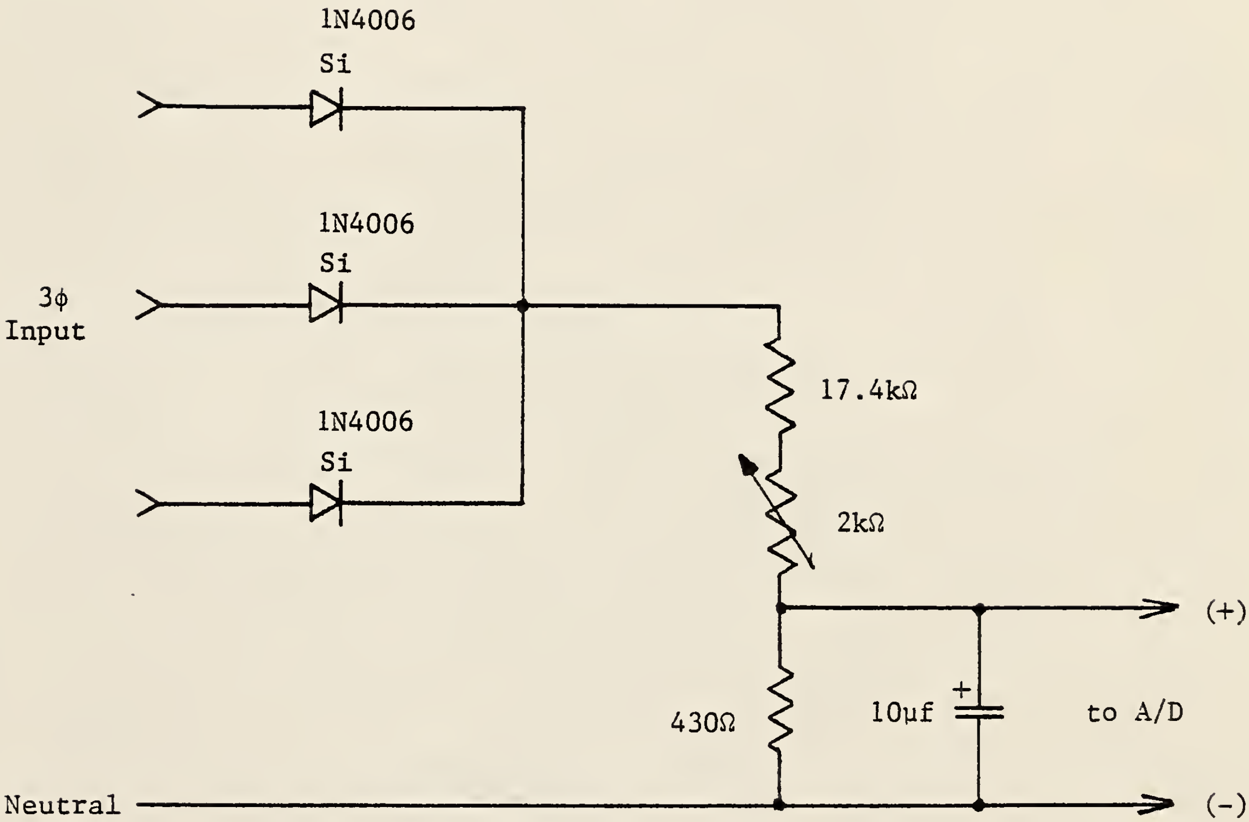


Fig. 2.13-1. Halfwave Rectifier for Alternator Output Voltage Transducer.

2.14 Analog to Digital Converter

Desirable features of an A/D converter for the Wind Laboratory data acquisition system include easy programming, no input-output ports needed on the microprocessor, no external logic, and being completely self-contained.

The Burr-Brown [15] MP21 is such a device with analog inputs and a digital output. The device contains a high speed, eight bit A/D converter, an input multiplexer that can accept up to sixteen single ended or eight differential signals, and an instrumentation amplifier. The block diagram is shown in Figure 2.14-1. The offset and gain are factory laser trimmed so that no external adjustments are required on the ± 5 volt or the 0 to 5 volt input range to obtain an absolute accuracy of better than $\pm 0.4\%$ (1 LSB). Our instrumentation used an input signal of 0 to 3 volts with only the addition of one resistor and a single potentiometer for gain adjustment. By changing the gain, input ranges as low as ± 10 mV can be used.

The MP21 is treated as memory with each analog input channel occupying one memory location. The analog inputs are read with a load or fetch instruction from the processor. Conversion time requirements demand that the address for a given analog channel be read twice in order to get one correct value. The first read addresses the channel, samples the input and starts the conversion. The first read also sets a flip-flop to note that it is the first read. After the required conversion time another read can be made to input data.

The conversion delay is obtainable using four different methods. One is to start the conversion with a read, allowing the MP21 to halt the processor for conversion. When the halt is finished the processor reads

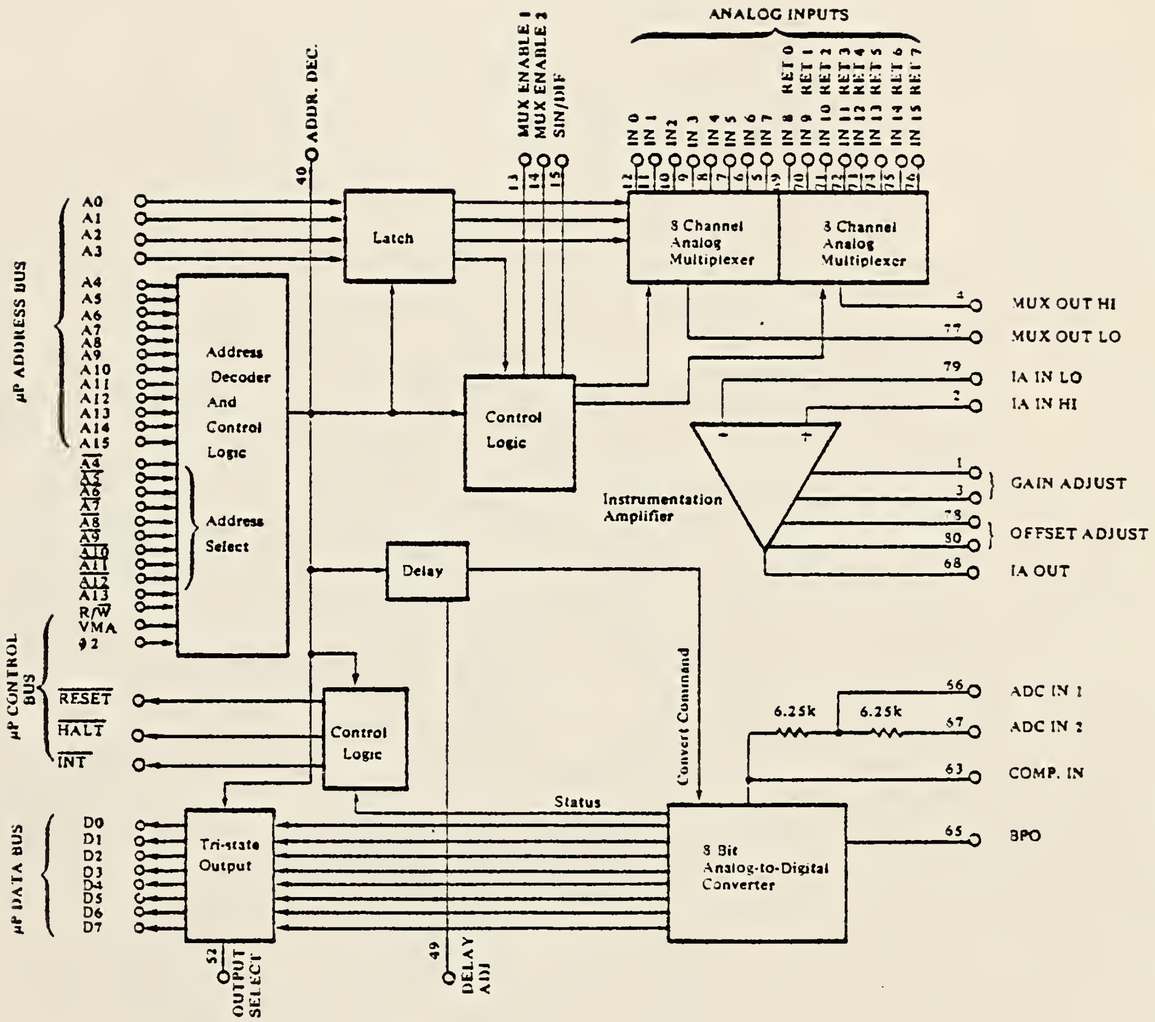


Fig. 2.14-1. MP21 Block Diagram.

the channel to fetch the data. The second delay method is to connect the Halt line of the MP21 to an input port of the processor. Periodically, after the first read, the processor checks the line to detect a complete conversion. When the conversion is complete, the MP21 is read again to obtain the new data. The third method is to connect the interrupt line of the MP21 to the processor. Conversion is started with a read and the MP21 will interrupt the processor when finished. At this point, the data can be fetched. The fourth, and the method used in the Wind Laboratory instrumentation system, is to read a channel and start the conversion. Then a sofware time delay equal to the conversion time is followed by a second read to fetch the data.

Conversion time is a function of amplifier gain, multiplexer setting, and the actual A/D conversion. This time is typically between 40 and 200 microseconds depending upon the gain of the amplifier. Industry tends to use successive approximation A/D's because they offer an excellent compromise between accuracy and speed. The MP21 uses such an A/D with a throughput of 25 kHz per channel. This includes 35 microseconds for multiplexing and amplification and 5 microseconds for A/D conversion. The throughput rate can be increased substantially if an external instrumentation amplifier is used. Burr-Brown, for instance, claims a throughput of 125 kHz per channel with their 3626 high speed amplifier.

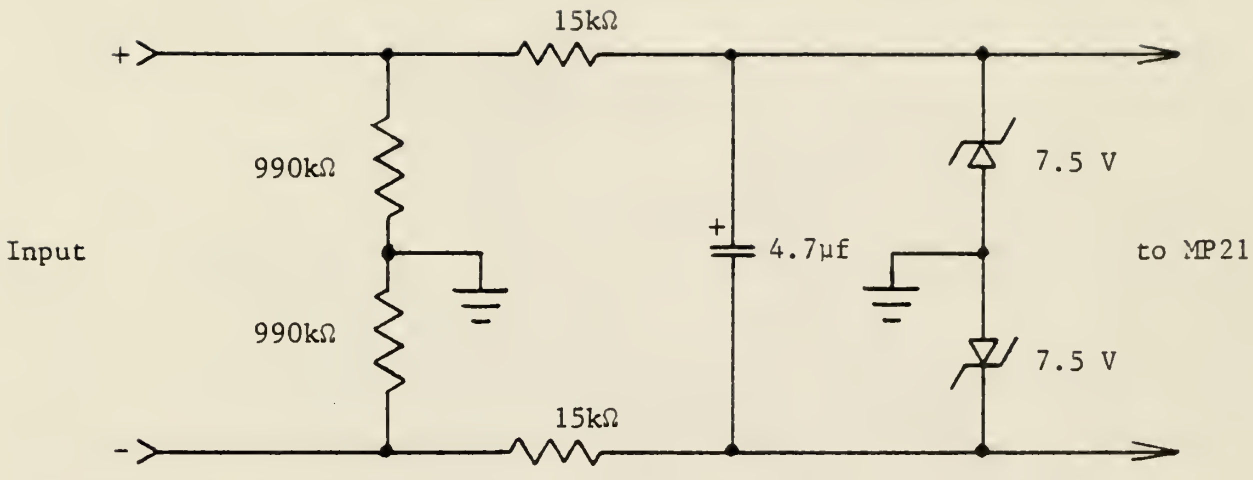
The MP21 is directly compatible with the 6800 and 6502 microprocessors. The MP20 performs the same function as the MP21 but is compatible with the 8080 family. Either device can be placed directly on the microprocessor address and data bus; each line is equivalent to one LSTTL load. In general, no external logic is needed because logic levels and timing are microprocessor compatible. The MP21 has fully decoded address capability and can lie anywhere above CØØØH without additional gating. On the Wind Laboratory system the two high order bits were inverted for compatibility with the KIM-1. The KIM-1 is decoded for addresses below 1FFFH. The memory map for the MP21 is given in Table 2.14-1. Edge card connections and MP21 connections are given in Appendix C.

Table 2.14-1. MP21 Memory Map

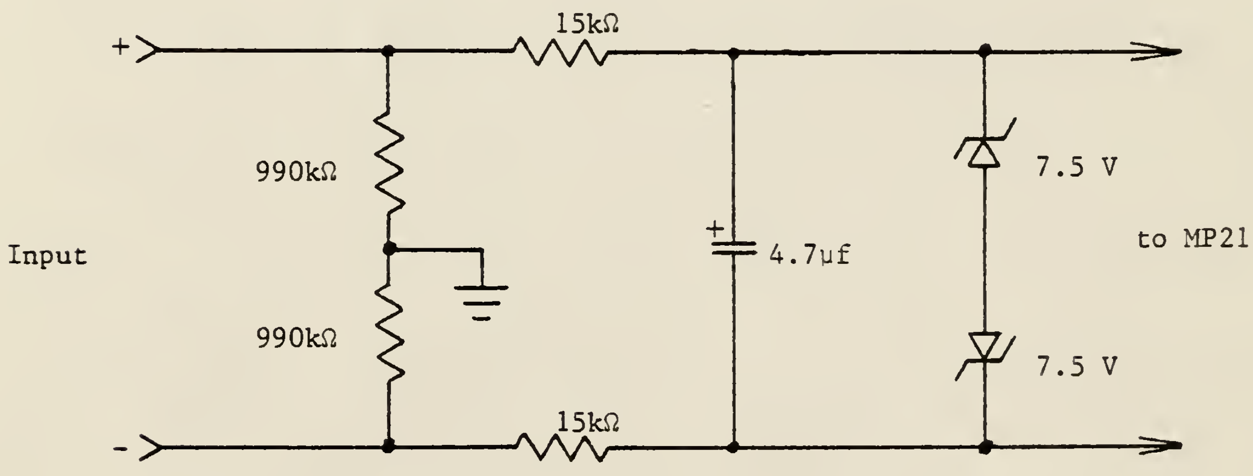
Analog Channel	Address
1	14ØØH
2	14Ø1H
3	14Ø2H
4	14Ø3H
5	14Ø4H
6	14Ø5H
7	14Ø6H
8	14Ø7H

The power requirements for the MP21 are ±30 and 90 mA at ±15 and 5 Vdc, respectively. The device when first viewed is an impressive 80 pin package, but the application and use of the MP21 is very simple and straightforward. After deciding on the mode of operation, and connections have been made to the address bus, data bus, control lines, power and analog inputs, the MP21 is ready to work.

The analog inputs are internally protected by reverse biased diode circuits against over voltages up to ±23 V. External protection is added by means of series resistors and Zener diodes. See Figure 2.14-2. The external diodes also protect the input from damage by static; however,



All channels except channel 7



Channel 7

Fig. 2.14-2. Input Protection for A/D (MP21).

static precautions should still be observed. Neither the internal diodes nor Zener diodes protect against lightning. The MP21 will work without difficulties over a wide range of input voltages. Typically, these voltages are between ± 10 mV to ± 5 V.

Problems arising with the MP21 were few. However, one problem that developed was that the 6502 does not have a Valid Memory Address (VMA) line. To compensate for this, the VMA line on the MP21 was tied high. In this mode of operation, everything operates properly unless the Halt capabilities are also used. The Halt feature is such that after a read of the MP21, the MP21 pulls the Halt line low. This stops the microprocessor for 40 microseconds, allowing for settling and conversion. Since the address lines on the 6502 are still valid, the MP21 decodes and starts conversion every other clock cycle. This decoding keeps the Halt line low and the processor is latched in the halt state. Writing a software loop of 40 microseconds avoids the use of the Halt line and also allowed the interrupts to be serviced at any time.

Another problem--and a very major one in outdoor work--is lightning protection. With wind turbine instrumentation, the input of the MP21 must be protected against lightning and transients. The proposed method is a series resistor and a parallel transient suppressor.

2.15 Lightning Protection

Any instrumentation system used in the out-of-doors is subject to lightning and its induced transients. Protection against lightning can be accomplished by many different methods.

Active lightning protectors typically come in three types of devices: crowbar, constant voltage, and combinations of these [16]. A crowbar device will effectively become a short to ground when the input voltage exceeds some value and remain shorted until the current drops to a low level. On the other hand, a constant voltage device will conduct very heavily when the voltage rises above a specified level and below this level the device conducts very little.

Common constant voltage devices used today are Zener diodes, varistors, and silicon voltage suppressors. These devices will all accomplish the same function, but vary significantly with respect to response time. A lightning induced voltage can rise to thousands of volts in a few microseconds. Therefore, it is important to select a device with an extremely fast response time. The silicon voltage suppressor has this feature.

Gas discharge tubes and spark gaps are the most widely used crowbars. To obtain a low cost device with fairly constant striking voltage, standard NE-2 neon lamps can be used. These lamps break down and ignite at approximately 80 Vdc and will conduct a few milliamperes of current until the lamp extinguishes at about 60 Vdc. At voltages above 170 Vdc, the lamp allows extremely large amounts of current to flow. Currents of these magnitudes will destroy the lamp if allowed to flow for more than a few microseconds; however, with lightning this is of little concern.

Combinations of neon lamps, 1.4 kΩ resistors and 6.8V silicon suppressors were used to protect the A/D inputs on the Wind Laboratory instrumentation system. The arrangement is shown in Figure 2.15-1. The A/D used in this system has differential inputs with input impedances of approximately 5 gigaohms. Therefore, the additional impedance of the resistor is of little importance. The resistance in this circuit can be

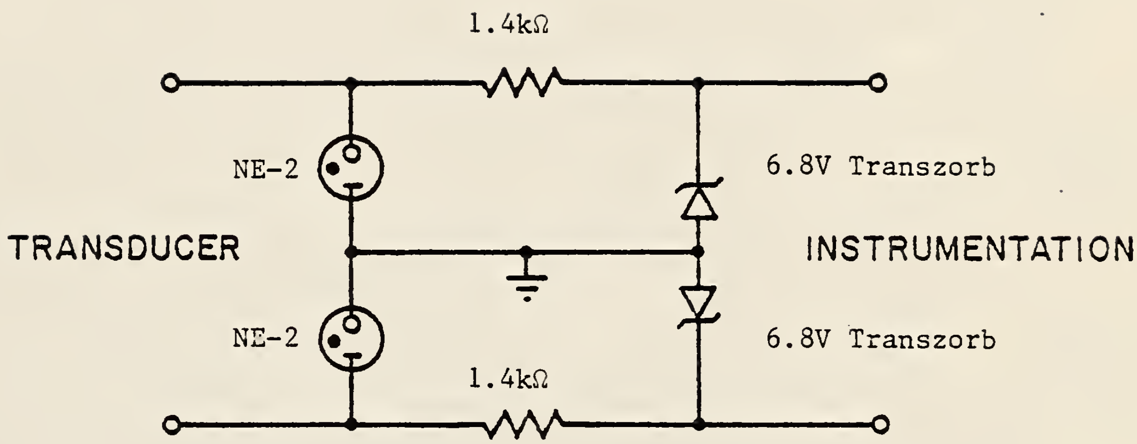


Fig. 2.15-1. Lightning Protection Circuit.

replaced by an inductor if the dc resistance is intolerable. The combination used eliminates impluse spikes, allows large fault currents to flow yet maintains a safe voltage at the output.

Power supply protection is also necessary to ensure that voltage transients do not damage the instrument. One of the simplest methods of providing protection is a battery placed in parallel with the power supply as a buffer.

None of these systems will provide protection against a direct hit, which will destroy the instrument. They will, however, protect against near misses.

Another possible method of protecting wind instruments from lightning is the use of light-coupled transducers. For anemometers, this would entail a fiber optic channel from a light source in a protected environment to the anemometer. The anemometer would interrupt the light with a chopper wheel and return the information through another fiber optic channel to a photo sensor in the protected instrument. A similar type arrangement could be utilized by a wind direction indicator employing a gray code. With fiber optics being the only exposed information channel, lightning problems would essentially be eliminated. Power consumption of the fiber optics system is not large, but may be substantially larger than the power requirements of a CMOS microprocessor. This would be an important consideration in a battery powered wind instrumentation system.

2.16 Calibrations and Errors

Errors can arise in any instrumentation system from many sources. It is of utmost importance to achieve a system that can be used with complete confidence. The only way to gain this confidence is careful calibration of each transducer and of the instrumentation system. With the Wind Laboratory system, each transducer was calibrated by methods given in their appropriate sections. The A/D was calibrated by a standard 1 volt cell and the pulse rate counters by a signal generator and frequency meter. Calibration must be done regularly to ensure quality data. Some possible errors can be reduced by proper design and the use of high quality devices such as instrumentation amplifiers.

3. SYSTEM SOFTWARE

3.1 Introduction

Software is given for two different modes of operation. The first mode of operation is binned data acquisition, and the second mode is sequential data acquisition. The sequential data acquisition program samples all of the transducers 6 times per second for 256 samples each. These sampled values are stored in memory and punched on paper tape after complete acquisition. The binned data acquisition system samples each channel 6 times per second and increments a memory location corresponding to the magnitude of the sampled value and its channel number.

The software is divided and written as subroutines for ease of programming. Subroutine and the main program flow charts are given in Appendix E and the cross-assembled code in Appendix F. The flowcharts and programs are hopefully self-explanatory and therefore little discussion is given here. However, generalized flow charts are provided in the following sections to allow an overview of the system software.

3.2 MOS Technology Cross-Assembler

To allow ease of programming an MOS Technology cross-assembler was used to assemble the programs. The KIM-1 program is punched on standard IBM cards by using the format given in the cross-assembler manual. The punched cards are fed to the computer with the proper job control cards [18] to route the cross-assembler output to a user available file. The file produced by the cross-assembler includes much unwanted output. Techniques given by the KSU CMS Manual [19] can be employed to delete the unwanted output. The output needed is type ';3'. This type of output is in the form ;3, 8 spaces, starting address, space, 16 bytes of data, space and 2 bytes of checksum. Everything punched following and including the first line of type ';3' data is the program. The program is retrieved on paper tape by use of a modem and TTY (see details in the CMS manual). The program given in Appendix D will load the cross-assembled paper tape into the appropriate memory locations.

3.3 Binned Data Acquisition

The complete software to control the instrument is given in detail in Appendices E and F. However, a brief explanation of the system is given here with the aid of the generalized flow chart shown in Figure 3.3-1. After power-up, the processor idles, checking the keyboard. A user selected channel (key) will display that channel's most recently sampled value. At regular intervals, the timer will interrupt the processor which in turn resets the timer, updates the calendar and collects new data. Data collection is performed as two reads or fetches from the microperipheral. The first read starts the conversion and, after an appropriate wait, the second read fetches the data. The collected data byte is used as an address to increment the appropriate bin. After complete data collection, the processor will return to the display routines. If any bin is full, the processor will output the complete data file including time, date, and checksums to the paper tape punch.

An appropriate sampling rate must be chosen to sample the transducers and give reconstructable results. The analog anemometers have the fastest usable response time. Selecting the sampling rate to accommodate

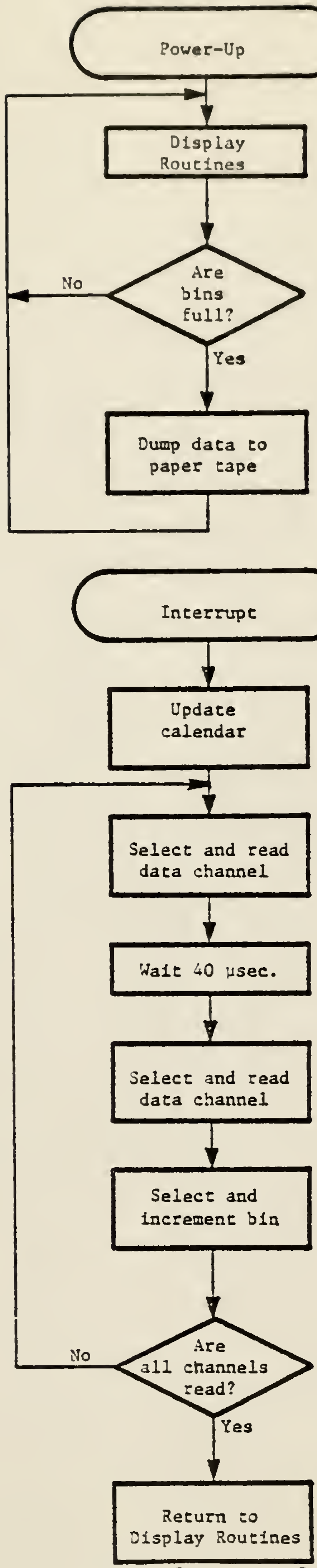


Fig. 3.3-1. Generalized Operating Schemes for Data Collection.

these anemometers will ensure that the sampling period is shorter than all other time constants of the wind turbine system. Analysis given by Bootman indicates that a sampling frequency of 1 to 4 samples per second would be adequate to reconstruct the original signal. Because of programming ease, a sampling frequency of 6 Hz was chosen. The analog inputs of the A/D board are low pass filtered to a 1.2 Hz cutoff frequency. With this cutoff frequency, sampling rates as low as 3 Hz can be made without a frequency aliasing problem. There is some question whether aliasing can be considered a problem with binned data sampling and needs further investigation.

3.4 Sequential Data Acquisition

The sequential data acquisition routine samples the transducers 6 times per second and records the sampled value in order of sampling for 256 samples of each transducer. A generalized flow chart is shown in Figure 3.4-1. The machine is initialized for one-sixth of a second interrupts and the channel count set to zero. After an interrupt to wait for 1/6 of a second, both digital channels and all 8 analog channels are read. Upon the collection of 256 samples from each channel, the computer jumps to the output routine of the binned data program and punches the data on paper tape.

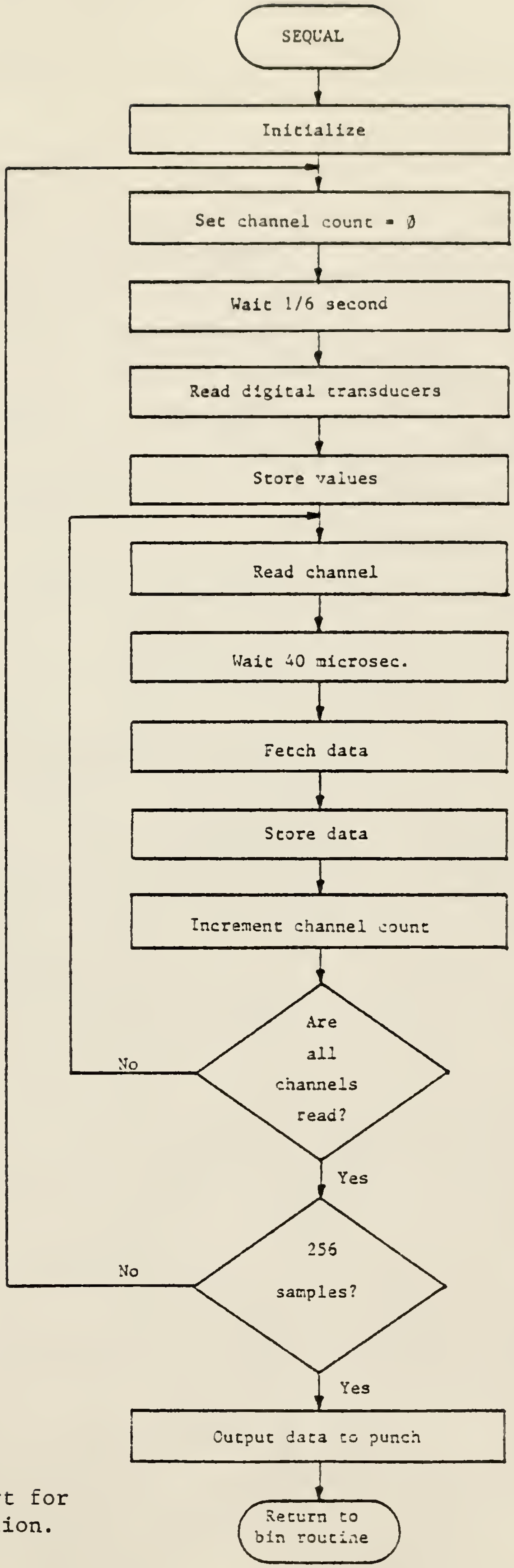


Fig. 3.4-1. Flow Chart for Sequential Data Collection.

4. SYSTEM OPERATION

4.1 Introduction

System operation is both simple and straightforward. System programs are recorded on audio cassette by methods given in the KIM-1 user manual. For operation the system is powered-on with ±15.7 Vdc, ±12 Vdc and +5 Vdc. The +12 Vdc is only required for the audio cassette operation. After power-on, the system program is loaded into the system memory. See Appendix A for deatils. Once the system program is loaded, the user must initialize time, date and mode of data collection. There are three types of data collection - binned data above angular velocity threshold, binned data and sequential data. In the binned data above angular velocity threshold mode, the transducers are sampled 6 times per second and the information built into a histogram only when the turbine's angular velocity is above a specified level. If the turbine's angular velocity is not great enough, the transducers are not sampled nor the bins incremented. The binned data mode functions the same as the binned data above angular velocity threshold mode only with a zero threshold. In either bin mode, data can be viewed while the system is running. Viewing is accomplished by the user selecting the channel of interest with the appropriate key. This operation displays in the KIM-1 address field, the last value the system sampled from the channel selected. A table of the channel numbers and their corresponding transducers is given in Appendix C.

In the binned data modes, the calendar does not update to a new year and must be done manually. It should also be noted that the delta wind speed is derived from positive changes in wind speed from the digital anemometer.

The sequential mode collects data in an ordered manner at 6 samples per second and stores the data in the microcomputer memory. After 256 consecutive samples are taken, the system dumps the data on paper tape and returns to the binned data mode. See Appendix G for detailed operations.

4.2 Memory Allocation

The microcomputer memory space is divided into regions for data, program, stack and temporary storage. Each transducer and computed value, such as mechanical power, has one page of memory reserved for data between Ø8ØØH and 13FFH. See Table 4.21. These locations are used for both sequential data and binned data acquisition modes. Locations between Ø2ØØH and Ø7FFH are reserved and contain the system program. Temporary storage locations are on page zero and the processor stack is confined to page 1.

4.3 Paper Tape Format

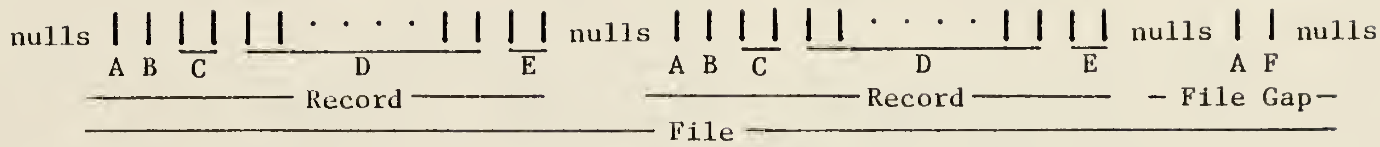
Data are collected and ordered in bins from Ø to 255. However, data are punched on paper tape in reverse order, high bin through low bin (i.e., bin 255, 254, 253,...,2, 1, Ø). The punch format is given in Figure 4.3-1 and is in the form of sync character, record type, number of data points, data and a two-byte checksum. After all records have been punched, a record type zero is punched to indicate end of file. An example time record is given in Figure 4.3-2, and record numbers which correspond to channel numbers are given in Table 4.3-1.

4.4 Data Reconstruction

All transducer values collected with the method of bins are mapped into a range or distribution. This range is defined as the bin width. The KSU Wind Laboratory system has 256 separate bins in which the span of

Table 4.2-1. System Memory Allocation

Address Page (Hex)	
13ØØ	Anemometer (Analog) #1
12ØØ	Torque
11ØØ	Electrical Power
1ØØØ	Alternator Voltage
ØFØØ	Wind Direction
ØEØØ	Air Temperature
ØDØØ	Air Pressure
ØCØØ	Anemometer (Analog) #2
ØBØØ	Angular Velocity
ØAØØ	Digital Anemometer
Ø9ØØ	Delta Anemometer
Ø8ØØ	Shaft Mechanical Power
Ø7ØØ	Program
Ø6ØØ	"
Ø5ØØ	"
Ø4ØØ	"
Ø3ØØ	"
Ø2ØØ	"
Ø1ØØ	Stack
ØØØØ	Temporary Storage



A ASCII Sync character (16H)

B Record type (non-zero)

C Number of points (16 bits, high byte low byte)

D Data (b bits) bytes punched in reversed order

E Check-sum (16 bits, high byte, low byte)

F Record type = Ø (indicates end of file)

Fig. 4.3-1. Paper Tape Format.

nulls	sync	DH	Ø	9	year	last min.	last hour	last day low byte	last day high byte	present min.	present hour	present day low byte	present day high byte	2 byte check-sum	nulls

Fig. 4.3-2. Example of Time Paper Tape File.

Table 4.3-1. Output Record Type

Record Number		
Dec	Hex	
Ø	Ø	End of file
1	1	1 - Analog anemometer
2	2	Torque
3	3	Electrical Power
4	4	Alternator voltage
5	5	Wind direction
6	6	Air temperature
7	7	Air pressure
8	8	2 - Analog anemometer
9	9	Digital anemometer
1Ø	A	Delta wind speed
11	B	Angular velocity
12	C	Shaft mechanical power
13	D	Time

the transducer is mapped. To properly reconstruct the transducer information some estimations must be made. All analog transducers used in the KSU system map a 3 volt signal range into the 256 bins as shown in Figure 4.4-1. Plotting a straight line through the center of the range yields a line 'A' and the following equation:

$$V = \frac{3 - \frac{3}{256}}{256} V' + \frac{3}{2(256)} \tag{4.4-1}$$

where V = output voltage

V' = bin number.

Equation 4.4-1 will yield results for all binned data taken with analog transducers. For the analog anemometer equation 2.13-1 yields:

$$u = 25\ V_0 + 2.3 \tag{4.4-2}$$

where u = wind speed (mph)

V_0 = output voltage.

Equation 4.4-1 and substituting into equation 4.4-2 gives:

$$u = 25 \left(\frac{3 - \frac{3}{256}}{256} V' + \frac{3}{2(256)} \right) + 2.3 \tag{4.4-3}$$

From information given in Section 2.11 on the torque transducer, it is known that with a torque of 112.99 Nm the output of the torque meter will be 3 V. This information and equation 4.4-1 yields the following results for turbine torque:

$$T = \left(\frac{3 - \frac{3}{256}}{256} T' + \frac{3}{2(256)} \right) 37.66 \tag{4.4-4}$$

where T = Torque at sensor (Nm)

T' = bin number.

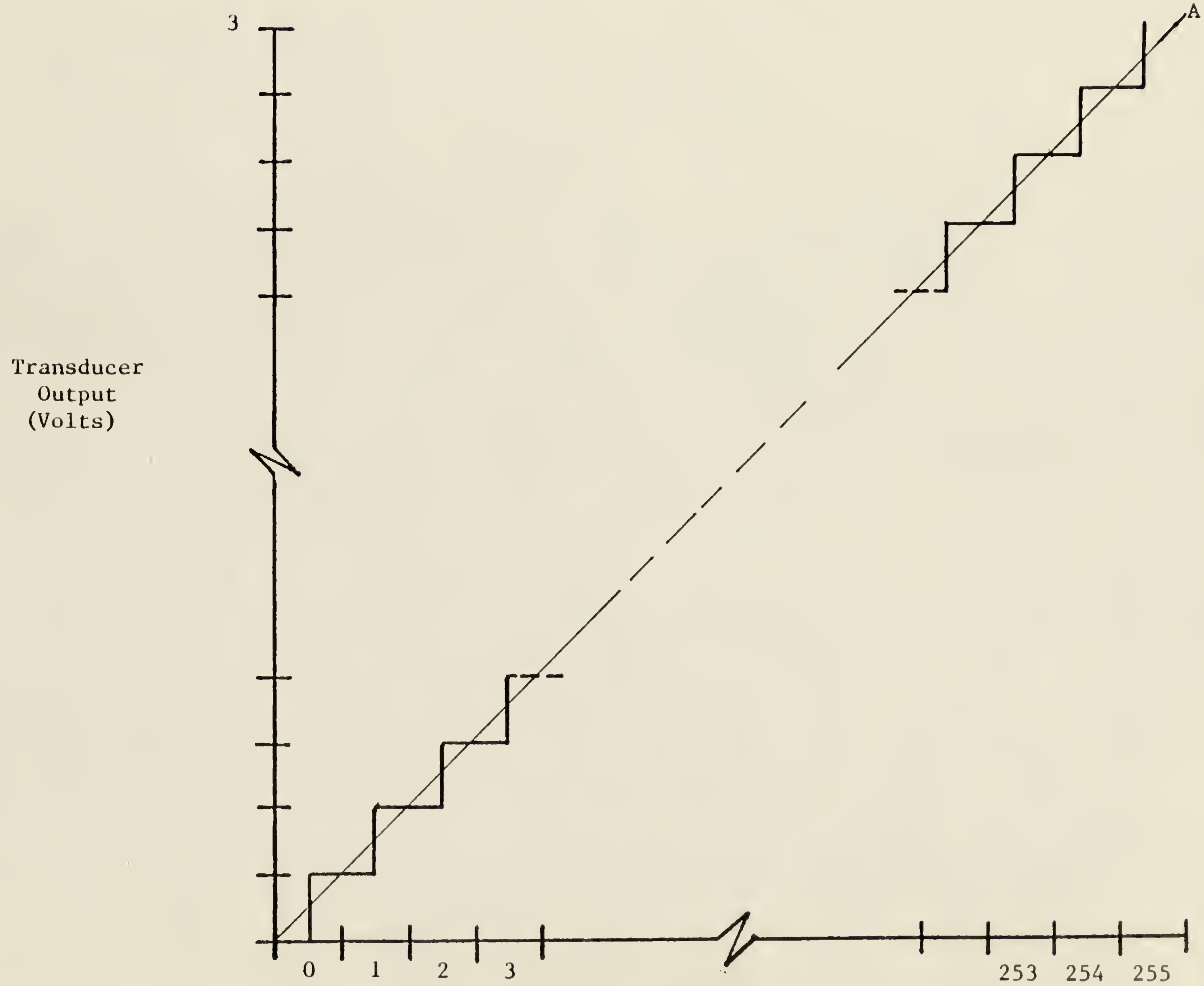


Fig. 4.4-1. Analog Transducer Output Mapped into Bins.

By following the above examples, relationships can be found for any analog transducer using the method of bins. Similar results can be found for the pulse rate transducers. For instance, it is known that from the angular velocity transducer

$$\omega_s = \frac{\pi}{5}\,\omega'' \qquad (4.4\text{-}5)$$

where ω_s = angular velocity at the transducer (rad/sec)

ω'' = sampled value.

The angular velocity values are also mapped into a range as shown in Figure 4.4-2. Equation 4.4-5 is also shown as line B. Upgrading the line to the center of each range or bin (line C) yields

$$\omega = \frac{\pi}{5}\,\omega' + \frac{\pi}{10} \qquad (4.4\text{-}6)$$

where ω' is the bin number.

To obtain a mechanical power value from the turbine, the instrumentation system does a multiplication of the sampled angular velocity (ω') and the sampled torque (T'). From equations 4.4-4 and 4.4-5 and Figures 4.4-1 and 4.4-2, it can be seen that this multiplication is a low or conservative value of the power product. See line F, Figure 4.4-3. To get a better value, the system does a T' + 1, ω' + 1 multiplication (Figure 4.4-3, line E) and adds the results to the T', ω' multiplication. However, only the high byte of addition is recorded, which is equivalent to a division by 256. To reconstruct the appropriate power value use equation 4.4-7. See line D, Figure 4.4-3.

$$P = 35.49\,P' + 17.75 \qquad (4.4\text{-}7)$$

where P = power in watts

P' = bin number.

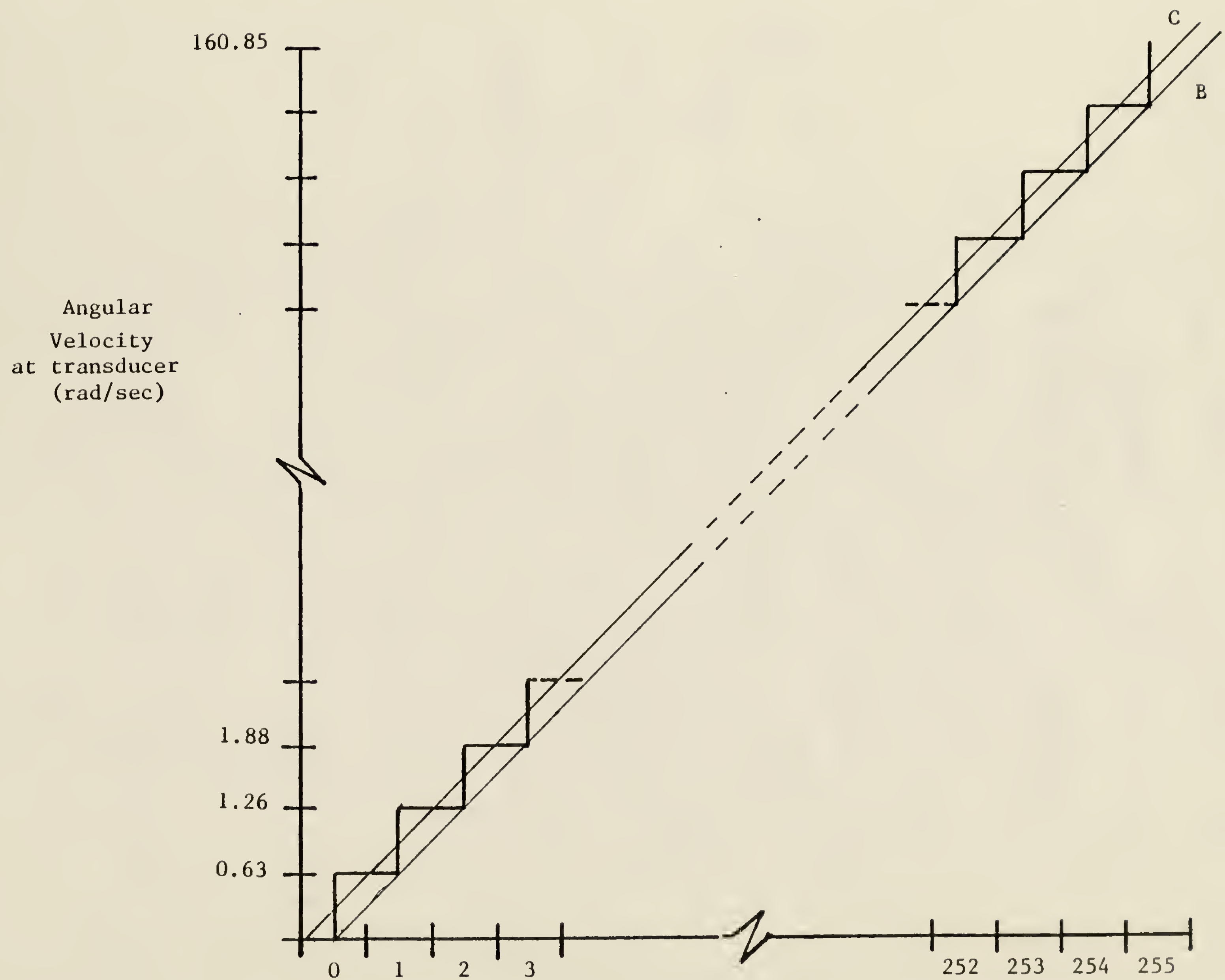


Fig. 4.4-2. Angular Velocity at Transducer Versus Bin Number.

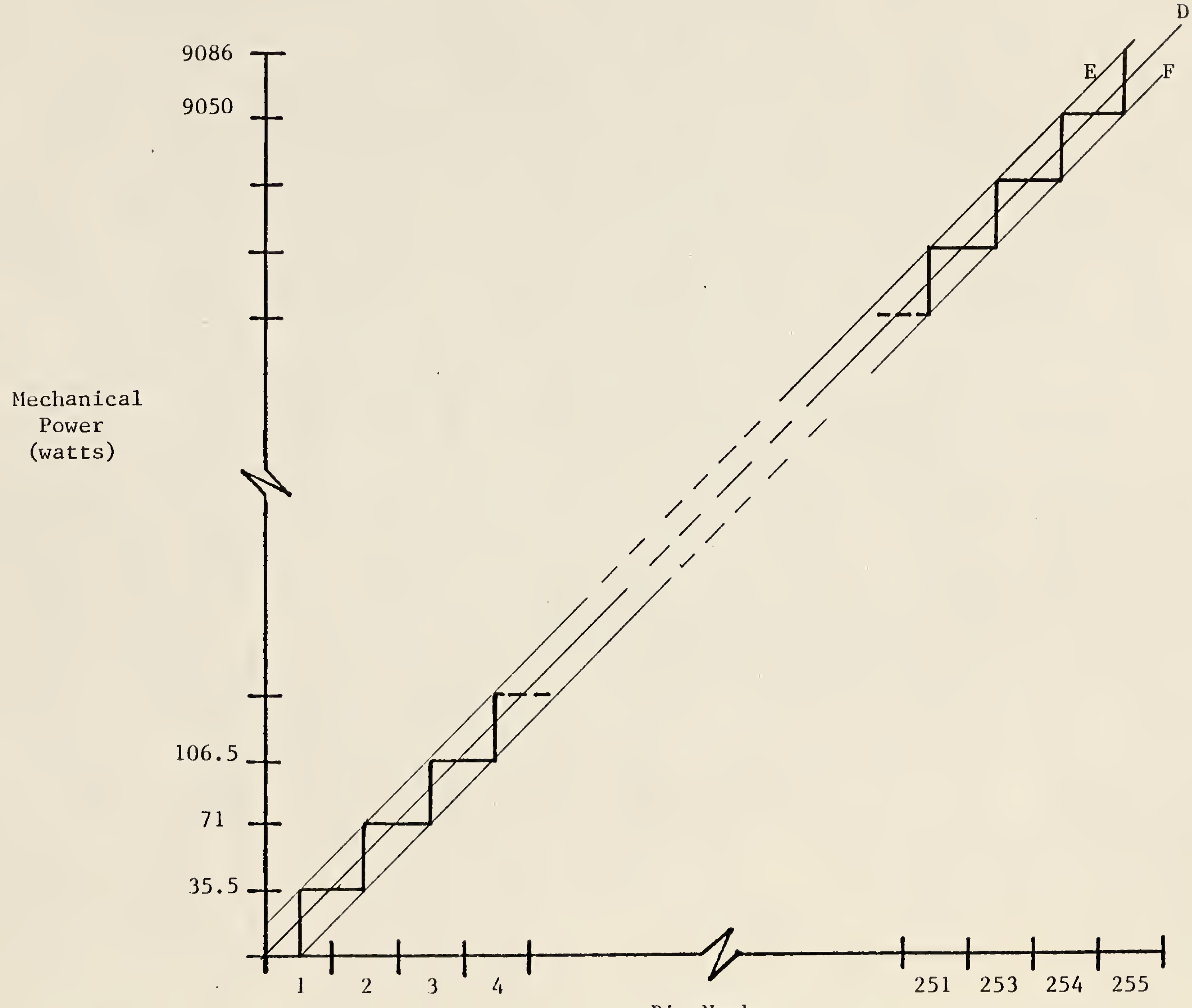


Fig. 4.4-3. Mechanical Power Versus Bin Number.

For example, assume that the sampled torque (T') equals 20 and the sampled angular velocity (ω') equals 10. The T',ω' multiplication would yield 200 or 60 W, which is a low estimate of power. Therefore, by using the product of the T' + 1, ω' + 1 multiplication averaged with the T', ω' product, a better estimate of the power will result, which is 215 or 77.5 W.

5. CONCLUSIONS

The KSU Wind Laboratory data acquisition system performed well and at the time of this writing is in use at the KSU Wind Laboratory. The system, although not elegant, is simple, low cost, and has enabled us to collect quality data.

There is only one major recommendation to be considered for the system. That is improved software. Better software would entail a more concisely written version and software that would run in ROM, for instant-on capabilities. The present software performs well, but alterations could be made to improve table functions. The tables could be moved to page zero and handled with zero page addressing, thus reducing software.

6. ACKNOWLEDGEMENTS

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8. APPENDICES

APPENDIX A

Modification of the S.D.S. 4k RAM Board [20] and Test Program [21]

The S.D.S 4k RAM board is assembled according to instructions given by S.D. Sales. The following modifications are made to adapt the RAM board for KIM-1 use.

1. Remove IC's 33, 35, 36 and 37. File these IC's for other projects.
2. Temporarily remove IC 39.
3. Jumper IC 39 socket pin 8 to 9 with a very short wire.
4. Bend pins 1, 8, 9, and 10 of IC 39 so that they point opposite from their original position.
5. Replace IC 39.
6. Using a piece of insulated wire about 2.5 inches long, strip about 1 inch of insulation from one end. From the component side of the board, push the stripped end all the way through address selection hole "a" which is near pin 1 of IC 34. Now, turn the board over, bend the wire flat, and push the end back through the other address selection hole "a" near pin 14 of IC 37. Solder both holes and clip the uninsulated excess.

   Strip the free end of the wire and push it into pin 3 of IC 33 socket.
7. Repeat step 6 three more times, connecting:

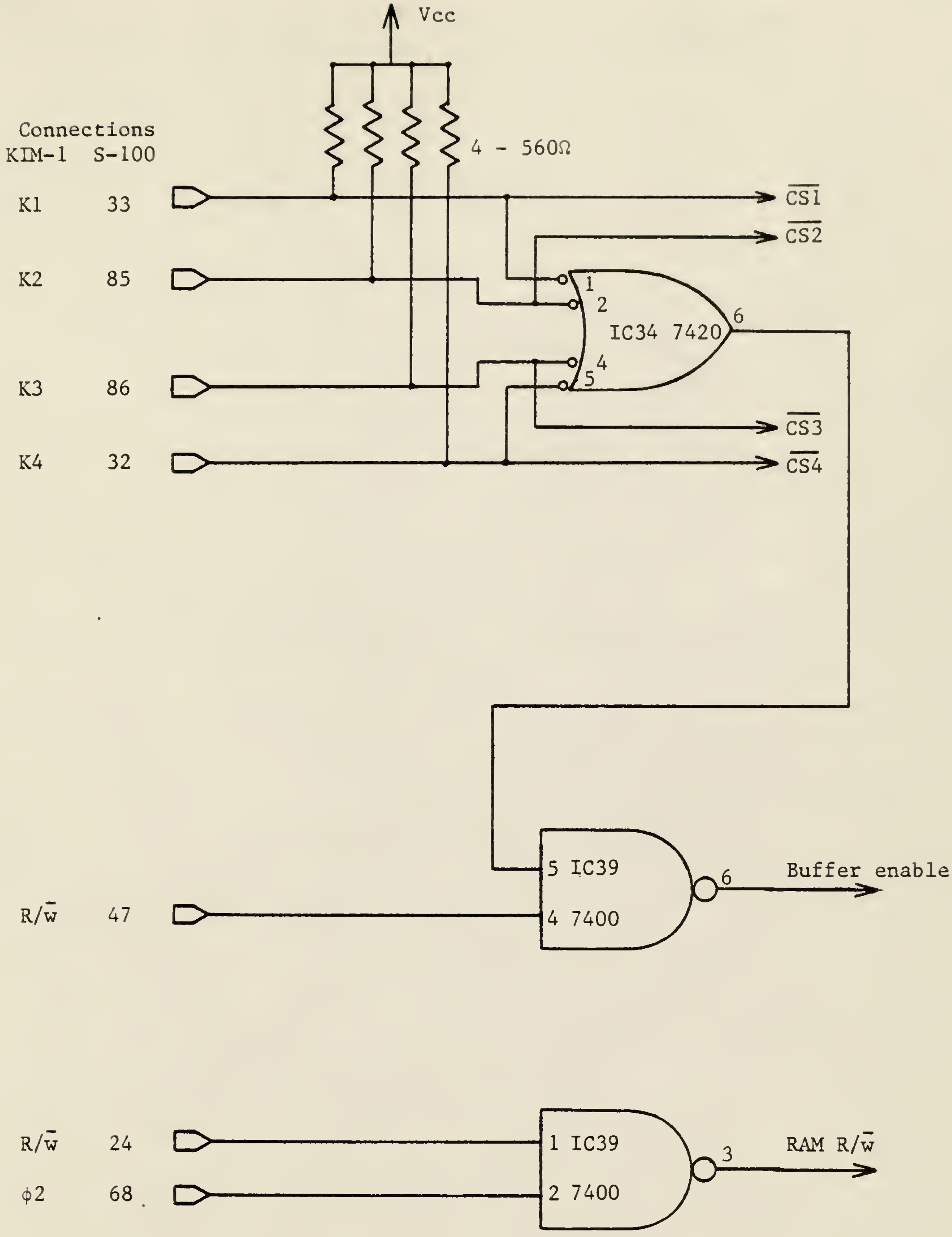
   b to b to pin 8 on IC 33 socket

   c to c to pin 11 on IC 33 socket

   d to d to pin 6 on IC 33 socket

8. Connect pin 1 of IC 39 (should be sticking straight up into the air) to a spare edge connector location such as 24.
9. Remove and address selection jumper wires which may be present in the holes between IC 34 and IC 37. Wire all four address selection holes $\bar{a}$, $\bar{b}$, $\bar{c}$, and $\bar{d}$ together on the component side of the board and connect to Vcc by inserting the end of the wire into pin 14 of IC 37. Make sure only $\bar{a}$, $\bar{b}$, $\bar{c}$, and $\bar{d}$ are so connected and solder these connections.
10. Bend the leads of four 560Ω 1/4 watt resistors into hairpins and cut the leads to about 1/4 of an inch past the end of the resistor. Then be sure the resistor leads are clear and free of all tarnish.
11. Insert one hairpin resistor into pins 13 and 12 on IC 37 socket and repeat for pin sockets 11 - 10, 9 - 8, and 5 - 6.
12. Finished.

The above procedure will modify the S.D. Sales logic to accommodate the KIM-1 decoding. The final modification diagram is given in the following pages. Also given is a table for the connection of the 4k RAM card to the KIM-1. A memory march test is provided to enable testing of the modified RAM.



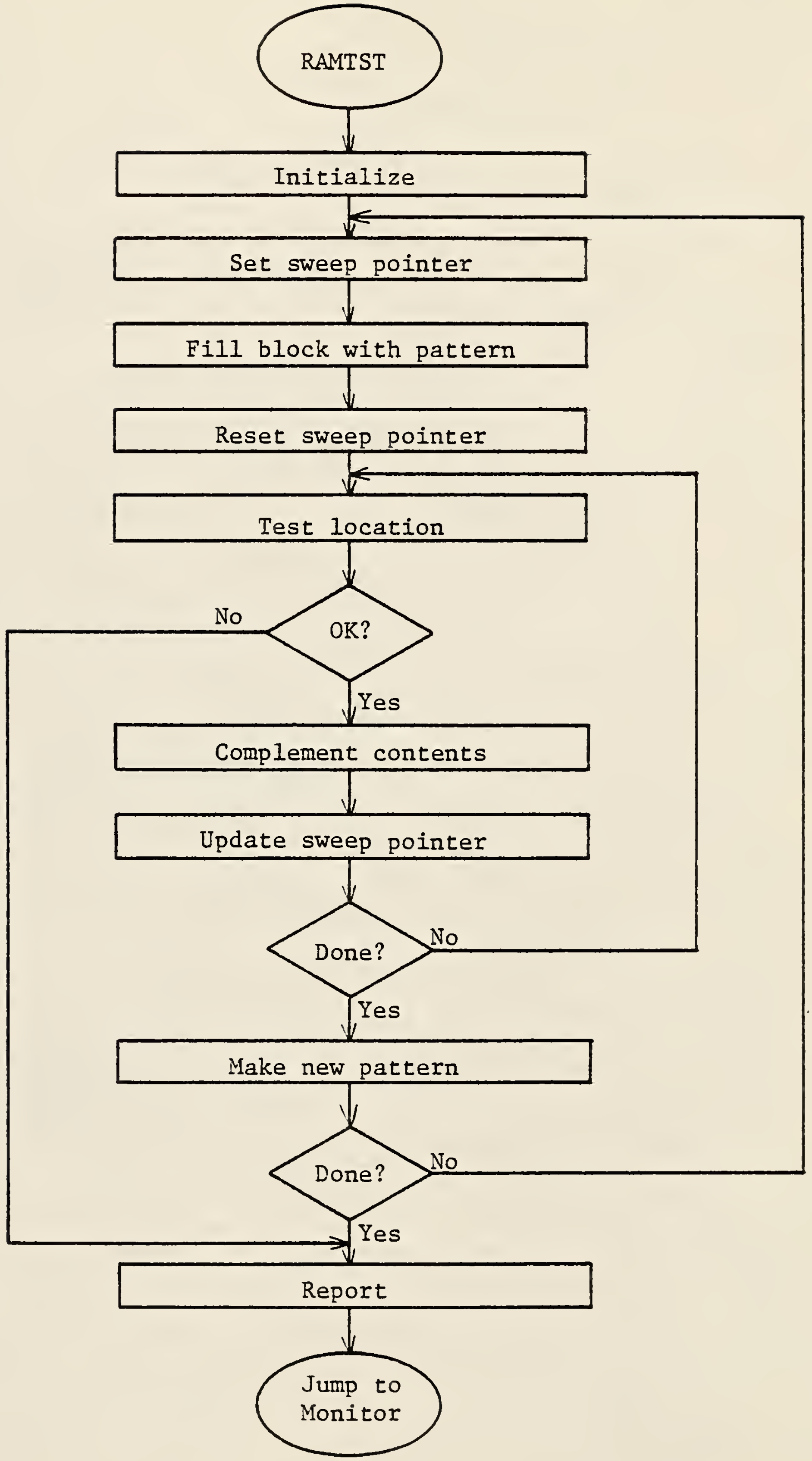
Logic diagram of final modifications.

Edge Connector for Modified S.D.S. 4k RAM

Locations

1	+8V	26		51	+8V	76	
2		27		52		77	
3		28		53		78	
4		29	A5	54		79	AØ
5		30	A4	55		80	A1
6		31	A3	56		81	A2
7		32	K4	57		82	A6
8		33	K1	58		83	A7
9		34	A9	59		84	A8
10		35	D01	60		85	K2
11		36	D0Ø	61		86	K3
12		37		62		87	
13		38	D04	63		88	D02
14		39	D05	64		89	D03
15		40	D06	65		90	D07
16		41	DI2	66		91	DI4
17		42	DI3	67		92	DI5
18		43	DI7	68	$\phi 2$	93	DI6
19		44		69		94	DI1
20		45		70		95	DIØ
21		46		71		96	
22		47	$R/\overline{w}$	72		97	
23		48		73		98	
24	$\overline{R/\overline{w}}$	49		74		99	
25		50	ground	75		100	ground

This program tests any RAM memory block below page 17 not including Ø1FAH to Ø1FFH (reserved for the stack). To test any memory block, place the lower memory block address into location 17F5H (low byte) and 17F6H (high byte) and the high memory block address plus 1 into location 17F7H (low byte) and 17F8H (high byte). Start the program at location 178ØH. If the memory test passes, the display will show the last address tested plus 1. If there is a bad location, the display will show that location. To test the memory with complemented test pattern, change MEMTST: to LDX #$FE and FLIP: to BCS NEXT.



Routine to test RAM.

Memory Test Program

Address	Code	Label	Mnemonic	Operand	Comments
178Ø	A2 01	MEMTST:	LDX	#$01	Install test pattern
1782	A9 8E	NEXT:	LDA	#$8E	Install volatile execution block
1784	8D EC 17		STA	VEB	(VEB) for STX
1787	2Ø 32 19		JSR	INTVEB	Set up starting address
178A	8A		%XA		Complement test pattern
178B	49 FF		EOR	#$FF	
178D	A8		TAY		and save in Y
178E	2Ø BE 17	FILL:	JSR	EXVEB	Execute VEB, test for done
1791	9Ø FB		BCC	FILL	If not done go back
1793	2Ø 32 19		JSR	INTVEB	Install starting address
1796	A9 EC	TEST:	LDA	#$EC	Install CPX in VEB
1798	8D EC 17		STA	VEB	
179B	2Ø EC 17		JSR	VEB	Test memory location
179E	DØ ØF		BNE	FAULT	If error install address
17AD	A9 8C		LDA	#$8C	Install STY in VEB
17A2	8D EC 17		STA	VEB	
17A5	2Ø BE 17		JSR	EXVEB	Execute VEB, test for done
17A8	9Ø EC		BCC	TEST	If not done go back
17AA	8A		TXA		Generate new test pattern
17AB	8A		ASL		
17AC	AA		TAX		
17AD	9Ø D3	FLIP1:	BCC	NEXT	If not done go back
17AF	86 F5	FAULT:	STX Z	#F5	Save test pattern
17B1	AD EE 17		LDA	VEB+2	Set up address of last cell
17B4	85 FB		STA A	$FB	Tested in display
17B6	AD ED 17		LDA	VEB+1	or ending address
17B9	85 FA		STA	Z$FA	
17BB	4C 22 1C		JMP	RST	Return to monitor
17BE	2Ø EC 17	EXVEB:	JSR	VEB	Execute VEB
17C1	2Ø EA 19		JSR	INCVEB	Increment address in VEB
17C4	AD ED 17		LDA	VEB+1	Test to see if ending
17C7	CD F7 17		CMP	EAL	address same as in
17CA	AD EE 17		LDA	VEB+2	VEB
17CD	ED F8 17		SBC	EAH	
17DØ	6Ø		RTS		

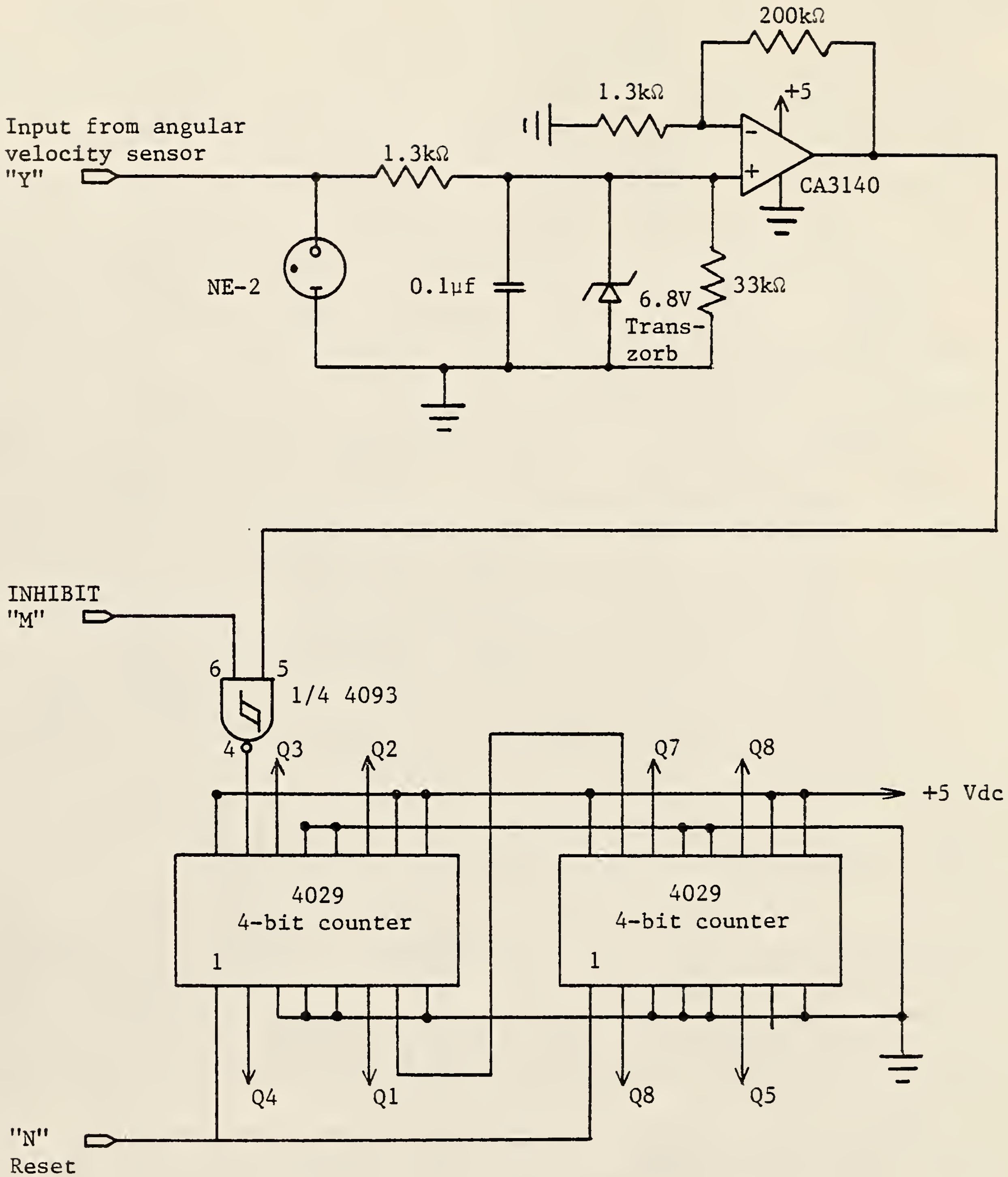
APPENDIX B

Multiplexer-Counter Board

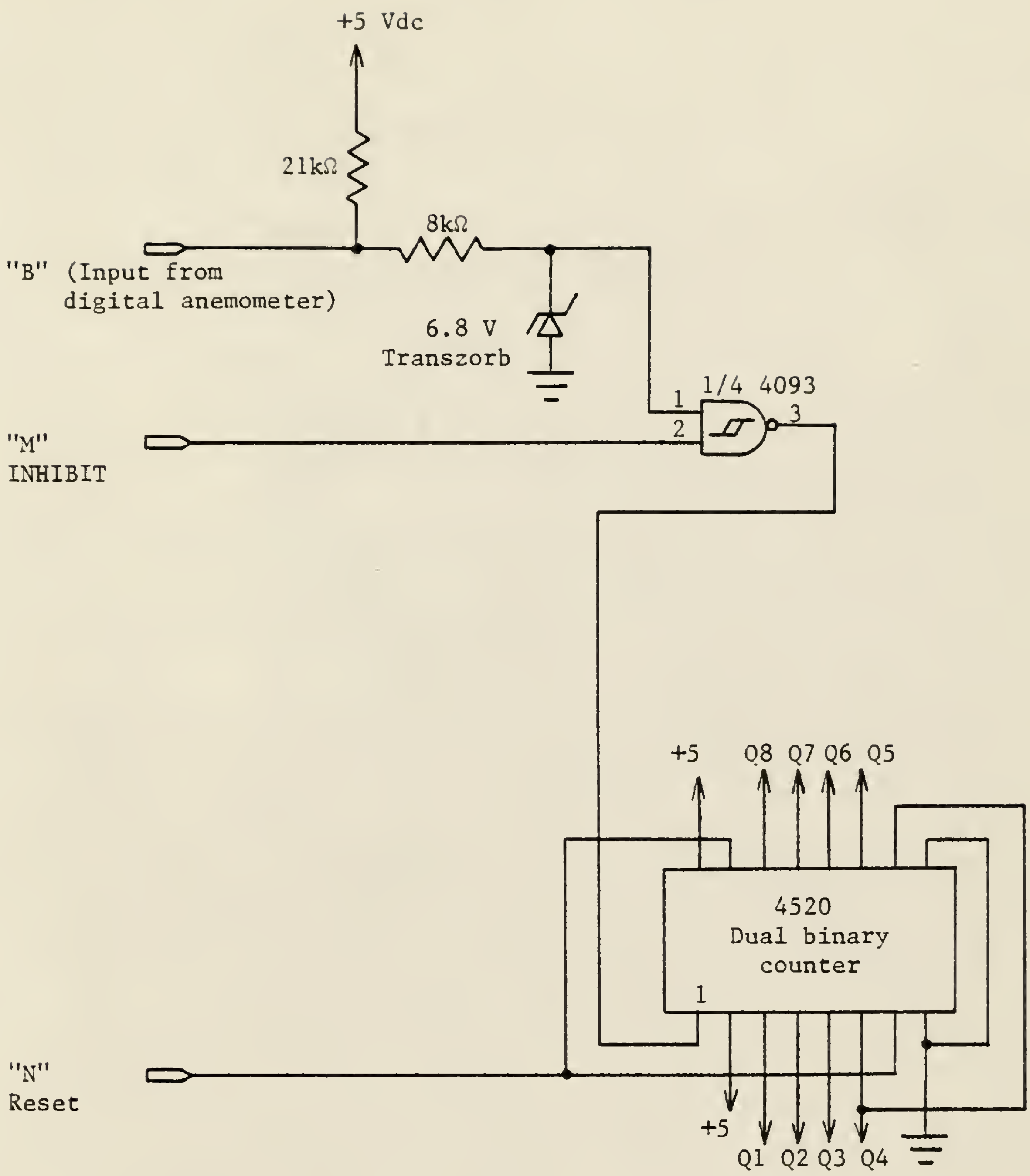
The schematic and edge connector locations for the Multiplexer-Counter Board are given on the following pages.

Mux-Counter Board Edge Connector

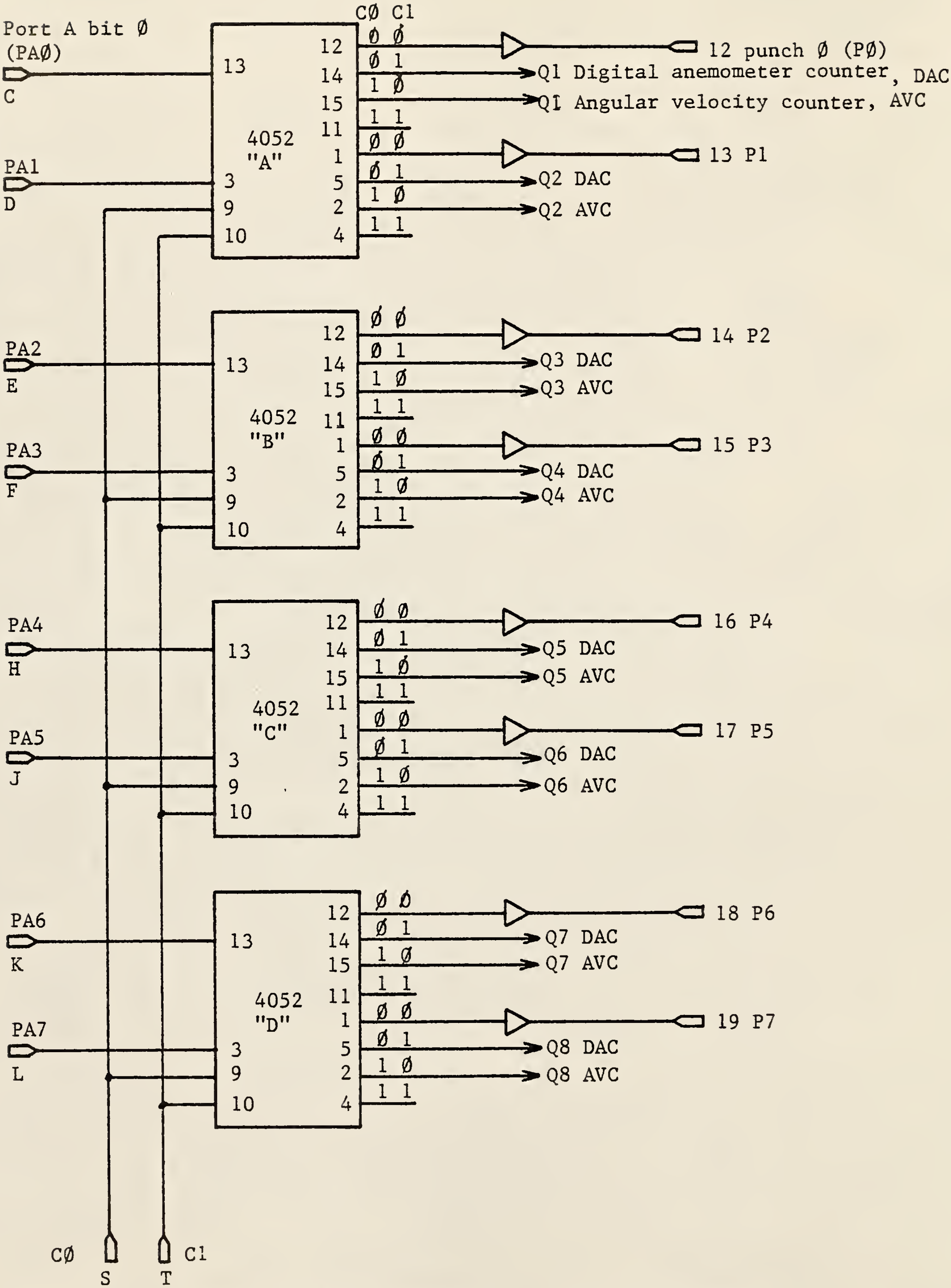
PIN NO.			PIN NO.			
1	+5 Vdc		A	+5 Vdc		
2	NC		B	Digital Anemometer input		
3	NC		C	Port AØ		
4	NC		D		A1	
5	NC		E		A2	
6	NC		F		A3	
7	NC		H		A4	
8	NC		J		A5	
9	NC		K		A6	
10	NC		L		A7	
11	Punch		M		B0	Inhibit counters
12	Data 1		N		B1	Reset counters
13	Data 2	To	P		B2	Busy (punching)
14	Data 3	Paper	R		B3	Punch Command
15	Data 4	Tape	S		B4	CØ
16	Data 5	Punch	T		B5	C1
17	Data 6		U	Power to Paper Tape Punch		
18	Data 7		V	NC		
19	Data 8		W	NC		
20	NC		X	NC		
21	NC		Y	Angular Velocity Input		
22	GND		Z	GND		



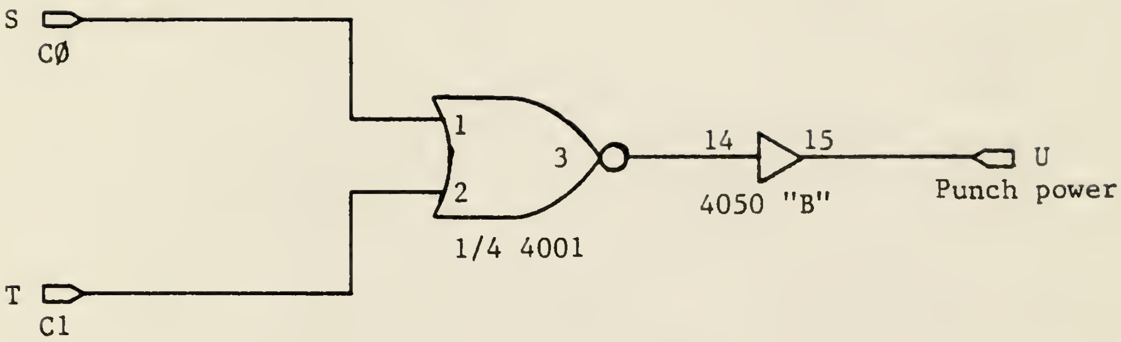
Angular velocity signal conditioning and pulse rate counter.



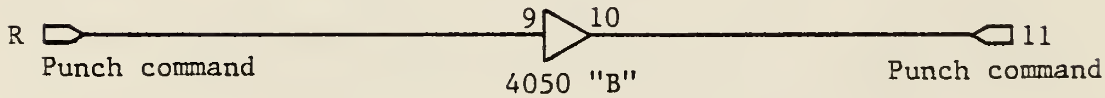
Digital anemometer input conditioning and pulse rate counter. Components are located on the Multiplexer - Counter board.



Multiplexer and punch buffers. Numbers and letters are edge card connector orientations.



Punch power configuration.



Buffer for punch command.

KIM-1 Application Connector

Pin No.		Pin No.	
1	GND	A	+ 5 Vdc
2	A3	B	
3	A2	C	
4	A1	D	
5	A4	E	
6	A5	F	
7	A6	H	
8	A7	J	
9	BØ	K	Decode Enable (GND)
10	B1	L	Audio IN
11	B2	M	
12	B3	N	+ 12 Vdc
13	B4	P	Audio Out (HI)
14	AØ	R	TTY KYBD RTRN(+)
15	B7*	S	TTY PTR RTRN(+)
16	B5	T	TTY KYBD
17		U	TTY PTR
18		V	
19		W	
20		X	
21		Y	
22	closed for TTY	Z	
	open for keyboard		

*IRQ from expansion connection Pin 4 is connected through a switch to B7.

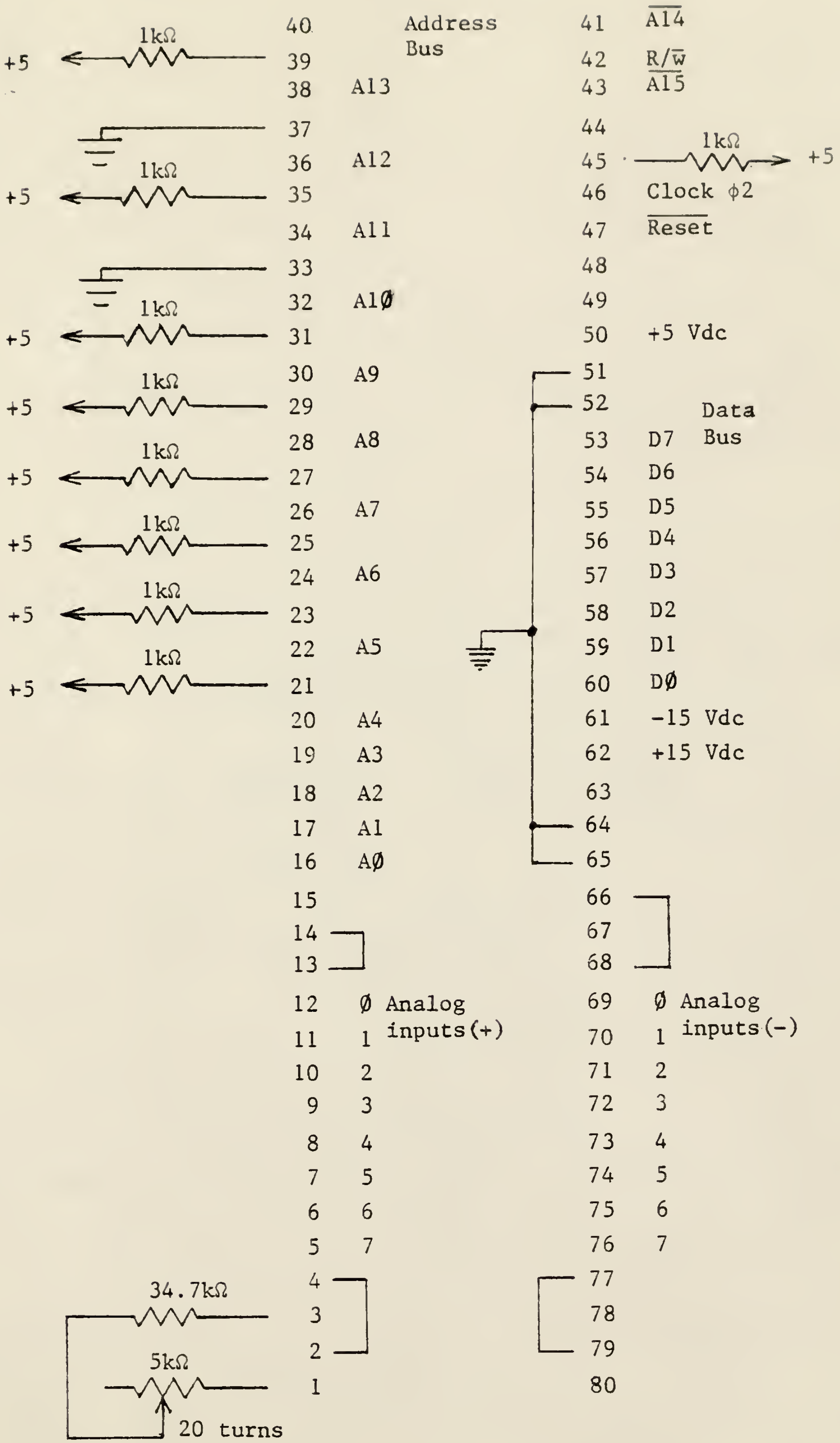
APPENDIX C

MP21 Connections

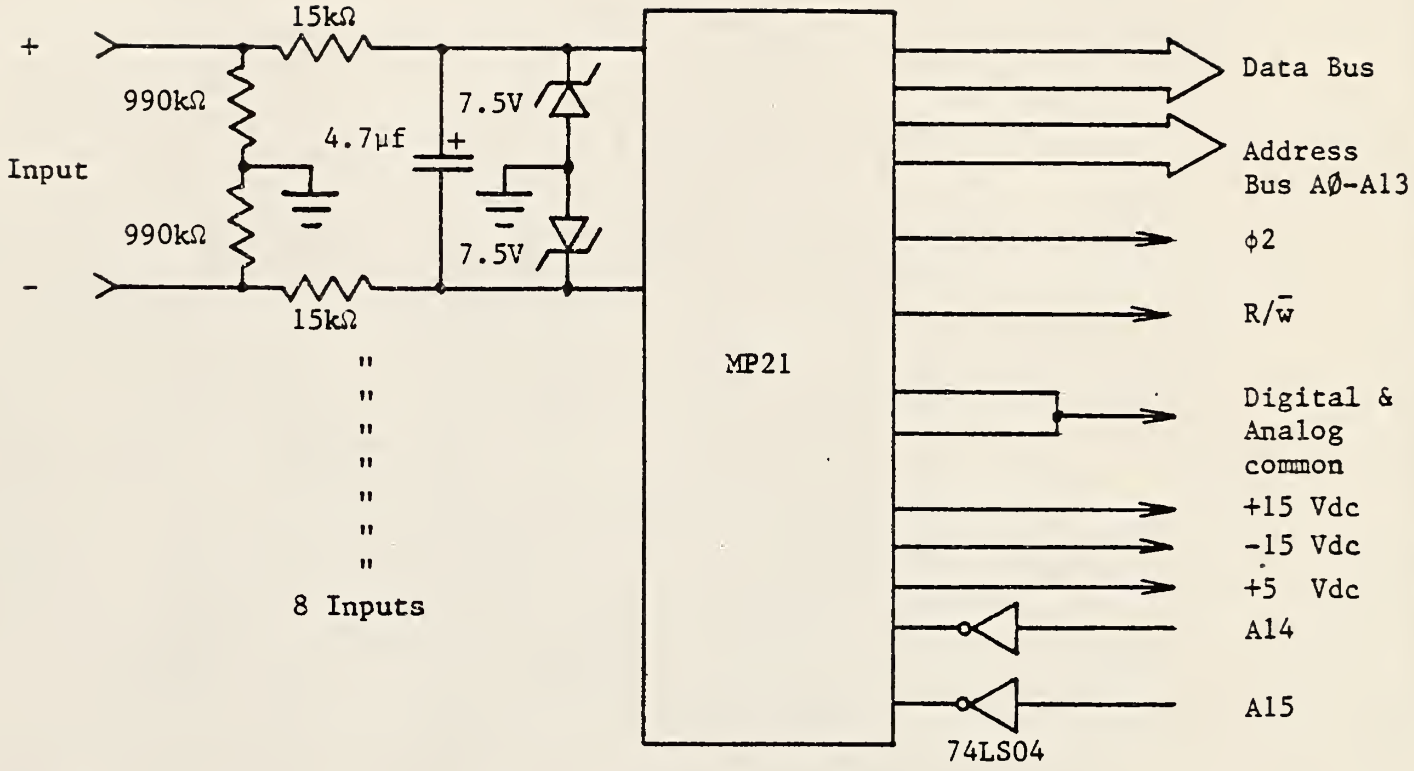
This appendix gives block diagrams, pin connections, and edge card connections for the A/D board.

Edge Connection for A/D Board

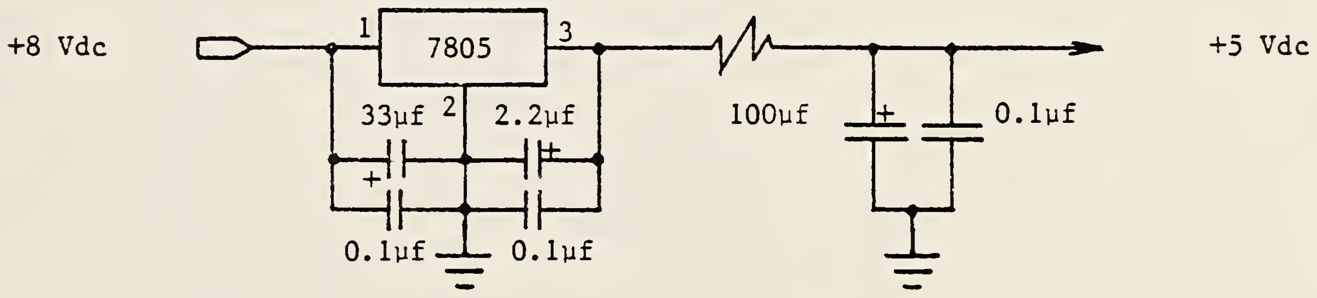
No.			No.			No.			No.		
1	+8 Vdc		26			51	+8 Vdc		76		
2	+15.7 Vdc		27			52	-15.7 Vdc		77		
3			28			53			78		
4			29	Address Bus:	A5	54			79	Address Bus:	AØ
5			30		A4	55			80		A1
6			31		A3	56			81		A2
7			32		A15	57			82		A6
8			33		A12	58	Analog Input:	+7	83		A7
9			34		A9	59		-7	84		A8
10			35			60		+6	85		A13
11			36			61		-6	86		A14
12	Analog Input:	+5	37		A1Ø	62		-5	87		A11
13		+4	38			63		-4	88		
14		+3	39			64		-3	89		
15		+2	40			65		-2	90		
16		+1	41	Data Bus:	D2	66		-1	91	Data Bus:	D4
17		+Ø	42		D3	67		-Ø	92		D5
18			43		D7	68	Clock $\phi 2$		93		D6
19			44			69			94		D1
20			45			70			95		DØ
21			46			71			96		
22			47	R/$\overline{w}$		72			97		
23			48			73			98		
24			49			74			99		
25			50	ground		75	$\overline{\text{Reset}}$		100	ground	

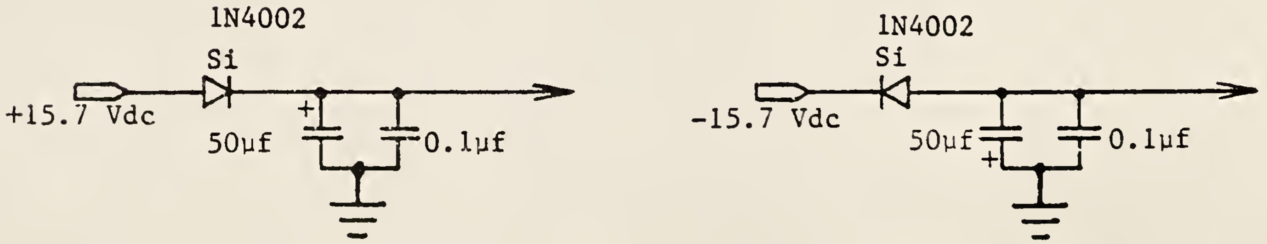


MP21 Connections



Block diagram of the Analog Microperipheral connection.





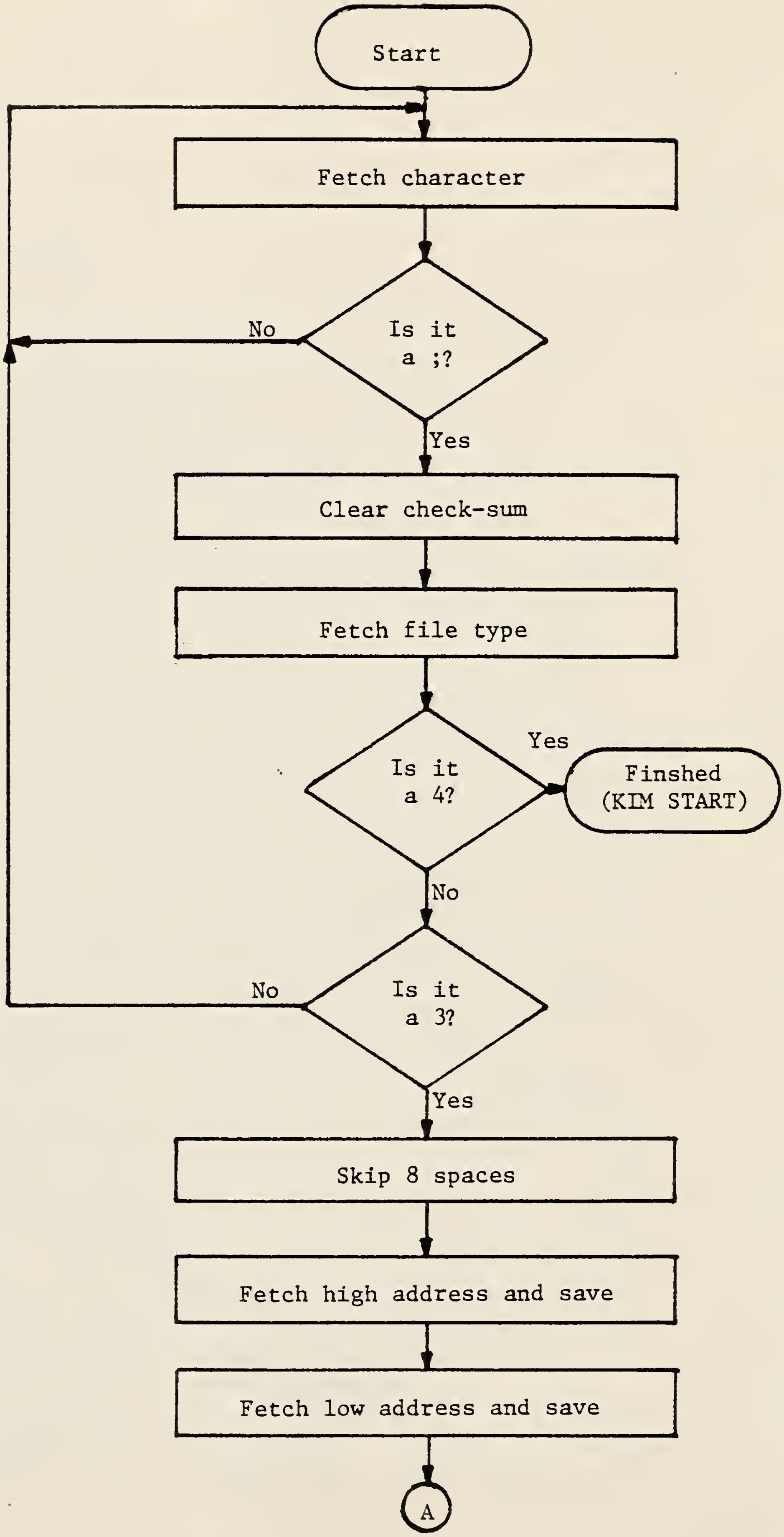
Power regulation and filtering on the Analog Microperipheral board.

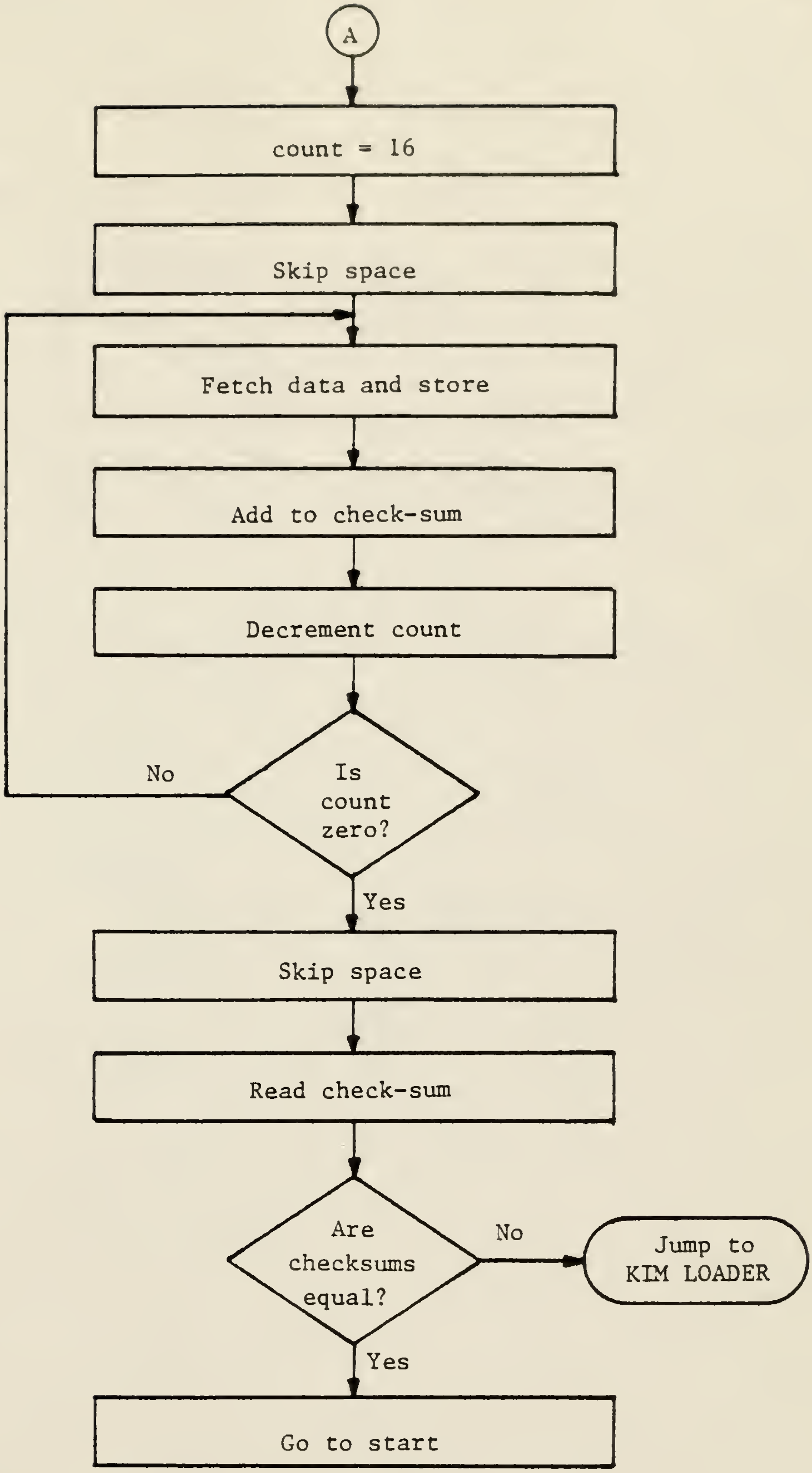
APPENDIX D

Cross-Assembler Reader

The program included in this section loads a paper tape coded program received from the MOS Technology cross-assembler into the KIM-1. To use the program, do the following:

1. Set address ØØF1H to ØØ.
2. Load cross-assembler reader program.
3. Set display pointer at 13ØØH.
4. Start the program (push GO).
5. Insert the cross-assembly tape into the tape reader.
6. Start the paper tape reader.
7. KIM-1 will return to the monitor when finished. If in error, the TTY will type 'ERR KIM'. Stop the tape reader and restart the tape before the error and restart the program at 13ØØH.


Start
Fetch character
Is it a ;?
No
Yes
Clear check-sum
Fetch file type
Is it a 4?
Yes
Finshed (KIM START)
No
Is it a 3?
No
Yes
Skip 8 spaces
Fetch high address and save
Fetch low address and save
A



Flow chart of program to load paper tape from cross-assembler.

Code for Cross-Assembler Reader

Location	OP Code		Mnemonic	Comments
13ØØ	2Ø	LOAD	JSR GETCH	Fetch character and
13Ø1	5A			look for ;.
13Ø2	1E			
13Ø3	C9		CMP #$3B	
13Ø4	3B			
13Ø5	DØ		BNE LOAD	
13Ø7	A9		LDA #$ØØ	IF; clear
13Ø8	ØØ			checksum.
13Ø9	85		STA CHKSUM	
13ØA	F7			
13ØB	85		STA CHKHI	
13ØC	F6			
13ØD	2Ø		JSR FETCH	Fetch character and
13ØE	5A			
13ØF	1E			if it is 4 return
131Ø	C9		CMP #'4'	to KIM-1 monitor.
1311	34			
1312	DØ		BNE COMP	
1313	Ø3			
1314	4C		JMP START	
1315	4F			
1316	1C			
1317	C9	COMP	CMP #'3'	If character is a
1318	33			3 skip 8
1319	DØ		BNE LOAD	spaces.
131A	E5			
131B	A2		LDX #8	
131C	Ø8			
131D	2Ø	LOOP1	JSR GETCH	Fetch and discard
131E	5A			for the 8 spaces.
131F	1E			
132Ø	CA		DEX	
1321	DØ		BNE LOOP1	If 8 spaces go on.
1322	FA			
1323	A2		LDX #$1Ø	Number of data
1324	1Ø			bytes per record.
1325	AØ		LDY #$ØØ	Clear Y.
1326	ØØ			
1327	2Ø		JSR GETBYT	Fetch high byte
1328	9D			address.
1329	1F			
132A	85		STA POINTH	Save.
132B	FB			
132C	2Ø		JSR GETBYT	Fetch low byte address.
132D	9D			
132E	1F			

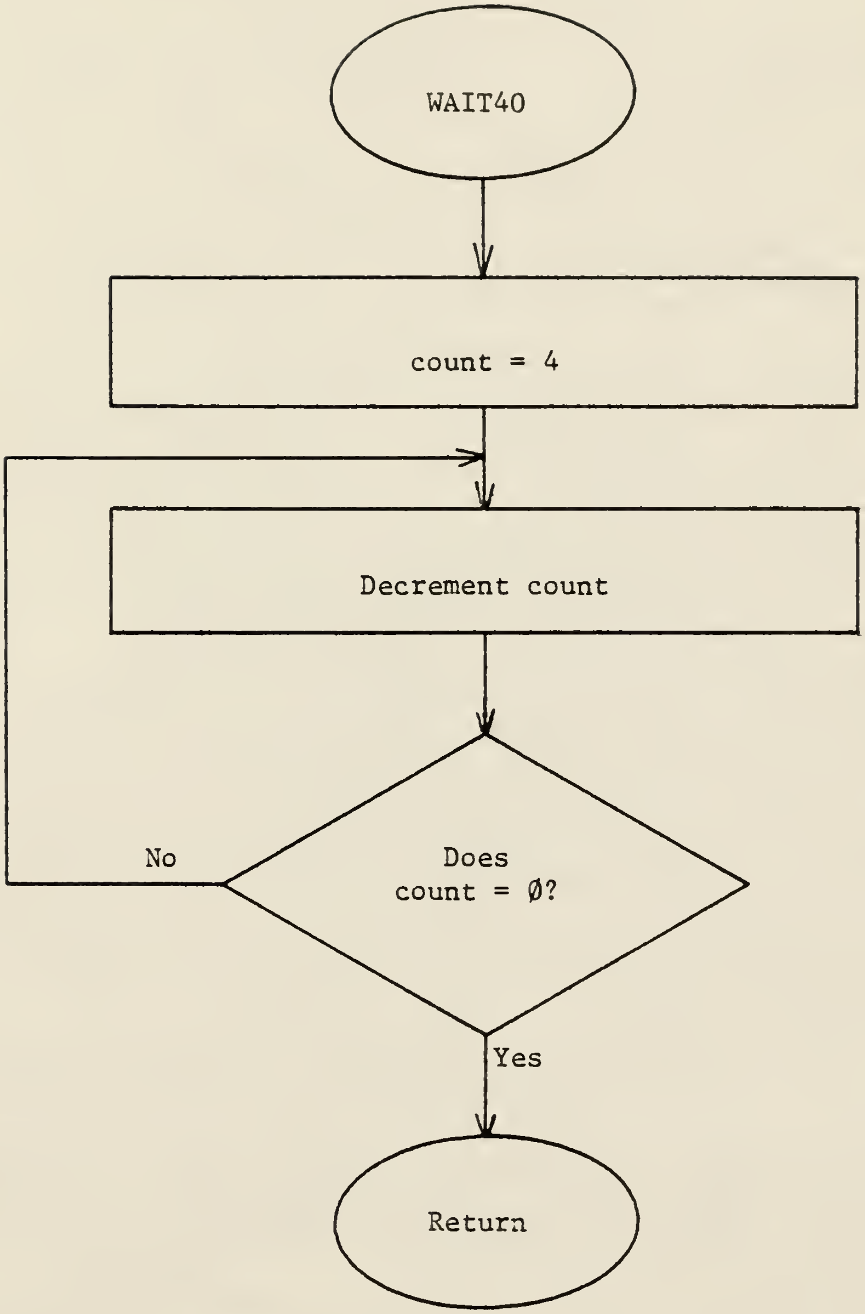
Location	OP Code		Mnemonic	Comments
132F	85		STA POINTL	Save.
133Ø	FA			
1331	2Ø		JSR FETCH	Skip space.
1332	5A			
1333	1E			
1334	2Ø	LOAD1	JSR GETBYT	Fetch data.
1335	9D			
1336	1F			
1337	91		STA (POINTL),Y	Store.
1338	FA			
1339	2Ø		JSR CHK	Add to checksum.
133A	91			
133B	1F			
133C	2Ø		JSR INCPT	Next address.
133D	63			
133E	1F			
133F	CA		DEX	Decrement number of data bytes per record.
134Ø	DØ		BNE LOAD1	Branch and fetch until
1341	F2			all data bytes are read.
1342	2Ø		JSR GETCH	Skip space.
1343	5A			
1344	1E			
1345	2Ø		JSR GETBYT	Fetch checksum
1346	9D			high byte.
1347	1F			
1348	C5		CMP CHKHI	Compare to KIM's
1349	F6			value.
134A	DØ		BNE ERROR	If not equal branch
134B	ØA			to ERROR.
134C	2Ø		JSR GETBYT	Fetch checksum
134D	9D			low byte.
134E	1F			
134F	C5		CMP CHKSUM	Compare to KIM's
135Ø	F7			value.
1351	DØ		BNE ERROR	If not equal branch
1352	Ø3			to ERROR.
1353	4C		JMP LOAD	Return to fetch
1354	ØØ			next record.
1355	13			
1356	4C	ERROR	JMP $1D3E	On error jump
1357	3E			to KIM error
1358	1D			loader routine.

APPENDIX E

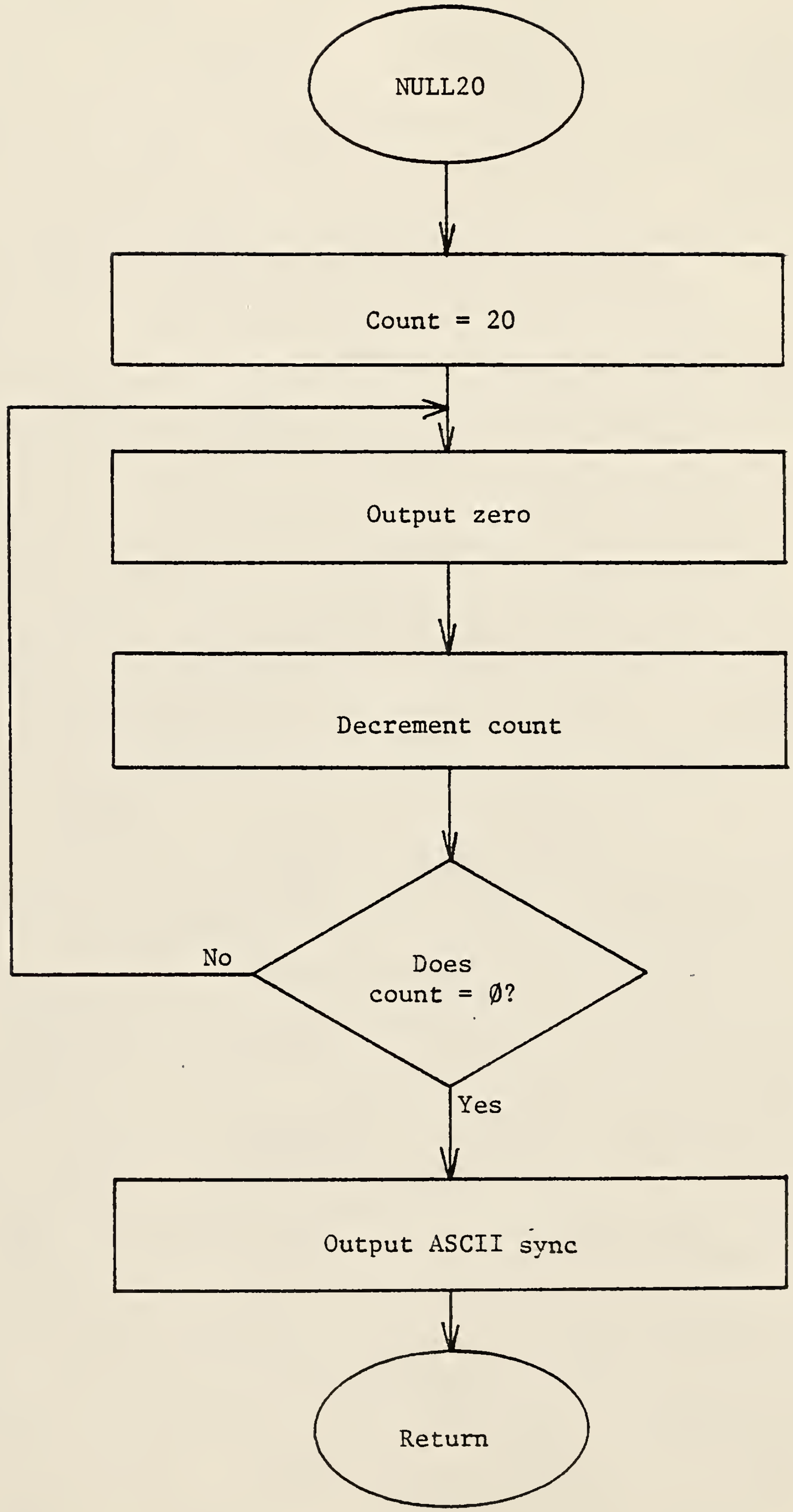
System Program Flow Charts

Flow charts of the complete system program and listings are given. The name of each flow chart corresponds to a routine in the listing.

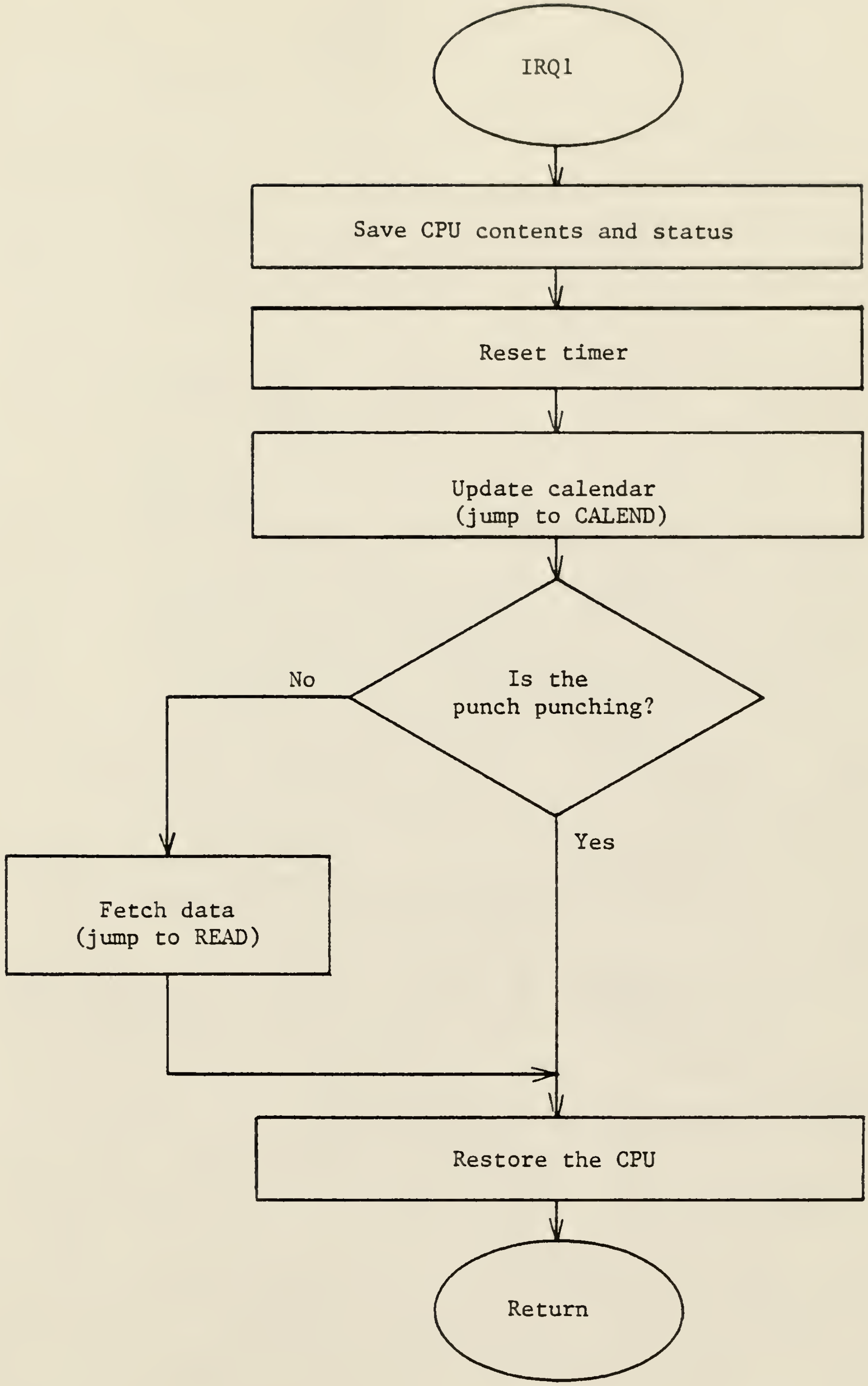
Routine Name	Function
WAIT4Ø	Time delay of 40 microseconds.
NULL2Ø	Output 20 nulls and an ASCII synch.
IRQ1	Interrupt routine for binned acquisition mode.
IRQ2	Interrupt routine for sequential acquisition mode.
MULT	8-bit by 8-bit multiply.
READ	Read digital transducers.
CALEND	Update calendar.
CLEARB	Clear bins.
OUTPOK	Output contents of the accumulator to the punch.
SCX-DIS	Select and display data.
OUTPUT	Turn on the paper tape punch.
DATACT	Collect data.
OUTSUB	Output contents of the bins.
CLEARØ	Initialize the processor.
ISOUTF	Idle until data collection.
AINA	Collect data (part of DATACT)
ONWAR	Turn off the punch.



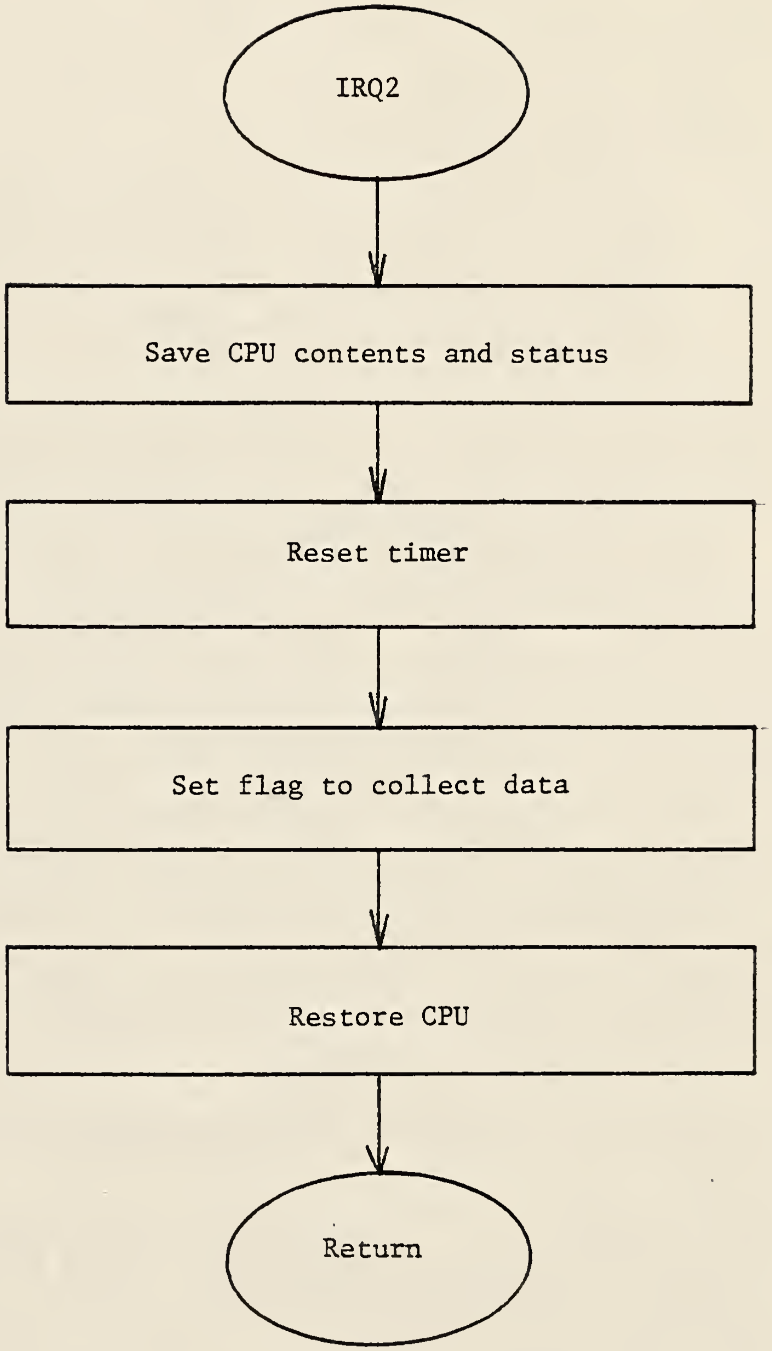
WAIT40 — Subroutine to wait 40 microseconds.



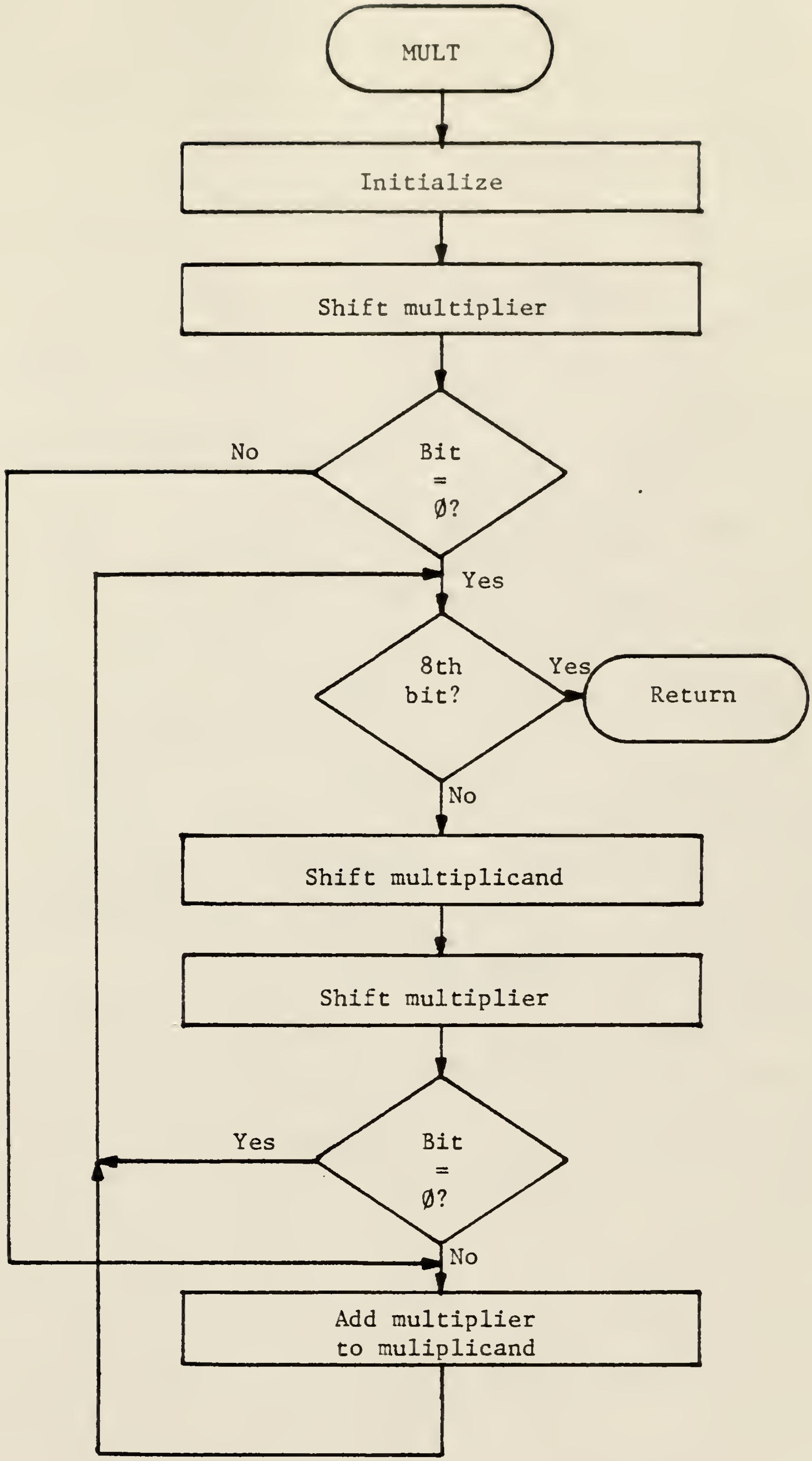
NULL20 — Subroutine to output 20 nulls and an ASCII sync.



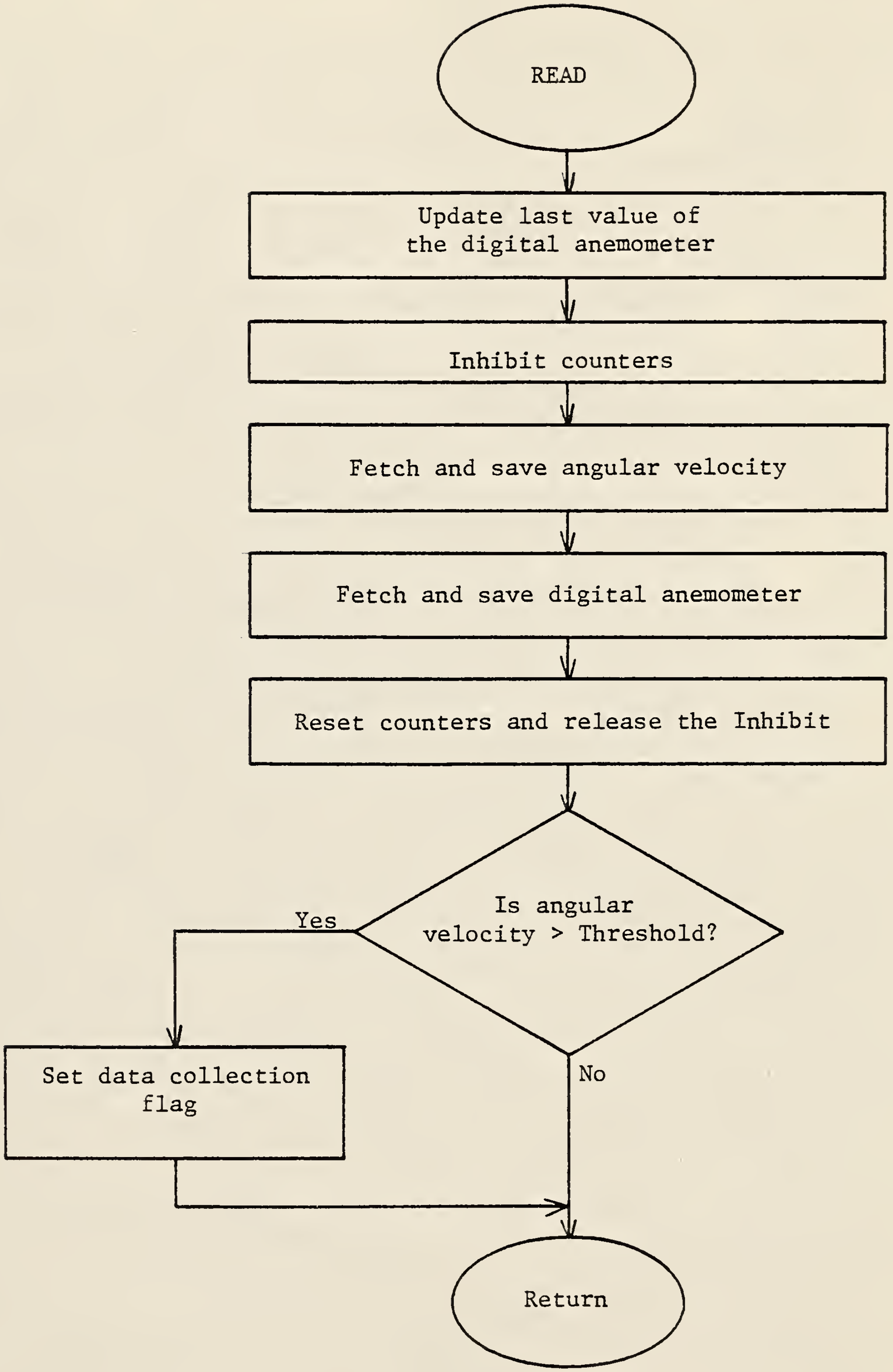
IRQ1 - Interrupt routine for binned data acquisition program.



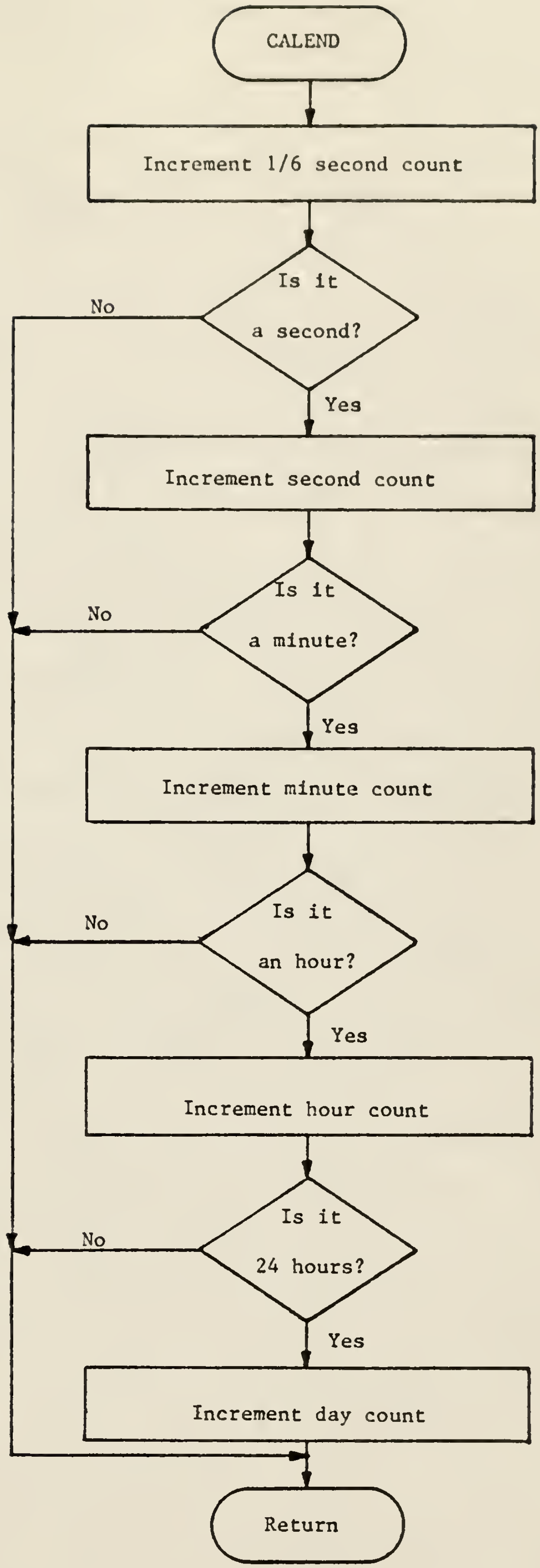
IRQ2 - Interrupt routine to set timer for sequential routine.



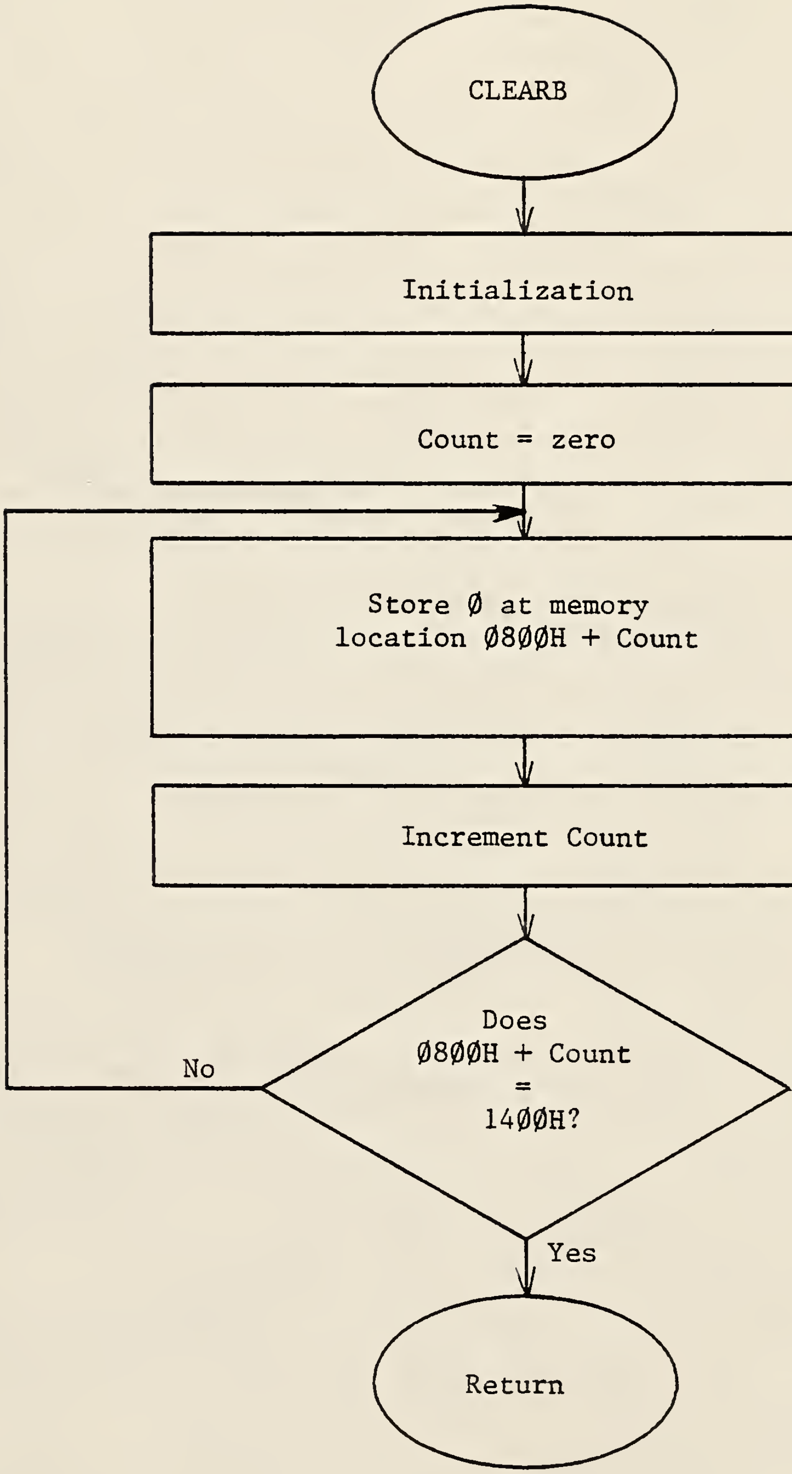
MULT — Multiply subroutine for two 8 bit unsigned numbers.



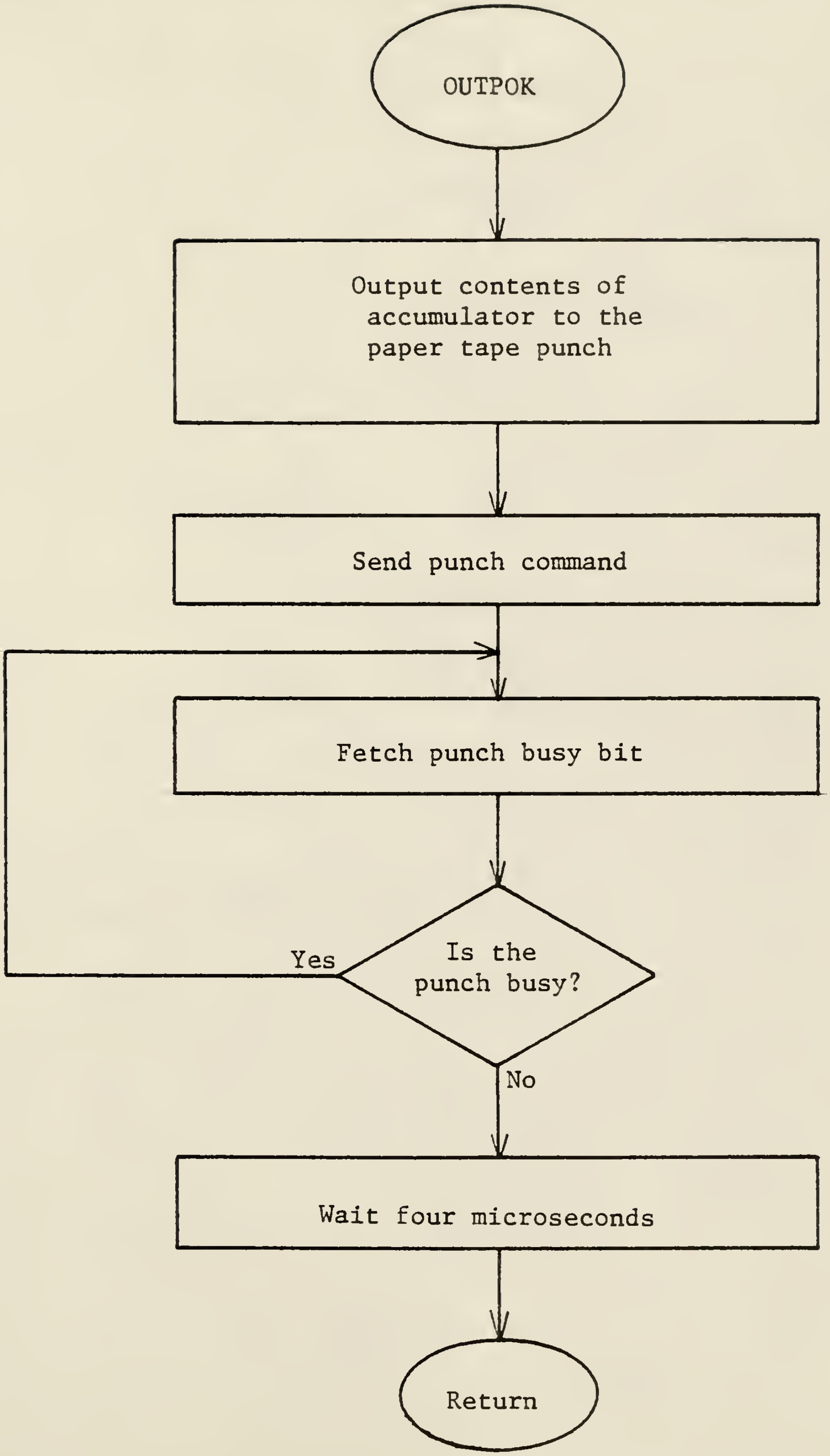
READ — Subroutine to fetch digital anemometer and angular velocity values. The routine has adjustable threshold for data collection.



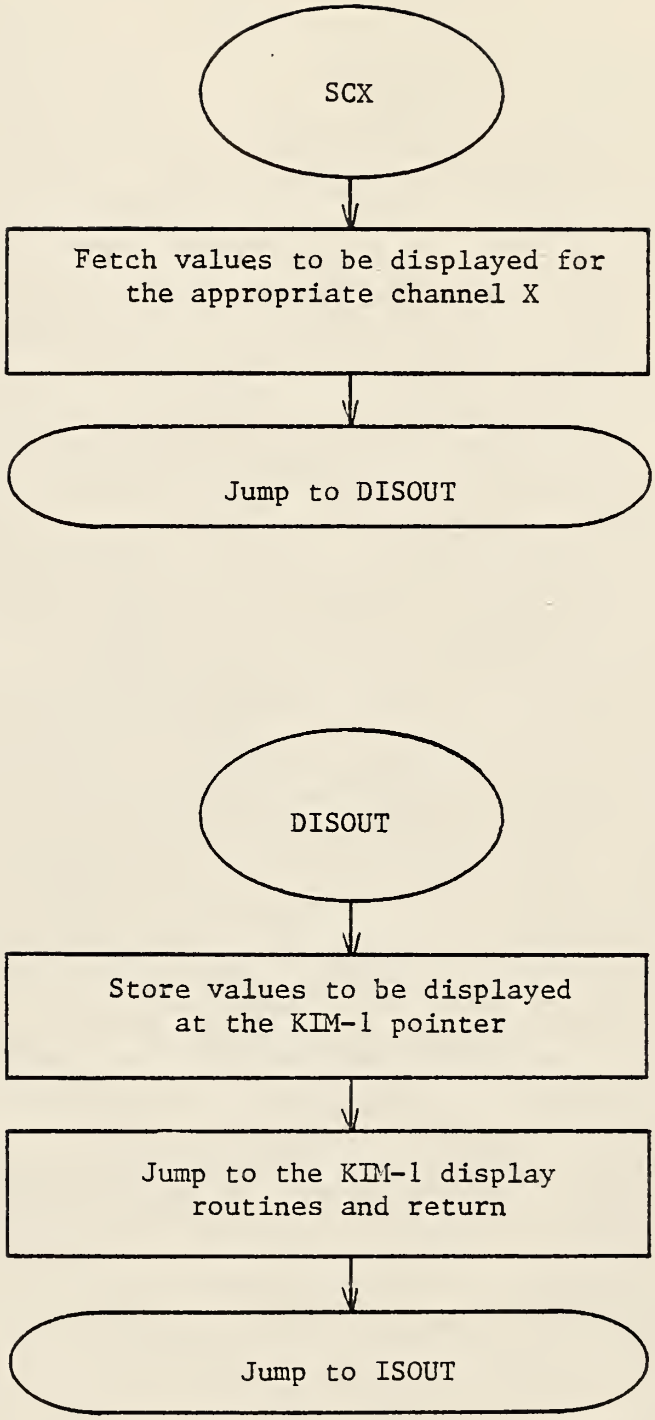
CALEND — Calendar subroutine (does not update year).



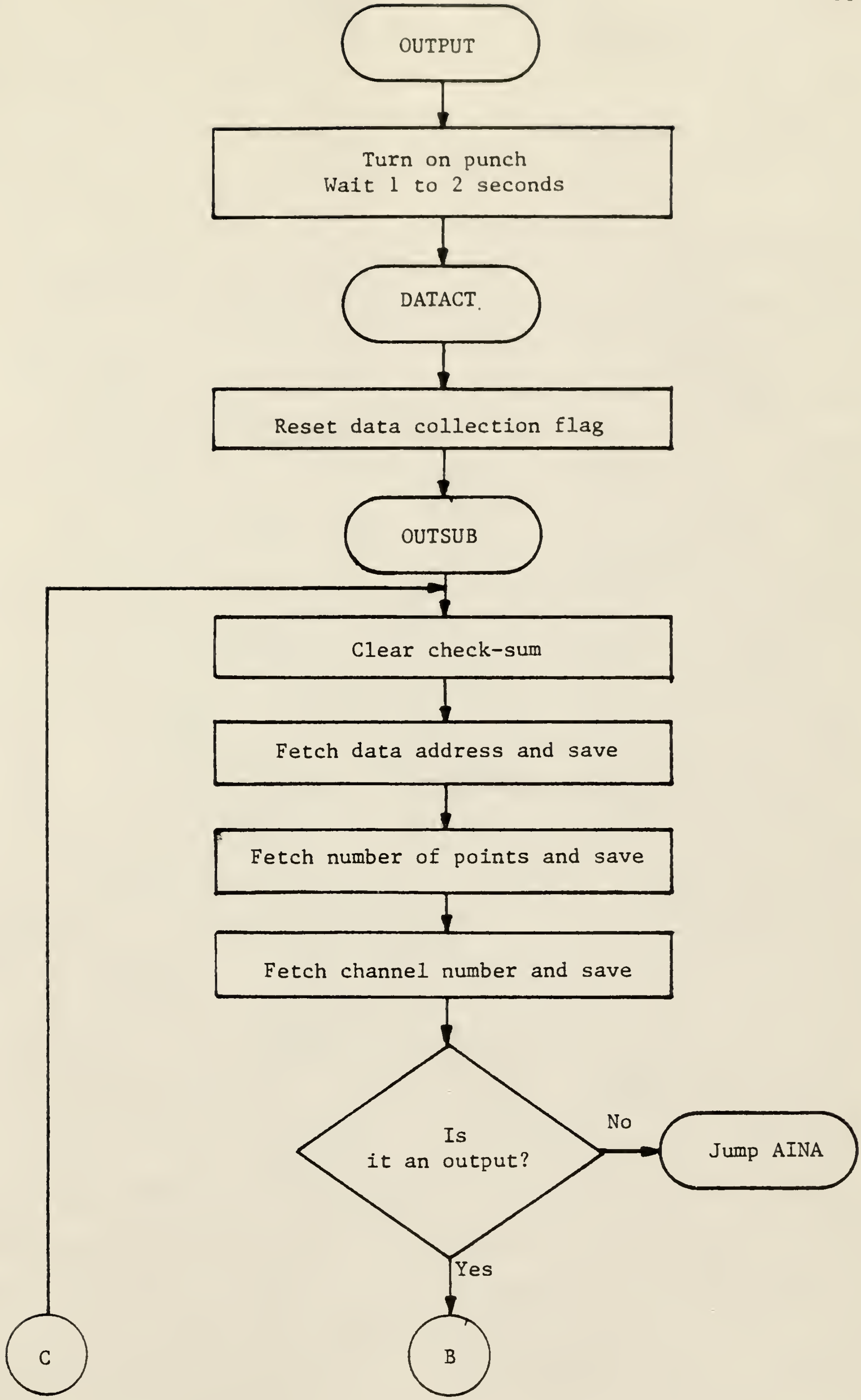
CLEARB — This subroutine clears all memory between Ø8ØØH and 13FFH.

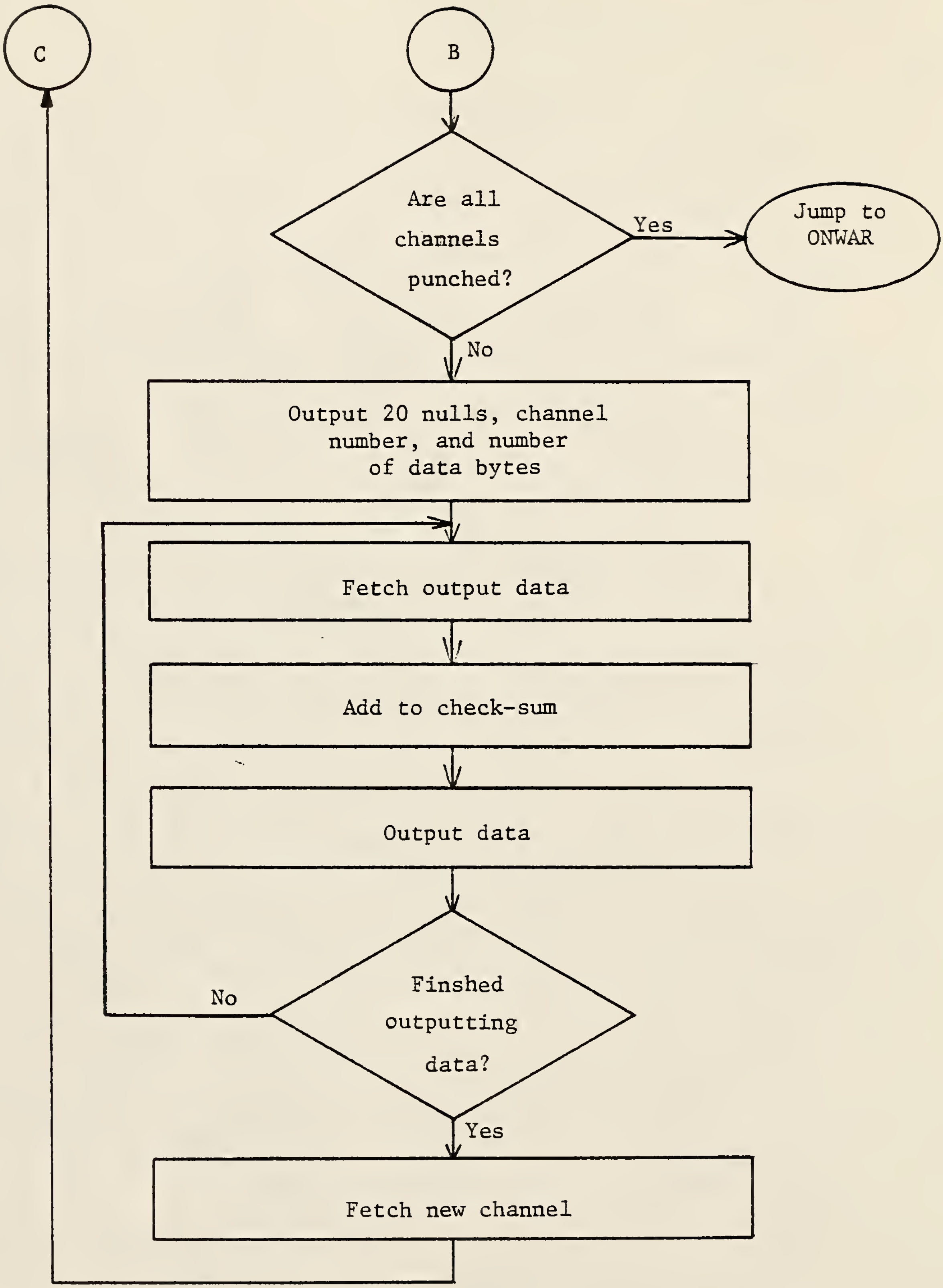


OUTPOK — Subroutine to output the contents of the accumulator to the paper tape punch.

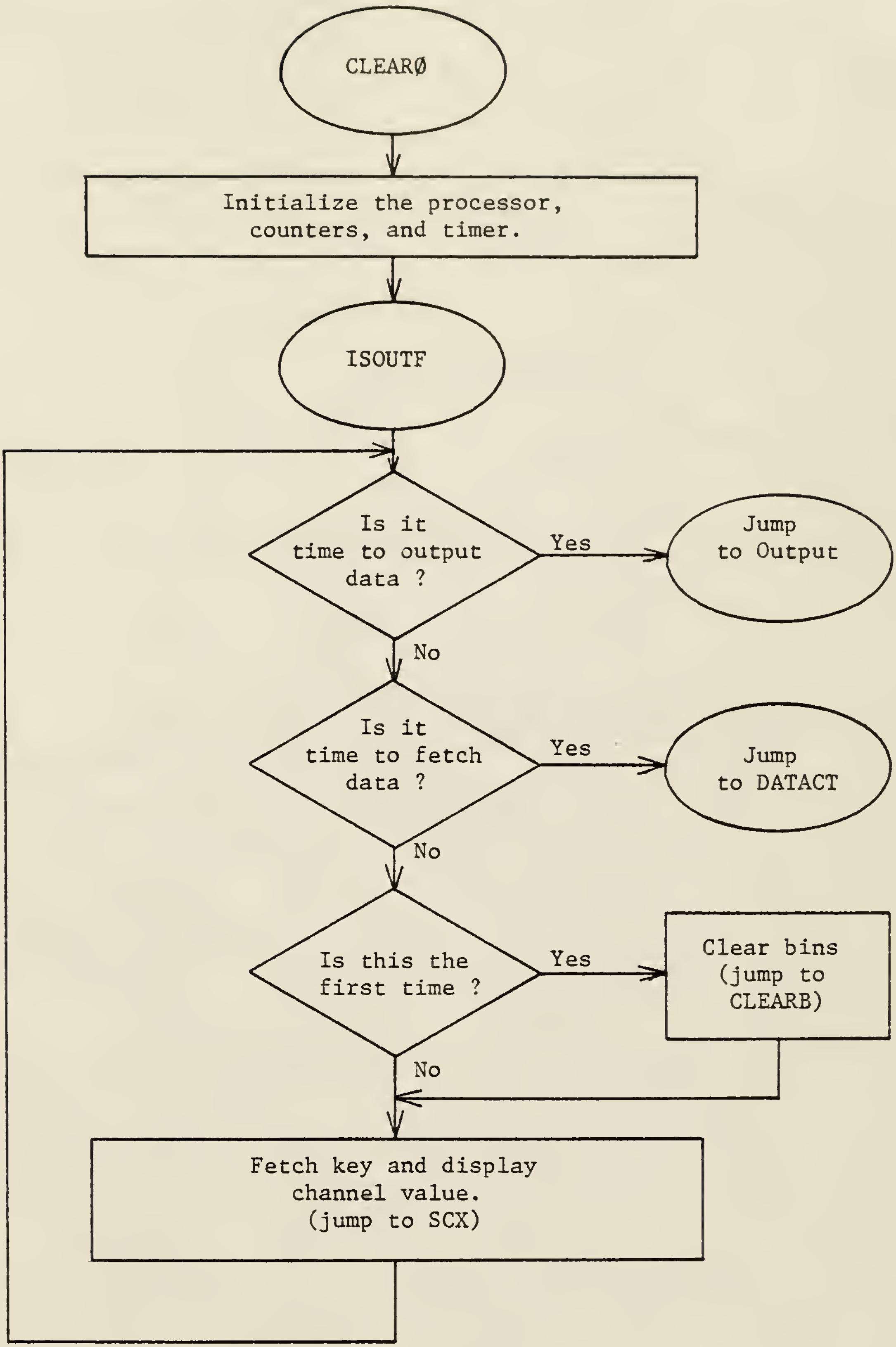


SCX, DIOUT — Subroutines to select and display data on the KIM-1 display.


OUTPUT
Turn on punch
Wait 1 to 2 seconds
DATACT
Reset data collection flag
OUTSUB
Clear check-sum
Fetch data address and save
Fetch number of points and save
Fetch channel number and save
Is
it an output?
No
Jump AINA
Yes
C
B

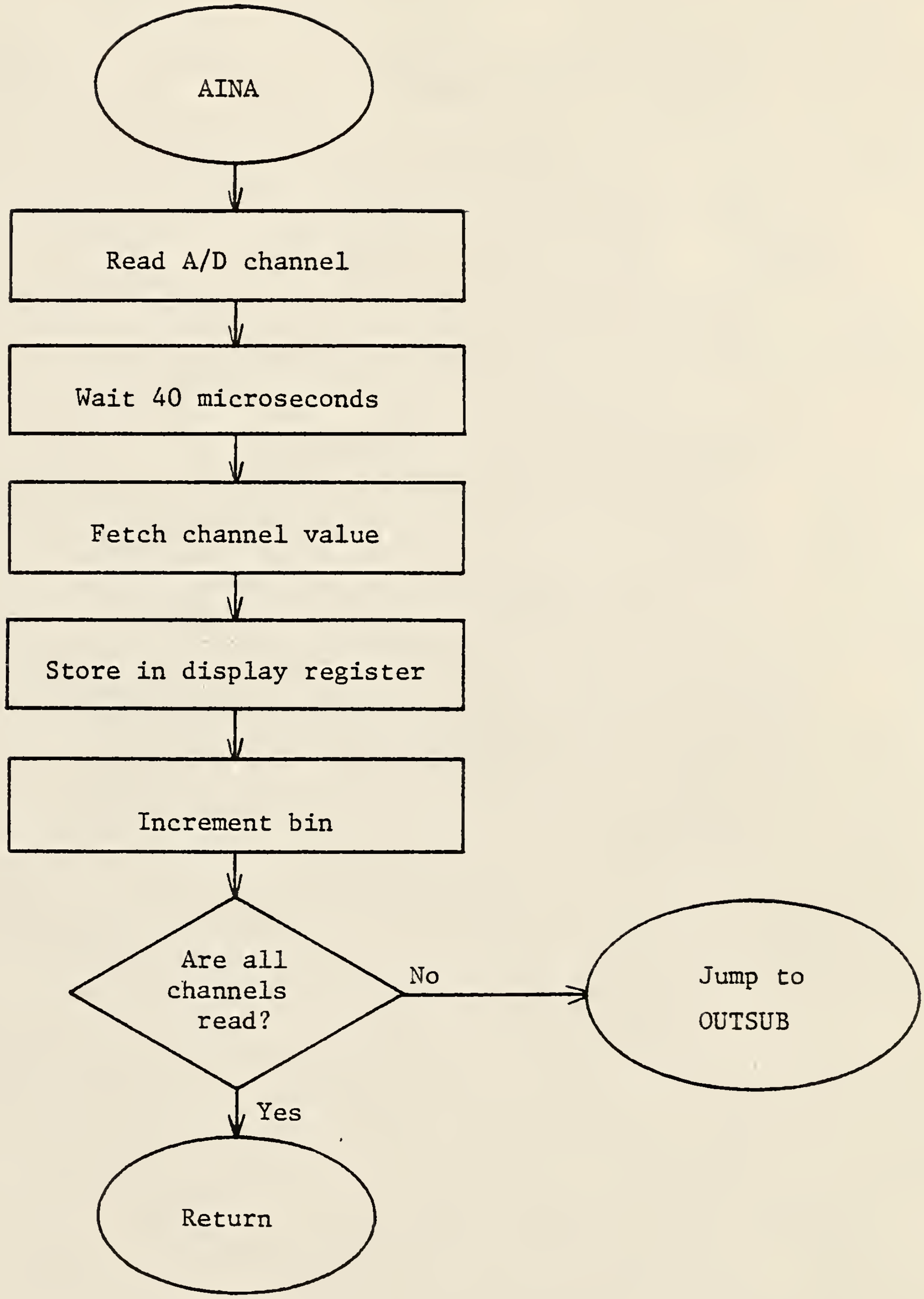


OUTPUT — This routine outputs data to the paper tape punch. It also handles the table for data input.

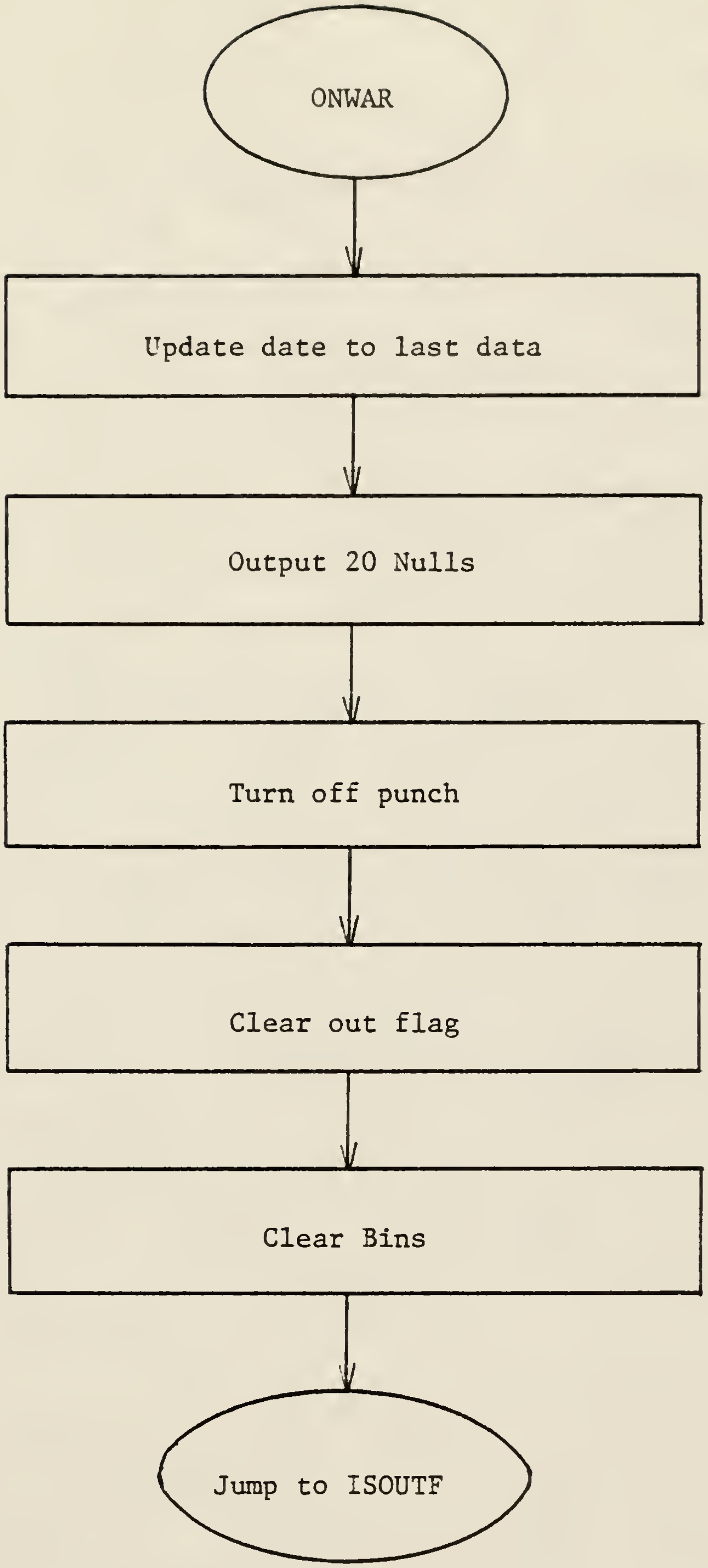


CLEARØ — Initializes the Data Collection System.

ISOUTF — The processor idles in this routine until interrupt.



AINA - This routine reads and fetches data values from the A/D.



ONWAR — This routine turns the punch off, updates time to last time, reinitializes the system and then returns to the main routine.

APPENDIX F

KIM-1 Data Collection Program Listing

The program listing given in this appendix is for both sequential data collection and the method of bins data collection. The listing is ordered from left to right as card number, memory location, code, mnemonic, operand, and comments.

```
CARD # LCC      CODE            CARD  10           20          30          40          50
  0000                  ;
  0000                  ;                           EQUATES
  0000                  ;                           SET UP FOR 6502-C2 I/C
  0000                  ;
  0000                          PRA =$1700          PORT A
  0000                          DDRA = $1701        DATA DRECTION PORT A
  0000                          PRB = $1702         PORT B
  0000                          DDRB = $1703        DATA DRECTION PORT B
  0000                          TIME = $170F        INTERRUPT TIMER CLOCK
  0000                          CHKL = $17E7        CHECK-SUM LOW FOR TAPE OUTPUT
  0000                          CHKH = $17E8        CHECK-SUM HIGH
  0000                          CHKT = $194C        CHECK-SUM SUBROUTINE KIM
  0000                          POINTL = $00FA      OUTPUT TO DISPLAY LOW BYTE
  0000                          POINTH = $00FB      OUTPUT TO DISPLAY HIGH BYTE
  0000                  ;
  0000                  ;
  0000                  ;
  0000                          *=0
  0000  4C 56 04                JMP CLEARO          JUMP TO INITIALIZATION ROUTINES
  0003                          SEC6      *=*+1     1/6 SEC COUNTER
  0004                          SECN      *=*+1     1 SEC COUNTER
  0005                          DAYH      *=*+1     DAY COUNTER HIGH
  0006                          DAYL      *=*+1     DAY COUNTER LOW
  0007                          HRS       *=*+1     HOURS COUNTER
  0008                          MIN       *=*+1     MIN COUNTER
  0009                          LDAYH     *=*+1     LAST DAY HIGH
  000A                          LDAYL     *=*+1     LAST DAY LOW
  000B                          LHRS      *=*+1     LAST HOURS
  000C                          LMIN      *=*+1     LAST MIN DATAOUT
  000D                          YEAR      *=*+1     YEAR DATE
  000E                  ;
  000E                          C1        *=*+1     TEMPORARY STORAGE FOR
  000F                          C2        *=*+1     CHANNELS USED FOR
  0010                          C3        *=*+1     KEYBOARD DISPLAY
  0011                          C4        *=*+1
  0012                          C5        *=*+1
  0013                          C6        *=*+1
  0014                          C7        *=*+1
  0015                          C8        *=*+1
  0016                          C9        *=*+1
  0017                          C10       *=*+1
  0018                          C11       *=*+1
  0019                          C12       *=*+1
  001A                  ;
  001A                          OUTF      *=*+1     OUTPUT FLAG WHEN SET OUTPUT DATA
  001B                          SECND     *=*+1     1 SEC FLAG SET TO 3CH EVERY SEC.
  001C                          DATACF    *=*+1     DATA COLLECTION FLAG
  001D                          MUL1H     *=*+1     MULTIPLICAND HIGH BYTE
  001E                          MUL1      *=*+1     MULTIPLICAND LOW BYTE
  001F                          MUL2      *=*+1     MULTIPLIER
  0020                          HIGHMP    *=*+1     HIGH PRODUCT
  0021                          LOWMP     *=*+1     LOW PRODUCT
  0022                          INF       *=*+1     INPUT FLAG SET FOR DATA READ
  0023                          RPM       *=*+1     VALUE OF DIGITAL ANGULAR VELOCITY
  0024                          ANEM      *=*+1     VALUE OF DIGITAL ANEMOMETER
```

```
CARD # LOC     CODE        CARD  10         20        30        40        50        60
       0025                      ANEML    *=*+1    LAST VALUE OF ANEM
       0026                      LPAGE    *=*+1    SAVE FOR PAGE ADDRESS LOW BYTE
       0027                      HPAGE    *=*+1    SAVE FOR PAGE ADDRESS HIGH BYTE
       0028                      LONOWP   *=*+1    SAVE FOR PCC LOW
       0029                      HINOWP   *=*+1    SAVE FOR PCC HIGH
       002A                      COUNT    *=*+1    REG. FOR IRQ ROUTINES
       002B                      CHKTC    *=*+1    TEMP. STORAGE FOR CHECK-SUM
       002C                      FIRSTF   *=*+1    FLAG FOR POWER-ON CLEAR BINS IF SET
       002D                      COUNTT   *=*+1    TEMP. REG. OF 40 MICROSEC. DELAY
       002E              ;
       002E              ;
       002E                      * = $0200
       0200              ;
       0200              ;
       0200              ;       WAIT40
       0200              ;
       0200  A9 04       WAIT40   LDA #4           WAIT 40 MICROSEC.
       0202  85 2D                STA COUNTT       SET COUNTER
       0204  C6 2D       VOL      DEC COUNTT       LOOP COUNT DOWN
       0206  D0 FC                BNE VOL
       0208  60                   RTS              RETURN
       0209              ;
       0209                      * = *+5
       020E              ;
       020E              ;  NULL20
       020E              ;  OUTPUT 20 NULLS AND THE ASCII SYNC
       020E  8A          NULL20 TXA                SAVE X
       020F  48                 PHA
       0210  A2 14              LDX  #20           SET COUNTER TO 20
       0212  A9 00       NULLNX LDA  #0            LOAD NULLS
       0214  20 3C 03           JSR  OUTPOK        OUTPUT NULL
       0217  CA                 DEX                DECREMENT COUNTER
       0218  D0 F8              BNE  NULLNX        DO 20 TIMES
       021A  A9 16              LDA  #%00010110    ASCII SYNC OUTPUT
       021C  20 3C 03           JSR  OUTPOK
       021F  68                 PLA                RESTORE X
       0220  AA                 TAX
       0221  60                 RTS
       0222              ;
       0222                     * = *+5
       0227              ;
       0227              ;  IRQ1 INTERRUPTS 6 TIMES PER SECOND
       0227  48          IRQ1     PHA              SAVE CPU ON STACK
       0228  8A                   TXA
       0229  48                   PHA
       022A  98                   TYA
       022B  48                   PHA
       022C  A9 A3                LDA #$A3         RESET KIM TIMER
       022E  8D 0F 17             STA TIME         INTERRUPT PERIOD=CONTENTS OF TIME/976.56
       0231  20 C8 02             JSR CALEND       UPDATE CALENDER
       0234  A9 00                LDA #00
       0236  C5 1A                CMP OUTF         OUTF SET DO NOT FETCH DATA
       0238  D0 05                BNE PON
       023A  85 1C                STA DATACF       RESET DATA COLLECTION FLAG
       023C  20 91 02             JSR READ         FETCH DATA
```

```
CARD # LOC    CODE       CARD  10          20          30          40          50          60
       023F   68         PON      PLA
       0240   A8                  TAY
       0241   68                  PLA
       0242   AA                  TAX              RESTORE CPU
       0243   68                  PLA
       0244   40                  RTI
       0245              ;
       0245                     * = *+5
       024A              ;
       024A              ;  IRQ2 INTERRUPTS  6 TIMES PER SECOND
       024A              ;
       024A   48         IRQ2     PHA              SAVE CPU
       024B   8A                  TXA
       024C   48                  PHA
       024D   98                  TYA
       024E   48                  PHA
       024F   A9 A3               LDA #$A3         SET KIM TIMER
       0251   8D 0F 17            STA TIME         INTERRUPT PERIOD=CONTENTS OF TIME/976.56
       0254   85 2A               STA COUNT        SET COUNT FLAG
       0256   68                  PLA
       0257   A8                  TAY
       0258   68                  PLA
       0259   AA                  TAX              RESTORE CPU
       025A   68                  PLA
       025B   40                  RTI              RETURN
       025C              ;
       025C                     * = *+5
       0261              ;
       0261              ;  1 BYTE BY 1 BYTE UNSIGNED MULTIPLY 2 BYTE PRODUCT
       0261              ;
       0261   A9 00      MULT  LDA   #00           MUL2 * MUL1 = PRODUCT
       0263   85 20            STA   HIGHMP        CLEAR PRODUCT HIGH AND LOW
       0265   85 21            STA   LOWMP
       0267   85 1D            STA   MUL1H         CLEAR HIGH BYTE OF MUL1
       0269   AA               TAX                 CLEAR X
       026A   46 1F            LSR   MUL2          SHIFT LEFT MUL2
       026C   B0 0D            BCS   RUN
       026E   E0 07      ITISO CPX   #7
       0270   F0 19            BEQ   DON
       0272   E8               INX
       0273   06 1E            ASL   MUL1
       0275   26 1D            ROL   MUL1H
       0277   46 1F            LSR   MUL2
       0279   90 F3            BCC   ITISO
       027B   A5 1E       RUN  LDA   MUL1
       027D   18               CLC
       027E   65 21            ADC   LOWMP
       0280   85 21            STA   LOWMP
       0282   A5 1D            LDA   MUL1H
       0284   65 20            ADC   HIGHMP
       0286   85 20            STA   HIGHMP
       0288   4C 6E 02         JMP   ITISO
       028B   60         DON   RTS
       028C              ;
       028C                     * = *+5
```

```
LOC     CODE         CARD  10        20        30        40        50        60
0291              ;
0291              ;       READ SUBROUTINE
0291              ;
0291  A5 24        READ LDA   ANEM         FETCH LAST VALUE OF ANEM
0293  85 25             STA   ANEML        STORE AT ANEML
0295  A9 00             LDA   #00          SET A PORT AS A INPUT
0297  8D 01 17          STA   DDRA
029A  A9 10             LDA   #$10         INHIBIT DIGITAL COUNTERS
029C  8D 02 17          STA   PRB          AND SELECT RPM COUNT
029F  AD 00 17          LDA   PRA          FETCH RPM COUNT
02A2  85 23             STA   RPM          STORE AT RPM
02A4  A9 20             LDA   #$20         SELECT ANEM COUNTER
02A6  8D 02 17          STA   PRB
02A9  AD 00 17          LDA   PRA          FETCH ANEM COUNT
02AC  85 24             STA   ANEM         STORE AT ANEM
02AE  A9 23             LDA   #$23         RESET COUNTER AND
02B0  8D 02 17          STA   PRB          RELEASE INHIBIT
02B3  A9 21             LDA   #$21         GO COUNT
02B5  8D 02 17          STA   PRB          LEAVE FOR PUNCH
02B8              ;  IF THRESHOLD IS GREATER THAN ANGULAR VELOCITY DO NOT COLLECT
02B8  A5 23             LDA RPM            ANGULAR VELOCITY LOAD
02BA              ;  THRESHOLD IS DEFINED AS THE CMP #THRESHOLD
02BA  C9 00             CMP #00            COMPARE ANGULAR VELOCITY TO THRESHOLD
02BC  90 04             BCC NOCOL          IF RPM < THRESHHOLD DO NOT COLLECT DATA
02BE  A9 01             LDA #1
02C0  85 1C             STA DATACF         SET DATA COLLECTION FLAG
02C2  60           NOCOL RTS               RETURN
02C3              ;
02C3                    * = *+5
02C8              ;
02C8              ;   CALEND
02C8              ;
02C8  A9 06       CALEND LDA #6
02CA  A2 00             LDX   #0           INCREMENT 1/6 SEC
02CC  E6 03             INC   SEC6         REGISTER
02CE  C5 03             CMP   SEC6         WHEN =1 SEC
02D0  F0 01             BEQ   ASEC         BRANCH TO ASEC
02D2  60                RTS
02D3  86 03       ASEC  STX   SEC6         CLEAR SEC6
02D5  E6 04             INC   SECN         INCREMENT SEC
02D7  A9 3C             LDA   #60
02D9  85 13             STA   SECND        SET FLAG FOR PUNCH POWER-UP
02DB  C5 04             CMP   SECN         WHEN = 60
02DD  F0 01             BEQ   AMIN         BRANCH
02DF  60                RTS
02E0  86 04       AMIN  STX   SECN         ETC.
02E2  E6 08             INC   MIN
02E4  C5 08             CMP   MIN
02E6  F0 01             BEQ   AHRS
02E8  60                RTS
02E9  86 08       AHRS  STX   MIN
02EB  E6 07             INC   HRS
02ED  A9 18             LDA   #24
02EF  C5 07             CMP   HRS
02F1  F0 01             BEQ   ADAY
```

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```
CARD # LOC    CODE          CARD  10          20          30          40          50          60
       02F3   60                  RTS
       02F4   86 07      ADAY  STX   HRS
       02F6   A5 06            LDA   DAYL
       02F8   18               CLC
       02F9   69 01            ADC   #1
       02FB   85 06            STA   DAYL
       02FD   A5 05            LDA   DAYH
       02FF   69 00            ADC   #00
       0301   85 05            STA   DAYH
       0303   60               RTS
       0304              ;
       0304              ;
       0304                    * = *+5
       0309              ; CLEARB
       0309              ;
       0309   A9 08      CLEARB  LDA #$08        CLEAR ALL MEMORY BETWEEN 080CH AND 13FFH
       030B   8D 15 03           STA THERE+2
       030E   A0 14              LDY #$14        STOP CLEAR AT 13FFH
       0310   A9 00      FEB     LDA #00         CLEAR ACCUM.
       0312   AA                 TAX             CLEAR X
       0313   9D 00 08    THERE  STA $0800,X     CLEAR PAGE,X
       0316   E8                 INX             CLEAR NEXT X
       0317   E0 00              CPX #00         CLEAR ALL 256
       0319   D0 F8              BNE THERE       DO NEXT PAGE
       031B   EE 15 03           INC THERE+2
       031E   CC 15 03           CPY THERE+2     FINSHED AT PAGE 14
       0321   D0 ED              BNE FEB
       0323   60                 RTS             RETURN
       0324              ;
       0324                    * = *+5
       0329              ;
       0329              ; INCPPC
       0329              ; INCREMENTS PC ON STACK(PPC), LONOWP, CARRY ADDED TO HINOWP
       0329   A5 28      INCPPC LDA  LONOWP      FETCH VALUE IN
       032B   18               CLC               LONOWP ADD 1
       032C   69 01            ADC   #1          AND SAVE
       032E   85 28            STA   LONOWP      FETCH VALUE IN
       0330   A5 29            LDA   HINOWP      HINOWP ADD
       0332   69 00            ADC   #00         CARRY AND
       0334   85 29            STA   HINOWP      SAVE
       0336   60               RTS
       0337              ;
       0337                    * = *+5
       033C              ;
       033C              ;    OUTPOK
       033C              ;
       033C              ;  USES ACCUM
       033C              ;  SUBROUTINE USED IN OUTPUT TO PUNCH
       033C              ;  LOAD DATA REGISTERS IN OUTPUT PORT
       033C   8D 00 17   OUTPOK STA PRA          OUTPUT DATA IN ACCUM
       033F   A9 08            LDA   #$08        LOAD PUNCH COMMAND
       0341   8D 02 17         STA   PRB
       0344   A9 01            LDA   #1          STOP PUNCH COMMAND
       0346   8D 02 17         STA   PRB
       0349   AD 02 17   BUSY  LDA   PRB         FETCH BUSY
```

```
CARD # LOC    CODE        CARD  10          20            30          40          50
       034C   29 04             AND   #%0000100   MASK ALL BUT BUSY
       034E   F0 F9             BEQ   BUSY        IF BUSY TEST AGAIN
       0350   EA                NOP               WAIT AFTER BUSY FOR
       0351   EA                NOP               PUNCH
       0352   60                RTS               RETURN
       0353               ;
       0353                       * = *+5
       0358               ;
       0358               ; SCX SUBROUTINES (KEYBOARD)
       0358               ; THESE SUBROUTINES SELECT THE OUTPUT DISPLAYED VALUE
       0358               ;
       0358   A9 BB       SC0      LDA #$BB
       035A   A2 BA                LDX #$BA
       035C   4C CD 03             JMP DISOUT
       035F   A5 0E       SC1      LDA C1
       0361   A2 00                LDX #0
       0363   4C CD 03             JMP DISOUT
       0366   A5 0F       SC2      LDA C2
       0368   A2 00                LDX #0
       036A   4C CD 03             JMP DISOUT
       036D   A5 10       SC3      LDA C3
       036F   A2 00                LDX #0
       0371   4C CD 03             JMP DISOUT
       0374   A5 11       SC4      LDA C4
       0376   A2 00                LDX #0
       0378   4C CD 03             JMP DISOUT
       037B   A5 12       SC5      LDA C5
       037D   A2 00                LDX #0
       037F   4C CD 03             JMP DISOUT
       0382   A5 13       SC6      LDA C6
       0384   A2 00                LDX #0
       0386   4C CD 03             JMP DISOUT
       0389   A5 14       SC7      LDA C7
       038B   A2 00                LDX #0
       038D   4C CD 03             JMP DISOUT
       0390   A5 15       SC8      LDA C8
       0392   A2 00                LDX #0
       0394   4C CD 03             JMP DISOUT
       0397   A5 24       SC9      LDA ANEM
       0399   A2 00                LDX #0
       039B   4C CD 03             JMP DISOUT
       039E   A5 17       SC10     LDA C10
       03A0   A2 00                LDX #0
       03A2   4C CD 03             JMP DISOUT
       03A5   A5 23       SC11     LDA RPM
       03A7   A2 00                LDX #0
       03A9   4C CD 03             JMP DISOUT
       03AC   A5 19       SC12     LDA C12
       03AE   A2 00                LDX #0
       03B0   4C CD 03             JMP DISOUT
       03B3   A5 06       SC13     LDA DAYL
       03B5   A6 05                LDX DAYH
       03B7   4C CD 03             JMP DISOUT
       03BA   A5 07       SC14     LDA HRS
       03BC   A2 00                LDX #0
```

```
CARD # LOC    CODE        CARD  10              20          30          40          50          60
       03BE  4C CD 03               JMP DISOUT
       03C1  A5 08       SC15       LDA MIN
       03C3  A2 00                  LDX #0
       03C5  4C CD 03               JMP DISOUT
       03C8              ;
       03C8                         *=*+5
       03CD              ;
       03CD  85 FA       DISOUT     STA $FA         ACCUM TO KIM POINTL
       03CF  86 FB                  STX $FB         X TO POINTH
       03D1  20 19 1F               JSR $1F19       KIM DISPLAY
       03D4  4C 70 04               JMP ISOUTF
       03D7              ;
       03D7                         * = *+5
       03DC              ;
       03DC              ; THIS ROUTINE ORDERS THE DATA COLLECTION AND OUTPUT
       03DC  A9 00       OUTSUB LDA #0              CLEAR CHECK-SUM
       03DE  8D E8 17               STA CHKH
       03E1  8D E7 17               STA CHKL
       03E4  68                     PLA             FETCH PCL FROM STACK
       03E5  85 28                  STA LONOWP      SAVE IN LONOWP
       03E7  68                     PLA             FETCH PCH FROM STACK
       03E8  85 29                  STA HINOWP      SAVE HINOWP
       03EA  20 29 03               JSR INCPPC      INCREMENT PPC; PPC IS FALSE PROGRAM COUNTER
       03ED  A0 00                  LDY #00         AT LOCATION HINOWP AND LONOWP
       03EF  B1 28                  LDA (LONOWP),Y  FETCH HIGH BYTE PAGE
       03F1  85 27                  STA HPAGE       SAVE HIGH BYTE
       03F3  20 29 03               JSR INCPPC
       03F6  B1 28                  LDA (LONOWP),Y  FETCH LOW BYTE PAGE
       03F8  85 26                  STA LPAGE       SAVE LOW BYTE
       03FA  20 29 03               JSR INCPPC
       03FD  B1 28                  LDA (LONOWP),Y  FETCH NUMBER OF DATA POINTS -1
       03FF  AA                     TAX             SAVE X
       0400  20 29 03               JSR INCPPC
       0403  B1 28                  LDA (LONOWP),Y  FETCH CHANNEL NO.
       0405  A8                     TAY             SAVE IN Y REG
       0406  A5 29                  LDA HINOWP      FETCH HIGH PPC
       0408  48                     PHA             PUT ON STACK
       0409  A5 28                  LDA LONOWP      FETCH LOW PPC
       040B  48                     PHA             PUT ON STACK
       040C  A9 00                  LDA #00
       040E  C5 22                  CMP INF         IF DATA COLLECTION TIME JUMP TO AINA
       0410  F0 03                  BEQ FURTH
       0412  4C C8 05               JMP AINA
       0415  C0 FF       FURTH      CPY #$FF        IF Y=FFH ALL BINS OR DATA ARE OUTPUT
       0417  D0 03                  BNE WITH        JUMP TO ONWAR AND UPDATE TIME TO LAST TIME
       0419  4C 97 05               JMP ONWAR
       041C  20 0E 02    WITH       JSR NULL20      OUTPUT NULLS AND SYNC
       041F  98                     TYA             MOVE CHANNEL NO. TO ACCUM
       0420  20 3C 03               JSR OUTPCK      OUTPUT CHANNEL NO.
       0423  8A                     TXA             MOVE NUMBER OF DATA POINT-1
       0424  18                     CLC
       0425  69 01                  ADC #1          INCREMENT ACCUM
       0427  A8                     TAY             NO. OF DATAPOINTS
       0428  A9 00                  LDA #00
       042A  69 00                  ADC #00
```

```
LOC    CODE        CARD  10          20          30         40         50         60
042C   20 3C 03          JSR OUTPOK              OUTPUT HIGHBYTE
042F   98                TYA                     DATA POINTS
0430   20 3C 03          JSR OUTPOK              OUTPUT LOW BYTE
0433   88                DEY
0434   B1 26       STATE LDA (LPAGE),Y
0436   84 2B             STY CHKTC               SAVE
0438   20 4C 19          JSR CHKT                COMPUTE CHECK-SUM
043B   A4 2B             LDY CHKTC               RESTORE Y
043D   20 3C 03          JSR OUTPOK              OUTPUT VALUE
0440   C0 00             CPY #0                  IF Y IS 0
0442   D0 EF             BNE STATE-1             FINSHED
0444   AD E8 17          LDA CHKH                OUTPUT HIGH CHECK-SUM
0447   20 3C 03          JSR OUTPOK
044A   AD E7 17          LDA CHKL                OUTPUT LOW CHECK-SUM
044D   20 3C 03          JSR OUTPOK
0450   60                RTS
0451               ;
0451                     * = *+5
0456               ;
0456   A9 00       CLEARO LDA #0                 CLEAR ACCUM
0458   48                PHA                     CLEAR PROCESSOR STATUS
0459   28                PLP
045A   85 2C             STA FIRSTF              RESET FIRST TIME FLAG
045C   20 09 03          JSR CLEARB              CLEAR BINS
045F   A9 FF       BACK  LDA #$FF                SET A PORT AS ALL
0461   8D 01 17          STA DDRA                OUTPUTS
0464   A9 21             LDA #$21                TURN PUNCH OFF RESET COUNTERS
0466   8D 02 17          STA PRB
0469   A9 3B             LDA #$3B                SET PORT B
046B   8D 03 17          STA DDRB
046E   A9 A3             LDA #$A3                RESET KIM COUNTER TO 1/6 SEC
0470   8D 0F 17          STA TIME
0473                     MOS=IRQ1/256*256
0473   A9 27             LDA #IRQ1-MOS           LOW BYTE OF IRQ1
0475   8D FE 17          STA $17FE               STORE IN IRQ VECTOR
0478   A9 02             LDA #IRQ1/256           HIGH BYTE OF IRQ1
047A   8D FF 17          STA $17FF               STORE IN IRQ VECTOR
047D   A9 00       ISOUTF LDA #00                IF OUTF IS SET GO TO OUTPUT
047F   C5 1A             CMP OUTF
0481   F0 03             BEQ FETCH
0483   4C 1C 05          JMP OUTPUT
0486   A5 1C       FETCH LDA DATACF              IF DATA COLLECTION TIME- COLLECT DATA
0488   C9 01             CMP #1
048A   D0 0E             BNE GETKEY              FETCH KEY
048C   20 B9 05          JSR DATACT
048F   A9 01             LDA #1
0491   C5 2C             CMP FIRSTF              IF FIRST TIME CLEAN BINS
0493   F0 05             BEQ GETKEY              THIS RESET COUNTERS
0495   85 2C             STA FIRSTF              RESET FLAG TO BRANCH NEXT TIME
0497   20 09 03          JSR CLEARB              CLEAR BINS
049A   20 6A 1F    GETKEY JSR $1F6A              KIM GETKEY
049D   C9 10            CMP #16                  MUST BE < 15 TO
049F   30 03            BMI KEY                  BE VALID
04A1   4C 7D 04         JMP ISOUTF               IF NOT VALID
04A4   C9 00       KEY  CMP  #0                  IF ZERO JUMP TO SUBROUTINE FOR CO
```

PAGE

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LOC     CODE        CARD  10          20          30          40          50
04A6   D0 03             BNE   NEXT1
04A8   4C 58 03          JMP   SC0
04AB   C9 01       NEXT1 CMP   #1
04AD   D0 03             BNE   NEXT2
04AF   4C 5F 03          JMP SC1                   JUMP TO SUBROUTINE C1  ETC.
04B2   C9 02       NEXT2 CMP   #2
04B4   D0 03             BNE   NEXT3
04B6   4C 66 03          JMP   SC2
04B9   C9 03       NEXT3 CMP   #3
04BB   D0 03             BNE   NEXT4
04BD   4C 6D 03          JMP   SC3
04C0   C9 04       NEXT4 CMP   #4
04C2   D0 03             BNE   NEXT5
04C4   4C 74 03          JMP   SC4
04C7   C9 05       NEXT5 CMP   #5
04C9   D0 03             BNE   NEXT6
04CB   4C 7B 03          JMP   SC5
04CE   C9 06       NEXT6 CMP   #6
04D0   D0 03             BNE   NEXT7
04D2   4C 82 03          JMP   SC6
04D5   C9 07       NEXT7 CMP   #7
04D7   D0 03             BNE   NEXT8
04D9   4C 89 03          JMP   SC7
04DC   C9 08       NEXT8 CMP   #8
04DE   D0 03             BNE   NEXT9
04E0   4C 90 03          JMP   SC8
04E3   C9 09       NEXT9 CMP   #9
04E5   D0 03             BNE   NEXT10
04E7   4C 97 03          JMP   SC9
04EA   C9 0A       NEXT10 CMP   #10
04EC   D0 03              BNE   NEXT11
04EE   4C 9E 03           JMP   SC10
04F1   C9 0B       NEXT11 CMP   #11
04F3   D0 03              BNE   NEXT12
04F5   4C A5 03           JMP   SC11
04F8   C9 0C       NEXT12 CMP   #12
04FA   D0 03              BNE   NEXT13
04FC   4C AC 03           JMP   SC12
04FF   C9 0D       NEXT13 CMP   #13
0501   D0 03              BNE   NEXT14
0503   4C B3 03           JMP   SC13
0506   C9 0E       NEXT14 CMP   #14
0508   D0 03              BNE   NEXT15
050A   4C BA 03           JMP   SC14
050D   C9 0F       NEXT15 CMP   #15          IF KEY NOT 0 TO 15
050F   D0 03              BNE   NEXT16
0511   4C C1 03           JMP   SC15         MUST BE ERROR
0514   4C 00 1C    NEXT16 JMP   $1C00        JUMP TO KIM MONITOR
0517               ;
0517               ;
0517               ;
0517                    * = *+5
051C               ;
051C               ;OUTPUT DATA TO PUNCH
051C               ;
```

```
CARD # LOC    CODE       CARD  10        20          30         40          50
       051C   A9 FF      OUTPUT LDA #$FF            PORT A AS AN OUTPUT
       051E   8D 01 17          STA DDRA            FOR PUNCH
       0521   A9 00             LDA #00             TURN ON PUNCH
       0523   85 22             STA INF             CLEAR IN FLAG
       0525   8D 02 17          STA PRB
       0528              ;WAIT FOR 1 TO 2 SEC FOR PUNCH TO COME UP
       0528   85 1B             STA SECND           RESET SECONDS FLAG
       052A   C5 1B      WAIMR  CMP SECND           SEE IF FLAG IS SET
       052C   F0 FC             BEQ WAIMR           IF IT IS GO ON
       052E   85 1B             STA SECND           RESET SECONDS FLAG
       0530   C5 1B      WAISMR CMP SECND           SEE IF FLAG IS SET
       0532   F0 FC             BEQ WAISMR          GO ON AFTER 1 TO 2 SEC
       0534              ;
       0534              ;
       0534   EA         OUT    NOP
       0535              ;OUTPUT ANALOG ANEMOMETER 1
       0535   20 DC 03          JSR OUTSUB
       0538   13 00             .DBYTE $1300
       053A   FF                .BYTE 255
       053B   01                .BYTE 1
       053C              ;OUTPUT TORQUE
       053C   20 DC 03          JSR OUTSUB
       053F   12 00             .DBYTE $1200
       0541   FF                .BYTE 255
       0542   02                .BYTE 2
       0543              ; OUTPUT ALTERNATOR VOLTAGE
       0543   20 DC 03          JSR OUTSUB
       0546   10 00             .DBYTE $1000
       0548   FF                .BYTE 255
       0549   04                .BYTE 4
       054A              ; OUTPUT WIND DIRECTION
       054A   20 DC 03          JSR OUTSUB
       054D   0F 00             .DBYTE $0F00
       054F   FF                .BYTE 255
       0550   05                .BYTE 5
       0551              ; OUTPUT AIR TEMP
       0551   20 DC 03          JSR OUTSUB
       0554   00 13             .DBYTE C6
       0556   00                .BYTE 0
       0557   06                .BYTE 6
       0558              ; OUTPUT AIR PRESSURE
       0558   20 DC 03          JSR OUTSUB
       055B   00 14             .DBYTE C7
       055D   00                .BYTE 0
       055E   07                .BYTE 7
       055F              ;  OUTPUT ANALOG ANEMOMETER 2
       055F   20 DC 03          JSR OUTSUB
       0562   0C 00             .DBYTE $0C00
       0564   FF                .BYTE 255
       0565   08                .BYTE 8
       0566              ; OUTPUT ANGULAR VELOCITY
       0566   20 DC 03          JSR OUTSUB
       0569   0B 00             .DBYTE $0B00
       056B   FF                .BYTE 255
       056C   0B                .BYTE 11
```

```
CARD # LOC    CODE        CARD   10          20          30          40          50
       05C3   48                 PHA                     PUT ON STACK FOR RTS
       05C4                      BAT=OUT/256*256
       05C4   A9 34              LDA #OUT-BAT            LOW VALUE FIRST OUTPUT ADDRESS-1
       05C6   48                 PHA                     PUT ON STACK FOR RTS
       05C7   60          SCALE  RTS                     FETCH NEW CHANNEL OFF STACK
       05C8   98          AINA   TYA
       05C9   C9 06              CMP #6                  JUMP HERE FROM OUTSUB
       05CB   90 03              BCC CNMOR               6 IS FIRST CHANNEL NOT BEING BINNED
       05CD   4C F0 05           JMP COMPUT
       05D0   AA          CNMOR  TAX
       05D1   CA                 DEX                     CHANNEL NUMBER-1 = ADDRESS
       05D2   BD 00 14           LDA $1400,X             START CONVERSION
       05D5   20 00 02           JSR WAIT40              WAIT FOR CONVERSION
       05D8   BD 00 14           LDA $1400,X             FETCH VALUE
       05DB   95 0E              STA C1,X                SAVE VALUE IN TEMP. STORAGE
       05DD   A8          INCBIN TAY                     INCREMENTS BINS, VALUE READ IN Y
       05DE   B1 26              LDA (LPAGE),Y           FETCH BIN LOCATION
       05E0   18                 CLC
       05E1   69 01              ADC #1
       05E3   91 26              STA (LPAGE),Y           STORE AT SAME LOCATION
       05E5   C9 FF              CMP #$FF                COMPARE FOR FULL BIN
       05E7   90 DE              BCC SCALE
       05E9   A9 01              LDA #1                  JUMP TO SCALE  SETTING OUTF
       05EB   85 1A              STA OUTF                IF BIN IS FULL
       05ED   4C C7 05           JMP SCALE
       05F0   C9 09       COMPUT CMP #9                  IF CHANNEL NO. IS 9
       05F2   D0 05              BNE CNNOW1
       05F4   A5 24              LDA ANEM
       05F6   4C DD 05           JMP INCBIN
       05F9   C9 0A       CNNOW1 CMP #10                 IF CHANNEL 10 INCREMENT BIN
       05FB   D0 0F              BNE CNNOW2              FOR DELTA ANEM
       05FD   A5 24              LDA ANEM
       05FF   38                 SEC
       0600   E5 25              SBC ANEML               ANEM-ANEML = DELTA WIND
       0602   90 05              BCC LESS                IF ANEML > ANEM BRANCH
       0604   85 17              STA C10                 TO LESS
       0606   4C DD 05           JMP INCBIN              IF NOT INCBIN
       0609   4C C7 05    LESS   JMP SCALE               GET NEW CHANNEL
       060C   C9 0B       CNNOW2 CMP #11
       060E   D0 05              BNE CNNOW3
       0610   A5 23              LDA RPM
       0612   4C DD 05           JMP INCBIN
       0615   C9 0C       CNNOW3 CMP #12
       0617   D0 32              BNE CNNOW4              COMPUTE POWER
       0619   A5 23              LDA RPM                 FETCH RPM COUNT
       061B   85 1E              STA MUL1                STORE MULTIPLICAND
       061D   A5 0F              LDA C2                  FETCH TORQUE
       061F   85 1F              STA MUL2                STORE MULTIPLIER
       0621   20 61 02           JSR MULT                COMPUTE POWER P=TW
       0624   A5 20              LDA HIGHMP              SAVE HIGH BYTE
       0626   48                 PHA
       0627   A5 21              LDA LOWMP               SAVE LOW BYTE
       0629   48                 PHA
       062A   18                 CLC
       062B   A5 23              LDA RPM                 FETCH RPM AND ADD 1
```

```
LOC     CODE        CARD  10          20          30          40          50          60
056D                ; OUTPUT MECHANICAL POWER
056D    20 DC 03          JSR OUTSUB
0570    C8 00             .DBYTE $0800
0572    FF                .BYTE 255
0573    0C                .BYTE 12
0574                ; OUTPUT TIME
0574    20 DC 03          JSR OUTSUB
0577    C0 05             .DBYTE DAYH
0579    C8                .BYTE 8
057A    CD                .BYTE 13
057B                ; FINSHED
057B                ; PUT THIS MACRO LAST AFTER ALL CHANNELS OUTPUT OR COLLECTED
057B    20 DC 03          JSR OUTSUB
057E    C0 00             .DBYTE 00
0580    C0                .BYTE 00
0581    FF                .BYTE  $FF
0582                ;
0582                ; OUTPUT ELECTRICAL POWER
0582    20 DC 03          JSR OUTSUB
0585    11 00             .DBYTE $1100
0587    FF                .BYTE 255
0588    C3                .BYTE 3
0589                ; OUTPUT DIGITAL ANEMOMETER
0589    20 DC 03          JSR OUTSUB
058C    CA C0             .DBYTE $0A00
058E    FF                .BYTE 255
058F    C9                .BYTE 9
0590                ; OUTPUT DELTA WIND SPEED
0590    20 DC 03          JSR OUTSUB
0593    C9 00             .DBYTE $0900
0595    FF                .BYTE 255
0596    CA                .BYTE 10
0597                ;
0597    A5 08       ONWAR LDA MIN
0599    85 0C             STA LMIN
059B    A5 07             LDA HRS
059D    85 0B             STA LHRS
059F    A5 05             LDA DAYH
05A1    85 09             STA LDAYH
05A3    A5 06             LDA DAYL
05A5    85 0A             STA LDAYL
05A7    20 0E 02          JSR NULL20      OUT 20 NULLS AND SYNC
05AA    A9 21             LDA #$21        TURN OFF PUNCH
05AC    8D 02 17          STA PRB
05AF    A9 00             LDA #00         CLEAR OUT FLAG
05B1    85 1A             STA OUTF
05B3    20 C9 03          JSR CLEARB      CLEAR BINS
05B6    4C 7D 04          JMP ISOUTF      RETURN
05B9                ;
05B9                ; THIS ROUTINE ADJUST THE STACK FOR OUTPUT
05B9    A9 00       DATACT  LDA #0
05BB    85 1C               STA DATACF    RESET DATACF
05BD    A9 01               LDA #1        SET INFLAG
05BF    85 22               STA INF
05C1    A9 05               LDA #OUT/256  HIGH BYTE FIRST OUTPUT ADDRESS-1
```

```
CARD # LOC    CODE          CARD 10            20        30          40          50
       06A0   8D FF 17            STA $17FF              STORE INTERRUPT VECTOR LOCATION
       06A3   A9 21               LDA #$21               TURN PUNCH OFF AND SET COUNTER
       06A5   8D 02 17            STA PRB
       06A8   A9 3B               LDA #$3B
       06AA   8D 03 17            STA DDRB               SET B AS INPUT/OUTPUT
       06AD   A9 62               LDA #$62               SET KIM TIMER
       06AF   8D 0F 17            STA TIME
       06B2   A9 02         START LDA #2                 FETCH DATA TWICE
       06B4   C5 2C               CMP FIRSTF             AND CLEAR BINS
       06B6   F0 04               BEQ THIRD              MAKES COUNTER 1ST DATA GOOD
       06B8   E6 2C               INC FIRSTF
       06BA   A2 00               LDX #00
       06BC   85 2A         THIRD STA COUNT
       06BE   C5 2A         ME    CMP COUNT              WAIT FOR INTERRUPT TO SET COUNT
       06C0   F0 FC               BEQ ME                 WHEN CHANGED COLLECT DATA
       06C2   A9 10               LDA #$10               SELECT RPM COUNTER
       06C4   8D 02 17            STA PRB
       06C7   AD 00 17            LDA PRA                FETCH ANGULAR VELOCITY
       06CA   9D 00 08            STA $0800,X            STORE RPM COUNT
       06CD   A9 20               LDA #$20               SELECT ANEM DIGITAL COUNT
       06CF   8D 02 17            STA PRB
       06D2   AD 00 17            LDA PRA                FETCH ANEM DIGITAL COUNT
       06D5   9D 00 0A            STA $0A00,X            STA ANEM
       06D8   A9 23               LDA #$23               RESET COUNTER
       06DA   8D 02 17            STA PRB
       06DD   A9 21               LDA #$21               RELEASE INHIBIT GO COUNT
       06DF   8D 02 17            STA PRB
       06E2   A0 00               LDY #00                CLEAR FOR MP21 CHANNEL
       06E4   A9 13               LDA #$13               LDA HIGH BIN
       06E6   8D F4 06            STA LOP3+2             STORE IN ADDRESS LOC
       06E9   B9 00 14      LOP4  LDA $1400,Y            START CONVERSION
       06EC   20 00 02            JSR WAIT40             WAIT
       06EF   B9 00 14            LDA $1400,Y            FETCH VALUE
       06F2   9D 00 13      LOP3  STA $1300,X            STORE IN MEMORY
       06F5   C8                  INY                    SET NEXT CHANNEL
       06F6   CE F4 06            DEC LOP3+2             SET NEXT LOWER PAGE
       06F9   C0 08               CPY #8                 DO ALL CHANNELS OF MP21
       06FB   D0 EC               BNE LOP4
       06FD   E8                  INX                    DO 256 SAMPLES
       06FE   E0 00               CPX #00
       0700   D0 B0               BNE START
       0702   AD 05 14            LDA $1405              DO CHANNEL MP21 5 TEMP
       0705   20 00 02            JSR WAIT40
       0708   AD 05 14            LDA $1405
       070B   85 13               STA C6                 STORE TEMP.
       070D   AD 06 14            LDA $1406              DO CHANNEL MP21 6 PRESSURE.
       0710   20 00 02            JSR WAIT40
       0713   AD 06 14            LDA $1406
       0716   85 14               STA C7                 STORE VALUE
       0718   A9 01               LDA #1                 SET OUT FLAG
       071A   85 1A               STA OUTF
       071C   4C 5F 04            JMP BACK               JUMP TO IS OUT FLAG SET
```

```
CARD # LOC      CODE        CARD  10        20        30
  769  071F                      .END


END OF MOS/TECHNOLOGY 650X ASSEMBLY VERSION 5
NUMBER OF ERRORS =    0,  NUMBER OF WARNINGS =    0
```

SYMBOL TABLE

SYMBOL	VALUE	LINE DEFINED	CROSS-REFERENCES								
ADAY	02F4	222	220								
AHRS	02E9	216	214								
AINA	05C8	611	373								
AMIN	02E0	211	209								
ANEM	0024	55	169	180	314	633	637				
ANEML	0025	56	170	639							
ARE	02C0	712	713								
ASEC	02C3	204	202								
BACK	045F	410	767								
BAT	05C0	607	608								
BUSY	0349	275	277								
CALEND	02C8	198	105								
CHKH	17E8	11	347	397							
CHKL	17E7	10	348	399							
CHKT	194C	12	392								
CHKTC	002B	62	391	393							
CLEARB	03C9	236	409	435	597						
CLEARO	0456	405	19								
COMPUT	05F0	631	614								
COUNT	002A	61	129	728	729						
COUNTT	002D	64	73	74							
C1	000E	32	290	620							
C10	0017	41	317	641							
C11	0018	42	****								
C12	0019	43	323	673							
C2	000F	33	293	652	663						
C3	0010	34	296								
C4	0011	35	299								
C5	0012	36	302								
C6	0013	37	305	533	684	760					
C7	0014	38	308	538	691	764					
C8	0015	39	311	698							
C9	0016	40	****								
DATACF	001C	47	109	191	427	602					
DATACT	05E9	601	430								
DAYH	0005	22	227	229	327	558	588				
DAYL	0006	23	223	226	326	590					
DDRA	1701	6	172	411	497	711					
DDRB	1703	8	415	720							
DISOUT	03CD	338	289	292	295	298	301	304	307	310	313	316
			319	322	325	328	331	334				
DON	0288	163	149								
FEB	0310	239	247								
FETCH	0486	427	425								
FIRSTF	002C	63	408	432	434	710	724	726			
FURTH	0415	374	372								
GETKEY	049A	436	429	433							
HIGHMP	0020	51	142	160	161	655	672				
HINCWP	0029	60	258	260	352	366					
HPAGE	0027	58	356								
HRS	0007	24	217	219	222	329	586				
INCBIN	05DD	621	634	642	647	674	699				
INCPPC	0329	254	353	357	360	363					
INF	0022	53	371	499	604						

```
CARD # LOC    CODE        CARD  10        20        30        40        50
       062D   69 01             ADC #1
       062F   85 1E             STA MUL1
       0631   A5 0F             LDA C2          FETCH TORQUE AND ADD 1
       0633   69 01             ADC #1
       0635   85 1F             STA MUL2        IF TORQUE = 255
       0637   B0 0F             BCS NO          DONE
       0639   20 61 02          JSR MULT        P1=(T+1)(W+1)
       063C   18                CLC
       063D   68                PLA
       063E   65 21             ADC LOWMP       P2=P1 + P
       0640   68                PLA
       0641   65 20             ADC HIGHMP
       0643   85 19             STA C12         SAVE P2 HIGH BYTE
       0645   4C DD 05          JMP INCBIN
       0648   4C C7 05  NO      JMP SCALE
       064B   C9 0D     CNNOW4  CMP #13         TIME ROUTINE
       064D   D0 03             BNE CNNOW5
       064F   4C C7 05          JMP SCALE
       0652   C9 06     ONNOW5  CMP #6          CHANNEL 6 AIR TEMP
       0654   D0 0E             BNE CNNOW6
       0656   AD 05 14          LDA $1405       START CONNVERSION
       0659   20 00 02          JSR WAIT40      WAIT
       065C   AD 05 14          LDA $1405       FETCH TEMP
       065F   85 13             STA C6
       0661   4C C7 05          JMP SCALE       GET NEW CHANNEL
       0664   C9 07     ONNOW6  CMP #7
       0666   D0 0E             BNE CNNOW7
       0668   AD 06 14          LDA $1406
       066B   20 00 02          JSR WAIT40      WAIT
       066E   AD 06 14          LDA $1406       FETCH PRESSURE
       0671   85 14             STA C7
       0673   4C C7 05          JMP SCALE       GET NEW CHANNEL
       0676   C9 08     ONNOW7  CMP #8          ANEM 2
       0678   D0 0E             BNE CNNOW8
       067A   AD 07 14          LDA $1407
       067D   20 00 02          JSR WAIT40
       0680   AD 07 14          LDA $1407       FETCH ANMEN 2
       0683   85 15             STA C8
       0685   4C DD 05          JMP INCBIN
       0688   68        ONNOW8  PLA             FINSHED
       0689   68                PLA             RESTORE STACK
       068A   60                RTS             RETURN
       068B             ;
       068B                    * = *+5
       0690             ;
       0690             ;  THIS ROUTINE SAMPLES SEQUENTIALLY EVERY 1/10 OF A SEC
       0690   A2 00     SEQUAL  LDX #00         CLEAR
       0692   8A                TXA
       0693   48                PHA             CLEAR PROCESSOR STATUS
       0694   85 2C             STA FIRSTF      CLEAR FLAG FIRST TIME (FIRSTF)
       0696   8D 01 17          STA DDRA        SET A AS INPUT
       0699                     ARE=IRQ2/256*256
       0699   A9 4A             LDA #IRQ2-ARE   LOAD IRQ2 LOW BYTE
       069B   8D FE 17          STA $17FE       STORE INTERRUPT VECTOR
       069E   A9 02             LDA #IRQ2/256   LOAD IRQ2 HIGH BYTE
```

SYMBOL	VALUE	LINE DEFINED	CROSS-REFERENCES									
IRQ1	0227	98	418	419	421							
IRQ2	024A	122	712	713	715							
ISOUTF	047D	423	341	439	598							
ITISO	026E	148	154	162								
KEY	04A4	440	438									
LDAYH	00C9	26	589									
LDAYL	00CA	27	591									
LESS	06C9	643	640									
LHRS	00CB	28	587									
LMIN	00CC	29	585									
LONOWP	0023	59	254	257	350	355	358	361	364	368		
LOP3	06F2	749	745	751								
LOP4	06E9	746	753									
LONMP	0021	52	143	157	158	657	670					
LPAGE	0026	57	359	390	622	625						
ME	06BE	729	730									
MIN	0008	25	212	213	216	332	584					
MOS	02C0	418	419									
MULT	0261	141	654	667								
MUL1	001E	49	151	155	651	662						
MUL1H	001D	48	144	152	159							
MUL2	001F	50	146	153	653	665						
NEXT1	04AB	443	441									
NEXT10	04EA	470	468									
NEXT11	04F1	473	471									
NEXT12	04F8	476	474									
NEXT13	04FF	479	477									
NEXT14	0506	482	480									
NEXT15	050D	485	483									
NEXT16	0514	488	486									
NEXT2	04B2	446	444									
NEXT3	04B9	449	447									
NEXT4	04C0	452	450									
NEXT5	04C7	455	453									
NEXT6	04CE	458	456									
NEXT7	04D5	461	459									
NEXT8	04DC	464	462									
NEXT9	04E3	467	465									
NO	0648	675	666									
NOCOL	02C2	192	189									
NULLNX	0212	85	88									
NULL20	02CE	82	377	592								
ONMOR	05C0	615	613									
ONNOW1	05F9	635	632									
ONNOW2	060C	644	636									
ONNOW3	0615	648	645									
ONNOW4	0643	676	649									
ONNOW5	0652	679	677									
ONNOW6	0664	686	680									
ONNOW7	0676	693	687									
ONNOW8	0688	700	694									
ONWAR	0597	584	376									
OUT	0534	510	605	607	608							
OUTF	001A	45	107	424	596	629	766					
OUTPCK	033C	270	86	90	379	386	388	394	398	400		
OUTPUT	051C	496	426									
OUTSUB	030C	346	512	517	522	527	532	537	542	547	552	557

SYMBOL	VALUE	LINE DEFINED	CROSS-REFERENCES									
			563	569	574	579						
POINTH	00FB	14	****									
POINTL	00FA	13	****									
PON	023F	111	108									
PRA	1700	5	175	179	270	733	737					
PRB	1702	7	174	178	182	184	272	274	275	413	500	594
			718	732	736	740	742					
READ	0291	169	110									
RPM	0023	54	176	186	320	646	650	660				
RUN	027B	155	147									
SCALE	05C7	610	627	630	643	675	678	685	692			
SC0	0358	287	442									
SC1	035F	290	445									
SC10	039E	317	472									
SC11	03A5	320	475									
SC12	03AC	323	478									
SC13	03B3	326	481									
SC14	03BA	329	484									
SC15	03C1	332	487									
SC2	0366	293	448									
SC3	036D	296	451									
SC4	0374	299	454									
SC5	037B	302	457									
SC6	0382	305	460									
SC7	0389	308	463									
SC8	0390	311	466									
SC9	0397	314	469									
SECN	0004	21	205	208	211							
SECND	001B	46	207	502	503	505	506					
SEC6	0003	20	200	201	204							
SEQUAL	0690	707	****									
START	0682	723	756									
STATE	0434	390	396									
THERE	0313	241	237	244	245	246						
THIRD	068C	728	725									
TIME	170F	9	104	128	417	722						
VOL	0204	74	75									
WAIMR	052A	503	504									
WAISMR	0530	506	507									
WAIT40	0200	72	618	682	689	696	747	753	762			
WITH	041C	377	375									
YEAR	000D	30	****									

APPENDIX G

System Operation

The KSU Wind Laboratory system operation is both straightforward and simple. Details given in this appendix include program loading procedures and actual data collection procedures.

To load the program from audio cassette:

1. Set the single step-IRQ switch to IRQ.
2. Set the TTY-DISPLAY switch to DISPLAY.
3. Set the tone on the tape player to high.
4. Set tape player volume to 1/2 plus.
5. Connect a patch cord between the output of tape player to input (IN) on the system.
6. Turn on the ± 15.7 V, + 12 V and + 5 V power supplies.
7. Follow the procedure given below by keying in the proper values:

Key	Display	Comments
RS	XXXX XX	Reset.
AD	XXXX XX	Address mode.
Ø Ø F 1	ØØF1 XX	
DA	ØØF1 ØØ	Data mode.
Ø Ø	ØØF1 ØØ	Set processor
AD	ØØF1 XX	status to zero.
1 7 F 9	17F9 XX	Tape number.
DA	17F9 XX	Address.
Ø 1	17F9 Ø1	Tape number = 1.
AD	17F9 Ø1	Address mode.
1 8 7 3	1873 XX	Tape input.
GO	Blank	Start program.

8. Start the audio cassette before the first of the program. (Rewind cassette.)

9. Finish when display shows ØØØØ 4C. If the display shows FFFF XX, there is an error in the tape read. Restart at step 1.

10. Stop the cassette player.

11. The program is ready to run in the binned data angular velocity threshold mode, after initialization of angular velocity threshold and calendar.

Calendar Time and Data

To enter the time and date, do the following:

Key	Display	Comments
RS	XXXX XX	Reset.
AD	XXXX XX	Address mode.
Ø Ø Ø 5	ØØØ5 XX	
DA	ØØØ5 XX	Data mode.
**	ØØØ5 **	Day of the year
+	ØØØ6 XX	high byte (Hex)
**	ØØØ6 **	Day low byte
+	ØØØ7 XX	
**	ØØØ7 **	Hour (24 hour
+	ØØØ8 XX	day)
**	ØØØ8 **	Minute
+	ØØØ9 XX	
**	ØØØ9 **	Last day high
+	ØØØA XX	byte.
**	ØØØA **	Last day low
+	ØØØB XX	byte.
**	000B **	Last hour
+	ØØØC XX	(24 hour day)
**	ØØØC **	Last minute
+	000D XX	
**	ØØØD **	Year (Hex)
		last two digits
AD		Address mode.

Selection of Angular Velocity Threshold

Determine the minimum value of angular velocity that data is to be recorded above and store the value at location 02BBH by keying in the following commands:

Key	Display	Comments
AD	XXXX XX	Addres mode
Ø 2 B B	Ø2BB XX	Select address
DA	Ø2BB XX	Data mode
**	Ø2BB **	

** Hexadecimal value of angular velocity threshold. Desired minimum RPM of the turbine multipled by 1.176 equals angular velocity threshold in decimal. Convert to hexadecimal before entering.

Input/Output to the Paper Tape Punch

The KIM-1 will output data to the punch when any bin is full. If the punch is punching and the data is not wanted, press the following keys:

Key	Display	Comments
RS	XXXX XX	Reset
AD	XXXX XX	Address mode
Ø Ø 1 A	ØØ1A Ø1	
DA	ØØ1A Ø1	Data mode
Ø Ø	ØØ1A ØØ	Reset output flag
AD		Address mode
Ø Ø Ø Ø	ØØØØ XX	Beginning of program
GO	Blank	Start data collection

Selection of Channels to be Recorded

Decide which channels are to be recorded and follow the format given in the listing of the output section of Appendix F. The table given in the output section dictates both data collection and output.

Data Collection by Method of Bins

After all initial inputs are made (date, time, etc.), do the following:

Key	Display	Comments
AD	XXXX XX	Address mode
Ø Ø Ø Ø	ØØØØ 4C	Beginning of program
GO	Blank	Start

Values of the current samples can be displayed by the following method:

Key and Channel Number	Displayed
1	Analog anemometer #1
2	Torque Meter
3	Electrical power
4	Alternator voltage
5	Wind direction
6	Air temperature
7	Air pressure
8	Analog anemometer #2
9	Digital anemometer
A	Delta wind speed (only positive values)
B	Angular velocity
C	Shaft power
D	Day high and low
E	Hour
F	Minute

Values are displayed in a ØØ** XX mode, where ** is the value of the channel.

Sequential Data Collection

For sequential data collection, key in the following:

Key	Display	Comments
RS	XXXX XX	Reset
AD	XXXX XX	Address mode
Ø 6 9 Ø	Ø69Ø A2	Beginning program
GO	Blank	Start

The system will return to the bin data collection mode after sequential data collection and output only the channels requested in that mode.

INSTRUMENTATION OF A SAVONIUS WIND
TURBINE

by

SAMUEL MARTIN BABB

B. S., Kansas State University, 1976

AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

This thesis describes instrumentation to measure performance of a Savonius wind turbine. Performance analysis requires data histograms of wind speed, turbine torque, and turbine power. These histograms are produced by a KIM-1 microcomputer and A/D system. Sensors--both analog and digital--for wind speed, wind direction, turbine velocity, turbine torque, air temperature, atmospheric pressure, and electrical power are described. Also included are the complete system software and operating procedures.