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Microprocessor Based Control System For The Umass Wind Furnace I

Daniel Handman

Richard Monopoli

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MICROPROCESSOR BASED CONTROL
SYSTEM FOR THE
UMASS WIND FURNACE I

Technical Report

by

Daniel Handman and Richard Monopoli
Electrical and Computer Engineering Department
University of Massachusetts
Amherst, Massachusetts 01003

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ABSTRACT

To maximize the efficiency of the UMass Wind Furnace I, a microprocessor based control system has been designed. The system can control blade pitch angle, yaw direction, and generator field current. The control scheme for the system is determined by the microprocessor program. Therefore, this control system can also be used to simulate various types of mechanical, electro-mechanical, electronic, and hydraulic controllers by writing an appropriate control program.

Introduction

This report describes a microprocessor based control system for the UMass Wind Furnace I. By basing the control system on a microprocessor, the control scheme can be changed by altering the control program. This will enable thorough testing of many control schemes and also provide the ability to simulate various types of blade pitch, generator field current, and yaw direction controllers.

The system will have the following nine basic components:

1. Signetics ABC 1500 microprocessor board.
2. Blade pitch system motor interface.
3. Yaw system motor interface.
4. Generator field current interface.
5. Sixteen analog input channels interface.
6. Eight digital inputs interface.
7. Eight digital outputs interface.
8. System Power Supply
9. Low battery voltage feather circuit.

Each of these components will be described in the following sections. A block diagram of the system is shown as Figure 1.

Microprocessor

The control system is based on a Signetics ABC 1500 Adaptable Board Computer. The ABC 1500 has the following features and components:

- a. Signetics 2650 8-bit microprocessor
- b. 500 eight bit words of read/write memory
- c. Signetics PIPBUG operating system ROM
- d. Teletype interface
- e. Two 8-bit parallel I/O ports
- f. Buffered outputs for address and data buses
- g. Microprocessor status outputs.

For complete information about the ABC 1500 refer to Signetics Application Note SP55, "The ABC Adaptable Board Computer," and to the "Signetics 2650 Microprocessor User Manual." The PIPBUG operating system is described in Signetics Application Note SS50.

Programs for the control system can be written in assembly language and entered onto the UMass computer system. An assembler for the signetics assembly language is available on the UMass computer. The assembler will read the assembly language program, assemble it, and generate a paper tape of the machine code. The program can be loaded into the microprocessor memory, through a teletype paper tape reader, using the Pipbug "Load" command. A description of how to use the UMass Computer to assemble programs is given in Appendix I. Programs can also be assembled by "hand." The machine code can be loaded into the microprocessor memory using the Pipbug "Alter Memory" command.

The 500 words of read/write memory provided on the ABC 1500 is not enough memory for the control system. An additional 1K(1024) words of read/write memory will be added. A schematic of the additional memory is shown in the Signets Application Note SP55. If necessary, an additional 28K words of memory can be added to the system.

The ABC 1500 has outputs for the 14-bit address bus and the 8-bit data bus. One control line ($M/\bar{I}\bar{O}$) determines whether the information on the address bus is a memory address ($M/\bar{I}\bar{O} = \text{true}$) or an I/O device address ($M/\bar{I}\bar{O} = \text{false}$). I/O device decoding is done with a single 8-input nand gate (7430) as shown in Figure 2. Four control signals ($M/\bar{I}\bar{O}$, \bar{R}/W , $E/\bar{N}\bar{E}$, OPREG) and the four least significant bits of the address bus are used. By using four address lines, only 16 input and 16 output devices are addressable. If more I/O ports are needed, the more significant address lines can be decoded. The four control signals operate as follows:

1. OPREG = true when all other signals are valid.
2. $E/\bar{N}\bar{E}$ = true when the processor is executing an extended I/O instruction (I/O device selected is on the I/O bus). $E/\bar{N}\bar{E} = \text{false}$ when the processor is executing a non-extended I/O instruction. (I/O being executed through port C or port D).
3. \bar{R}/W = true when the processor is executing a write instruction to memory or an I/O device.
 $\bar{R}/W = \text{false}$ when the processor is executing a read instruction from memory or an I/O device.
4. $M/\bar{I}\bar{O}$ explained above.

The output of the nand gate will be a pulse for the duration of OPREQ as shown by the signal timing diagram. This pulse can be used for I/O ports to clock data between the data bus and the I/O device.

Two 8-bit I/O ports (C port and D port) are provided on the ABC 1500. These ports are addressable by non-extended I/O instructions. Non-extended I/O instructions are only two words long and only take two machine cycles (6 microseconds) to execute as opposed to extended I/O instructions which are three words long and take 3 machine cycles (9 microseconds) to execute.

The ABC 1500 printed circuit board has jumper wire connections to select various options. A list of the jumpers used is in Appendix II.

8 Digital Inputs and 8 Digital Outputs

The interfaces for 8 digital outputs and for 8 digital inputs are shown in Figure 3. When the processor executes a write extended instruction addressing the 8 digital outputs interface, the contents of a register is placed on the data bus and is clocked from the data bus into the 7475 latches. The information is held until the next write-extended instruction addressing the 8 digital outputs interface is executed. When the processor executes a read extended instruction addressing the 8 digital inputs interface the 8T26 tri state buffers are enabled, transferring the data at the inputs to the data bus. The 8T26 buffers are in tristate mode at all other times.

Generator Field Current Interface

The field current interface supplies current to the generator field proportionally to an 8-bit number sent from the microprocessor. The interface can supply field current in the range of 0 to 1 amp; therefore, field

current is adjustable in 3.9 milliamp increments. A schematic of the interface is shown in Figure 4 and the operation is as follows:

When the processor executes a write-extended I/O instruction addressing the field current interface, a word (8-bits) is clocked from the data bus into two 4-bit latches. The 8-bit output of the latches is converted into an analog voltage by a resistor ladder network driven by LM224 op amps. (The op amps are used as buffers because the outputs of the latches are not 0 volts when the output is logical 0.) The output of the D/A is in the range of 0 to 1 volt d.c. This analog voltage controls a regulated current supply circuit consisting of an op amp, a power transistor, and a 1 ohm resistor. The op amp compares the desired field current signal (output of the D/A) to a feedback signal proportional to the current passing through the generator field winding. The op amp supplies enough base current to the transistor to make the feedback signal equal to the desired field current signal.

I_f (field current) = 1 amp/volt $\times v_{in}$ (output of A/D). This transfer function does not depend on the generator field winding resistance. This is necessary because the field winding resistance varies with temperature.

Manual control of the field current is achieved by switching the input of the current regulator circuit from the D/A output to a potentiometer wired as a variable voltage divider.

Pitch and Yaw Motor Interfaces

The blade pitching system and the yaw direction system use 24 volt D.C. motors. The interfaces between the ABC 1500 and the motors consist of a pulse width modulator (shown in Figure 5) and a switching transistor

bridge amplifier (shown in Figure 6). The pulse width modulator is controlled by a word sent from the ABC 1500. When the processor executes a write extended instruction addressing a motor interface, the I/O device decoding circuit clocks a word from the data bus into two 4-bit latches. The most significant bit of the word controls motor direction and the seven least significant bits control motor speed. (Since there are 7 bits to determine motor speed, the motor can be driven at 128 speeds.) Two 4-bit magnitude comparators are wired together to form a 7-bit magnitude comparator. The 7-bit input is connected to the "A" inputs of the magnitude comparator. The "B" inputs of the magnitude comparator are connected to the output of a 7-bit binary counter. The counter skips the 0_{10} state and counts from 1_{10} to 127_{10} . The counter is run from the system clock (1 MHz). The "A=B" and "A>B" outputs are or-ed together to form an "A \geq B" output. This output will be true whenever the magnitude of the input word is greater than or equal to the output of the counter. Therefore, the "A \geq B" output will be a square wave of period = $127 \times \text{clock period} = 127 \text{ microseconds}$. The duty cycle of the output (% time output true) = $(\text{input \#}/127) \times 100\%$. An example of this pulse width modulation scheme for a 2-bit system (4 motor speeds) is shown in Figure 7.

The pulse width modulated signal is gated to the +W output or to the -W output depending on the most significant bit of the input word. The +W and -W outputs are connected to the +W and -W inputs of the switching transistor bridge amplifier. When the +W input of the bridge amplifier is true current flows through the motor from M1 to M2. When the -W input of the bridge amplifier is true, current flows through the motor from M2 to M1.

Manual control of blade pitch angle and yaw direction are necessary for testing and servicing the wind generator. The implementation of manual motor speed and direction controls for the yaw and pitching systems is shown in Figure 8. When the auto/manual switch is in the automatic position, the +W and -W outputs of the pulse width modulator are connected to the +W and -W inputs of the bridge amplifier. When the auto/manual switch is in the manual position, the +W and -W inputs of the bridge amplifier are connected through a direction control switch and a push button drive switch to a manually controlled pulse width modulator circuit. The speed control potentiometer in the manual pulse width modulator changes the pulse width of the output signal, varying the speed of the motor. The direction control switch sets the direction the motor will drive when the drive control pushbutton is pressed.

The yaw direction system also has a damp/drive feature. In the damp mode, the yaw motor leads are shorted together to make the motor act as a damper. In the drive mode the yaw motor is connected to the bridge amplifier. To allow processor and manual control of the damp/drive feature, the motor leads are connected to a DPDT relay (refer to Figure 9). When the auto/manual switch is in the manual position, the relay coil is connected to the damp/drive switch. When the auto/manual switch is in the automatic position, the relay coil is controlled by bit $\emptyset = \text{true}$, the relay is in the drive mode. When bit $\emptyset = \text{false}$, the relay is in the damp mode.

16 Analog Inputs Interface

The circuit for interfacing 16 analog channels to the ABC 1500 is shown as Figure 10. The interface is based on a National Semiconductor ADC0816 "Single Chip Data Acquisition System." The main components of the ADC0816 are a sixteen channel analog multiplexer, address latches for the analog multiplexer, and an 8-bit successive approximation type analog to digital converter. The 4-bit address signal for the analog multiplexer is received from the ABC 1500 port C. The 8-bit output of the A/D is sent to the ABC 1500 port D. The interface also makes use of the $\overline{\text{OPACK}}$ and WPC control signals of the ABC 1500. The operation of these control signals is as follows:

WPC: When the processor executes a write port C instruction, the contents of the specified register is transferred to port C. the WPC signal goes to logical one for the duration of one clock period (1 microsecond) when the data has been transferred to port C.

$\overline{\text{OPACK}}$: When $\overline{\text{OPACK}} = \text{true}$ the processor is put into a wait state. When $\overline{\text{OPACK}} = \text{false}$, the processor is in the running state.

The operation of the interface is as follows:

The number of an input channel (0-15) is loaded into a register. The processor then executes a write port C instruction, transferring the contents of the register to port C. The WPC line is connected to the start convert (start) and address latch enable (ALE) inputs of the ADC 0816. When WPC pulses, the least significant 4-bits of port C are clocked into the input latches of the analog multiplexer, and the A/D starts converting the selected

channel. While the A/D is converting the end of convert (EOC) output of the ADC 0816 goes to logical zero. The EOC line is connected through an inverter to the ABC OPACK line. Therefore, when the A/D is converting the processor is put in the wait state. When the conversion is completed, EOC goes to logical one (OPACK driven to logical zero) and the processor starts running again. The next instruction that the processor executes is a read port D instruction. This will read the output of the A/D, through port D, into a register.

The ADC 0816 is powered by a single 5-volt supply. Therefore, the analog inputs must be in the range of 0 to 5 volts. The zener diodes across the inputs are for overvoltage protection. The initial control system will have five sensors that produce analog outputs. The sensors are:

1. Rotor RPM sensor: The rotor speed sensor is a d.c. tachometer generator. It has a linear voltage output of 0.13 volts per rotor rpm. The output of the tachometer will be connected to the ADC 0816 through a resistor voltage divider.
2. Pitch Angle Sensor: A potentiometer is geared to the pitching linkage to provide a pitch angle signal. The potentiometer is connected across +5 volts and ground. The output is taken from the wiper.
3. Yaw Direction Sensor: A potentiometer is geared to the yaw direction system. The potentiometer is connected across its volt and ground and the yaw direction signal is taken from the wiper.
- 4 & 5. Wind Speed and Direction: A Climatronics anemometer is mounted on a tower on top of the Solar Habitat I. The Climatronics

Wind Speed and Direction chart recorder has d.c. voltage outputs that are proportional to wind speed and wind direction. These outputs are in the range of 0 to 1 volt and will be connected to the ADC 0816 through op amps.

System Power Supply

The power supply requirements of the system are:

48 volts d.c. at 1.0 amps

24 volts d.c. at 10 amps

5.0 volts d.c. at 2 amps.

The 5.0 volt d.c. supply powers the ABC 1500 and all of the TTL integrated circuits in the interfaces. The 48 volt supply is for the generator field current interface. The field current interface has a current regulator output circuit so that the 48 volt supply does not have to be regulated. The 24 volt supply is used to power the pitch and yaw motors; therefore, it does not have to be regulated.

A schematic of the system power supply is shown as Figure 11. The 48 supply is made by cascading a 24 volt, 1 amp, power supply with the 24 volt, 10 amp supply. The batteries float across the outputs. If line power is lost, the system will be powered by the batteries. Due to the long length of the leads between the motors and the controller (approximately 100 feet), it may be desirable to drive the motors from a higher voltage. The Stancor P-8621 transformer has taps for 24, 26, 28, and 30 volts. The power bridge rectifier can be connected to any of the taps as long as additional batteries are put in series with the 24 volt battery (i.e., if the 30 volt tap is used, a six volt battery should be put in series with the 24 volt battery). If the 24 volt supply is increased, the 48 volt supply

will be increased by the same amount. This will not effect the field current interface because of the current regulator circuit.

Low Battery Voltage Feather Circuit

When line power is lost, the control system will be powered by the batteries. If line power is lost for an extended amount of time, the batteries will completely discharge. The low battery voltage feather circuit monitors the battery voltage and will interrupt the processor if the battery volrage drops below a predetermined level. In response to the interrupt, the processor will feather the wind generator. A schematic of the circuit is shown as Figure 12.

The 24-volt supply is used as the input to the 5 volt regulator. The regulator will produce 5 volts at the output for any input voltage greater than 8 volts. Therefore, the output of a voltage divider connected to the 5-volt supply is used as a reference volrage. The output is compared to the reference voltage with an LM311 voltage comparator. The output of the LM311 is connected to the $\overline{\text{INTREQ}}$ (interrupt request) input of the ABC 1500. When the 24 volt supply output decreases such that the divider output is less than the reference voltage the LM311 drives $\overline{\text{INTREQ}}$ to logical zero. When INTREQ equals logical zero, the processor finishes executing the current instruction and then begins to execute a "Zero Branch to Subroutine, Relative" instruction. This instruction is a branch to an address relative to page zero, word zero of memory. The instruction also sets the INTACK (interrupt acknowledge) output of the processor to logical one. When the INTACK signal is generated, the processor reads the relative address from the data bus. The INTRACK signal is used to enable the 8T98 tri-state

buffers, clocking the relative address onto the data bus. The relative address used, -63_{10} , will cause the processor to branch to location 8129_{10} . The subroutine that starts at location 8129_{10} will feather the wind generator, and halt the microprocessor.

Sample Program

This section describes a sample program that will control the wind generator the same way that the existing control system does. The existing system uses the yaw motor as a damper (motor leads shorted together). The controller senses rotor speed and uses an I_f vs RPM look-up table to determine generator field current; the blade pitch angle is determined as follows:

If windspeed ≥ 50 mph then the machine is feathered (pitch angle = 90°).

If RPM < 10 then pitch angle is set to 40° .

If $10 < \text{RPM} < 167$ then pitch angle is set to 0° .

If RPM > 167 then pitch angle is increased at full speed of the pitch motor until RPM 167.

A flow chart for a program to accomplish the above control scheme is shown as Figure 13. In order to write the program, the following device and signal address assignments are assumed.

<u>I/O DEVICE</u>	<u>I/O BUS ADDRESS</u>
Pitch Motor Interface	0
Yaw Motor Interface	1
Field Current Interface	2
8 Digital Inputs Interface	3
8 Digital Outputs Interface	4

<u>Analog Signal</u>	<u>Analog Input Channel #</u>	<u>Signal Remarks</u>
Rotor Speed	0	256 rpm full scale
Pitch Angle	1	128° full scale
Wind Speed	3	256 mph full scale

SAMPLE PROGRAM

<u>LABEL</u>	<u>OPERATION</u>	<u>COMMENTS</u>
	LODI R0, 00	Set R0 = 0
	WRTE R0, 04	Set yaw relay to damp
START	LODI R3, 02	Set R3=2
	WRTC R3	Convert windspeed
	REDD R3	R3 = windspeed
	LODI R1, 01	R1=1
	WRTC R1	Convert pitch angle
	REDD R1	R1 = pitch angle
	LODI R2, 0	R2=0
	WRTC R2	Convert RPM
	REDD R2	R2=RPM
	LODZ R2	R0=RPM

<u>LABEL</u>	<u>OPERATION</u>	<u>COMMENTS</u>
	LODA R0, 6000	R0=field current value from lookup table
	WRTE R0, 2	Send field current value to interface
	COMI R3, 50	Compare wind speed to 50 mph
	BCTA 2, SKP1	Go to SkP1 if windspeed < 50
	COMI R1, 90	Compare pitch angle to 90°
	BCTA 2, SKP2	Go to SKP2 if pitch angle 90°
	LOPI R1, 0	R1=0
	WRTE R1, 0	Stop pitch motor
	BCTA 3, START	Go to START
SKP2	LODI R1, 256	Set R1=256
	WRTE R1, 0	Increase pitch angle at full speed
	BCTA 3, START	Go to START
SKP1	COMI R2, 10	Compare RPM to 10
	BCTA 1, SKP3	If RPM > 10 go to SKP3
	COMI C1, 40	Compare pitch angle to 40°
	BCTA 1, GREATER	If pitch angle >40° go to GREATER
	BCTA 2, LESS	If pitch angle <40 go to LESS
	LODI R1, 0	R1=0
	WRTE R1, 0	Stop pitch motor
	BCTA 3, START	Go to START
GREATER	LODI R1, 127	
	WRTE R1, 0	Decrease pitch angle at full speed
	BCTA 3, START	Go to START

<u>LABEL</u>	<u>OPERATION</u>	<u>COMMENTS</u>
LESS	LODI R1, 256	
	WRTE R1, 0	Increase pitch angle at full speed
	BCTA 3, START	Go to START
SKP3	COMI R2, 167	Compare RPM to 167
	BCTA 1, SKP4	If RPM >167 go to SKP4
	COMI R1, 0	Compare pitch angle to 0°
	BCTA 1, NOT 0	If pitch angle 0° go to NOT 0
	WRTE R1, 0	Stop pitch motor
	BCTA 3, START	Go to START
NOT 0	LODI R1, 127	
	WRTE R1, 0	Decrease pitch angle at full speed
	BCTA R1, 256	
SKP4	LODI R1, 256	
	WRTE R1, 0	Increase pitch angle at full speed
	BCTA 3, START	Go to START.

This program will execute the control loop a minimum of 1400 times per second. It requires 129 words of memory.

System Operation

After a program for the controller has been written, assembled, and a paper tape of the machine code has been generated (see Appendix I) the system is started as follows:

1. Set pitch, yaw, and field current controls to manual mode.
(This is necessary because when the system is powered up, data in the latches in the interfaces is indeterminate.)
2. Turn power switch on.
3. Press RESET button.
4. Use the LOAD command of the Pipbug operating system to load the program into memory.
5. Use the GOTO command of the Pipbug operating system to start executing the program.
6. Set Pitch, Yaw, and Field Current switches to auto mode. Whenever the system is reset to the Pipbug operating system, all auto/manual switches should be set to manual.

Appendix I - Assembling Programs

To use the Signetics Assembler program on the UMass Computing System, the following steps are taken:

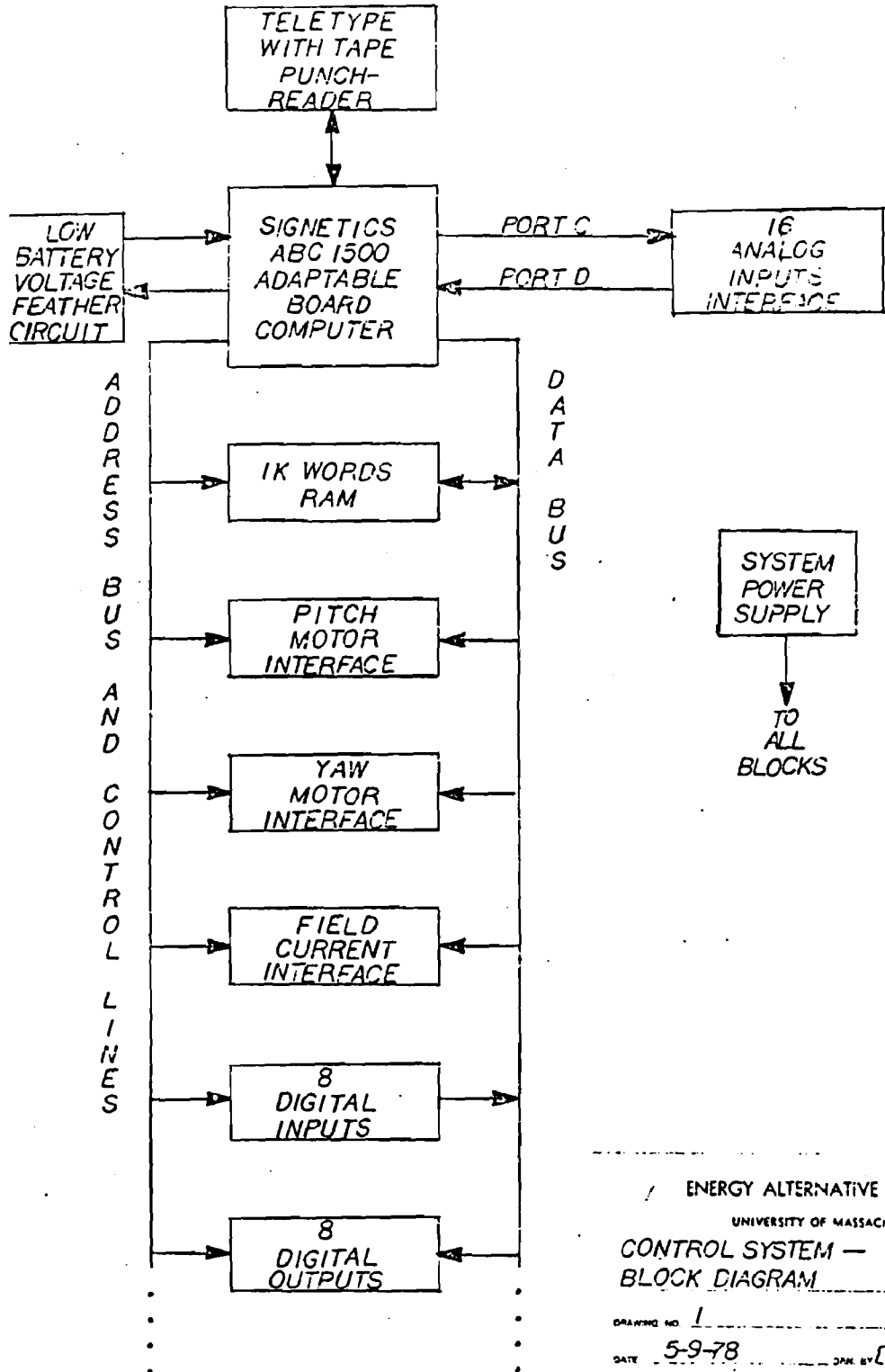
1. Tape the assembly language program into a TEXT FILE.
2. Assign the text file to TAPE 9 using the Rename Command: `RENAME, TAPE9=Text file name`
3. Use Get command to access assembler program:
`GET, SIGNET B/UN=AORM1Ø8`
4. Assemble the program by typing:
`SIGNETB,,,TAPE3,,,`
5. To get a listing of the assembly language program and the error messages generated by the assembler, type:
`REWIND,TAPE3`
`LIST,F=TAPE4`
6. To produce a paper tape of the machine code, type:
`REWIND, TAPE4`
Then turn teletype tape punch on and type:
`LIST, F=TAPE4`

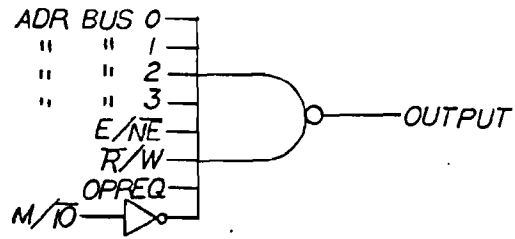
Appendix II - ABC 1500 Jumpers Used

<u>Jumper Connections</u>	<u>Comments</u>
W12-W13	For Pipbug and RAM memory configuration
W15-W16	" " " " "
W6-W7	For 20 milliamp current loop IY interface
W4-W5	" " " " " " "
W9-W10	For internal clock
W19-W20	For read/write control of C and D busses with one line only.
W21-W22	For disabling C port on interrupts.

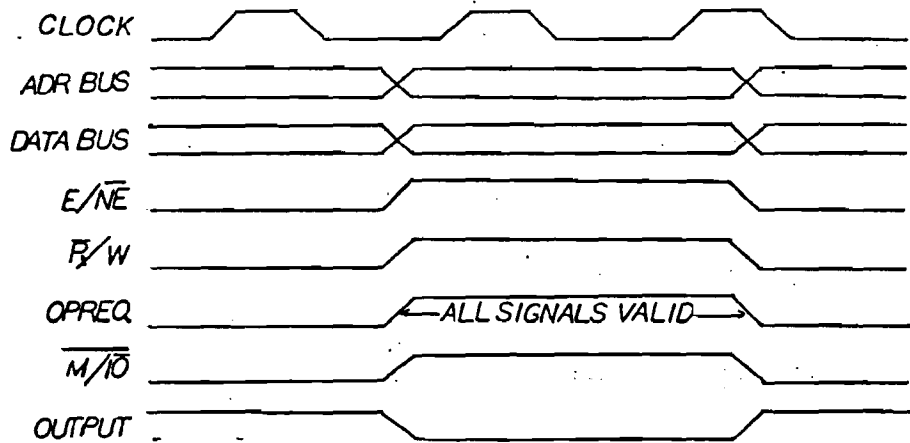
Appendix III - Figures 1 through 13Figure

1. Control System Block Diagram
2. I/O Port Decoding
3. Eight Digital Inputs/Outputs Interface
4. Generator Field Current Interface
5. Pulse Width Modulator
6. Bridge Amplifier
7. Two Bit Pulse Width Modulator
8. Manual Pitch and Yaw Controls
9. Yaw Damp-Drive Controls
10. Sixteen Analog Inputs Interface
11. Power Supply
12. Low Battery Voltage Feather Circuit
13. Flow Chart - Sample Program





IO PORT DECODING



SIGNAL TIMING

ENERGY ALTERNATIVE PROGRAM

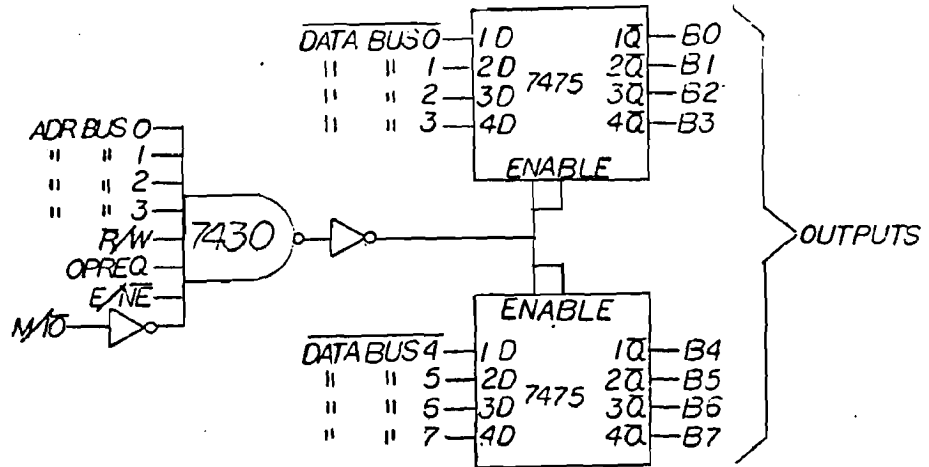
UNIVERSITY OF MASSACHUSETTS

IO PORT DECODING

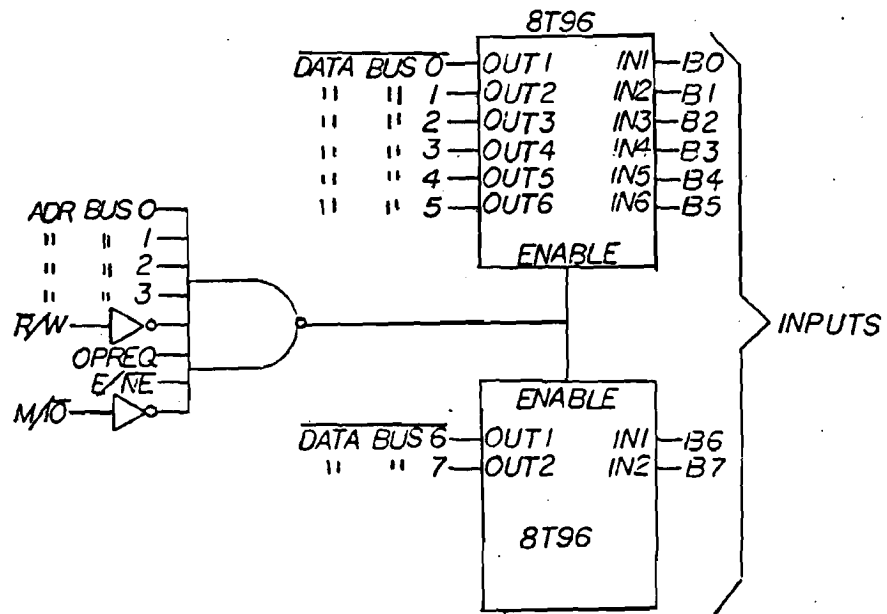
DRAWING NO. 2

DATE 5-9-78

DRN BY D.H.



8 DIGITAL OUTPUTS INTERFACE



8 DIGITAL INPUTS INTERFACE

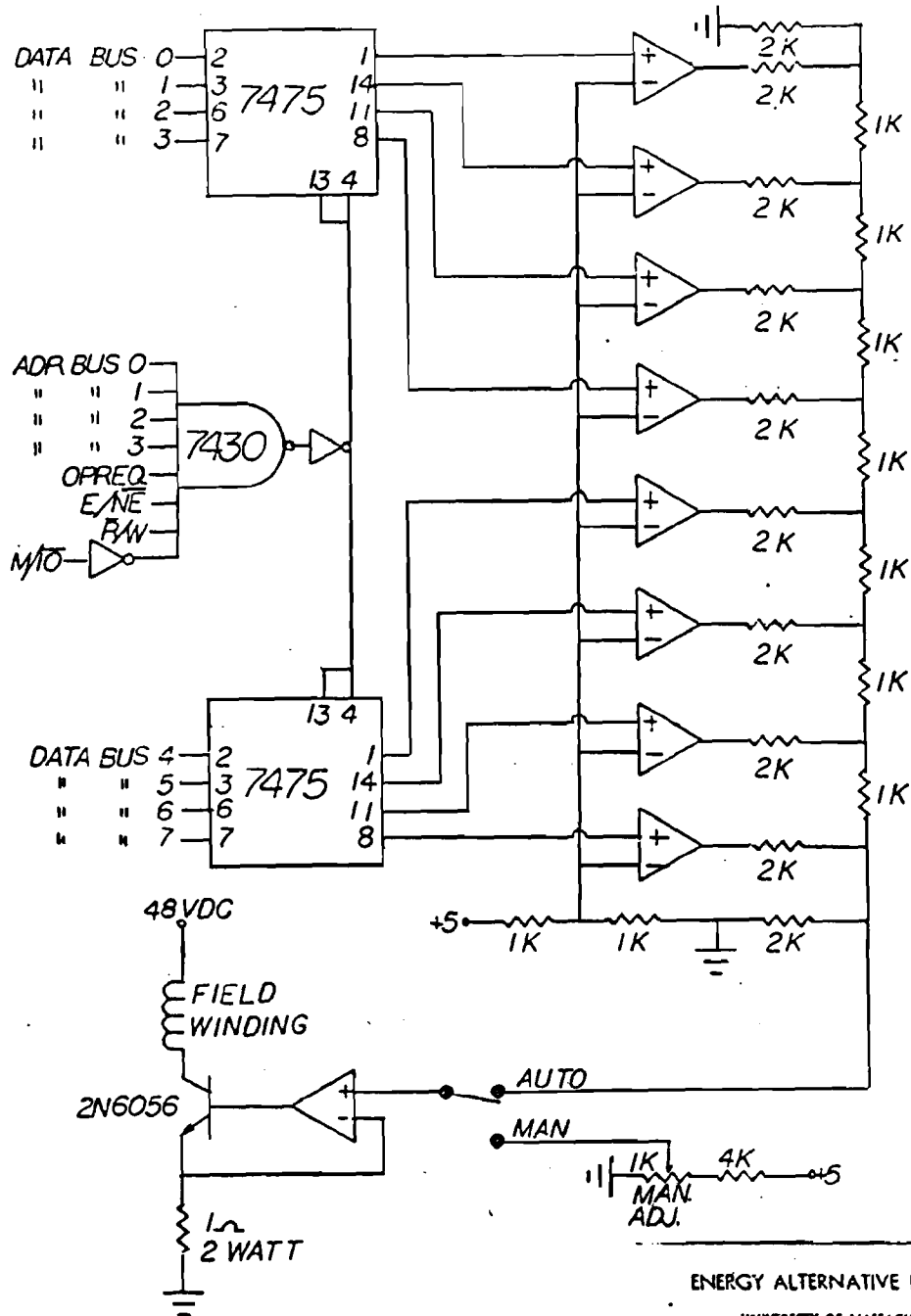
ENERGY ALTERNATIVE PROGRAM

UNIVERSITY OF MASSACHUSETTS

8 DIGITAL INPUTS/OUTPUTS
 INTERFACES

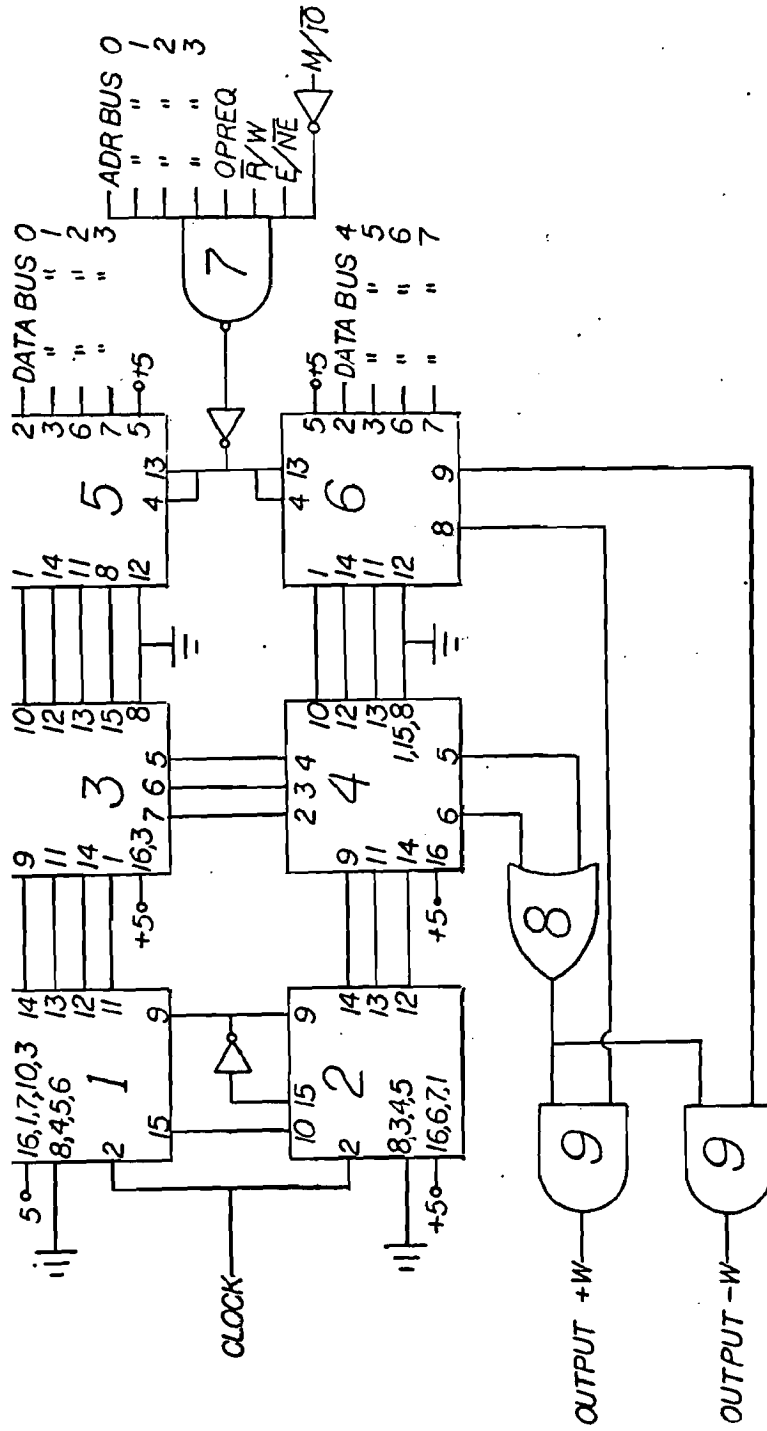
DRAWING NO. 3

DATE 5-9-78 DFL BY D.H.



ALL OP AMPS ARE LM224

ENERGY ALTERNATIVE PROGRAM
 UNIVERSITY OF MASSACHUSETTS
 GENERATOR FIELD CURRENT
 INTERFACE
 DRAWING NO. 4
 DATE 5-9-73 DESIGNED BY D.H.



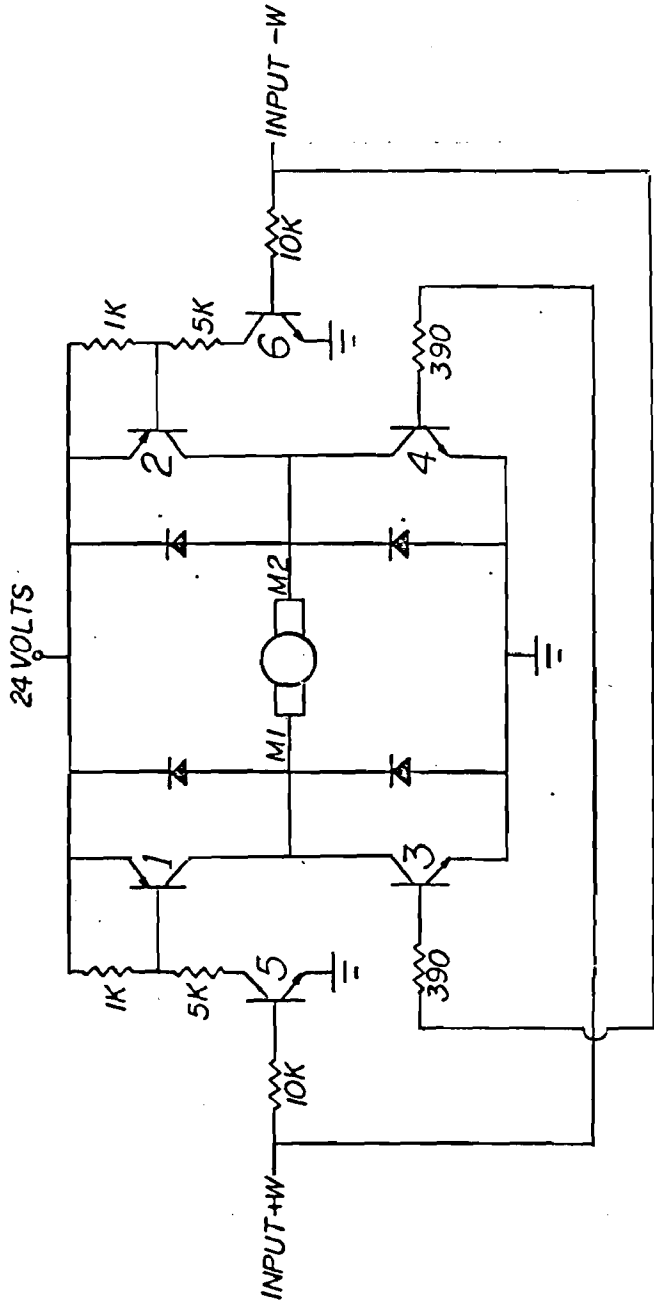
ENERGY ALTERNATIVE PROGRAM
UNIVERSITY OF MASSACHUSETTS

PULSE WIDTH MODULATOR

DRAWING NO. 5
DATE 5-9-78

ENG. BY D.H.

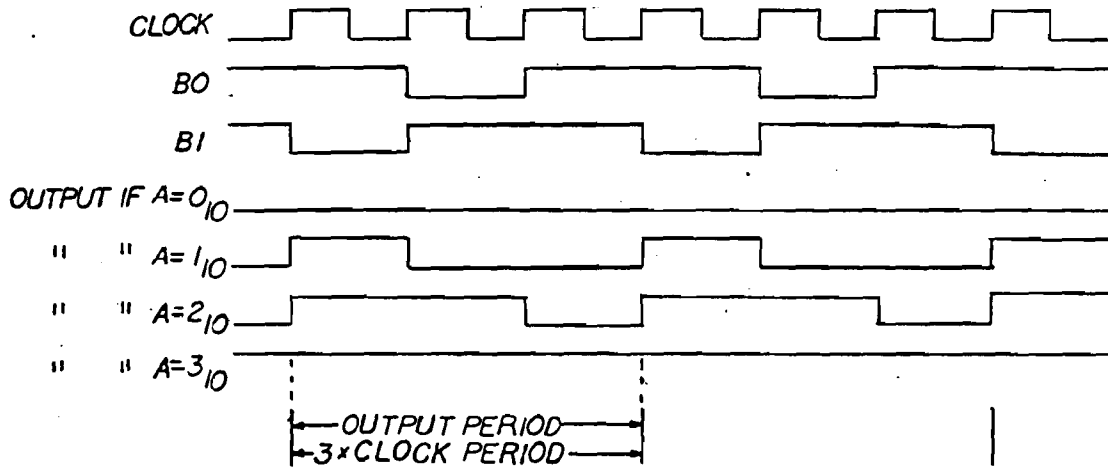
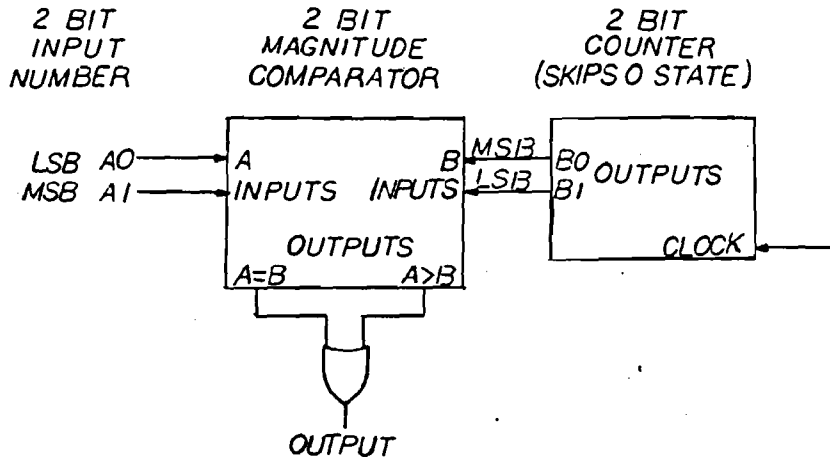
CHIP#	TYPE
1,2	74163-4 BIT COUNTER
3,4	7485 " " COMPARATOR
5,6	7475 " " LATCH
7	7430 AND GATE
8	7432 OR
9	7409 AND "



TRANSISTOR #	TYPE
1,2	PCA 8350A
3,4	2N6384
5,6	2N3904

ENERGY ALTERNATIVE PROGRAM
 UNIVERSITY OF MASSACHUSETTS
 BRIDGE AMPLIFIER

WORKING NO. 6
 DATE 5-9-78
 UNIT BY D.H.



$$\text{DUTY CYCLE} = \frac{A}{3} \times 100\%$$

ENERGY ALTERNATIVE PROGRAM

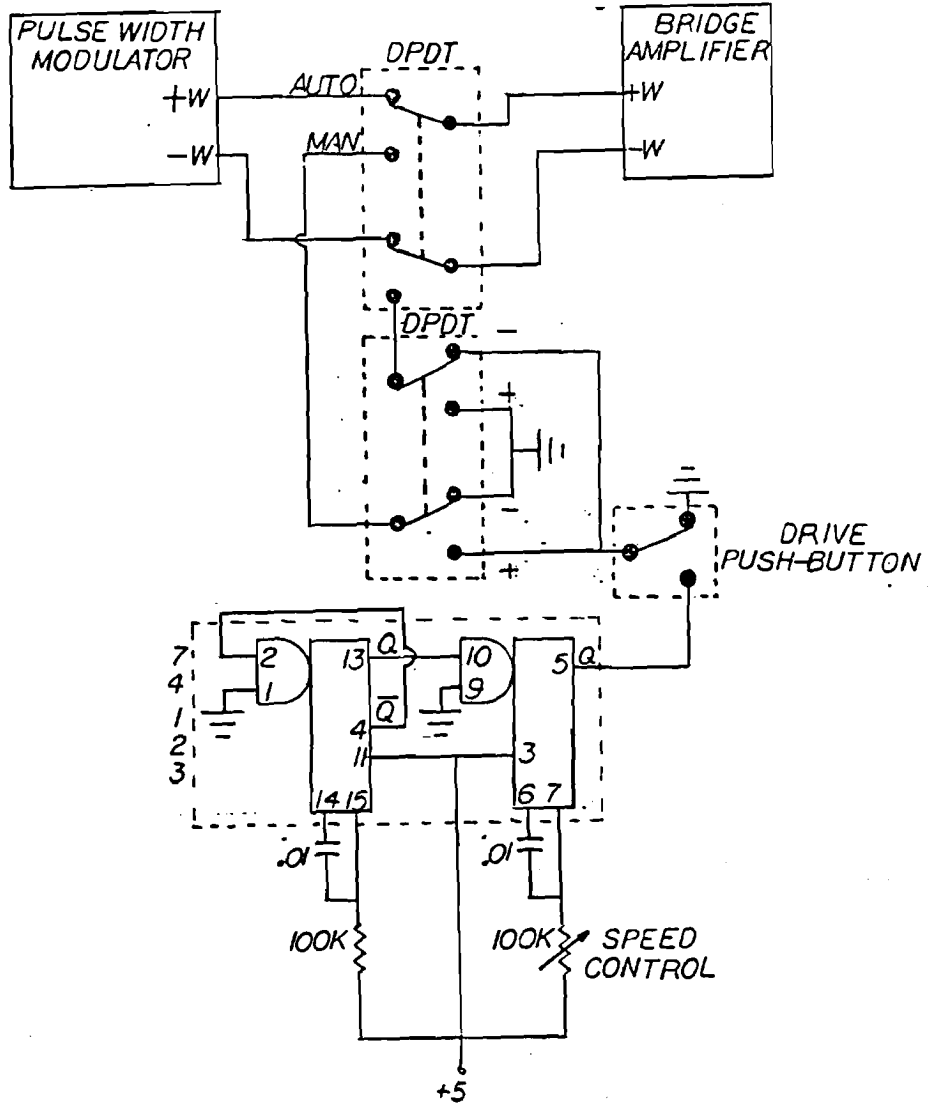
UNIVERSITY OF MASSACHUSETTS

2 BIT PULSE WIDTH MODULATOR

DRAWING NO. 7

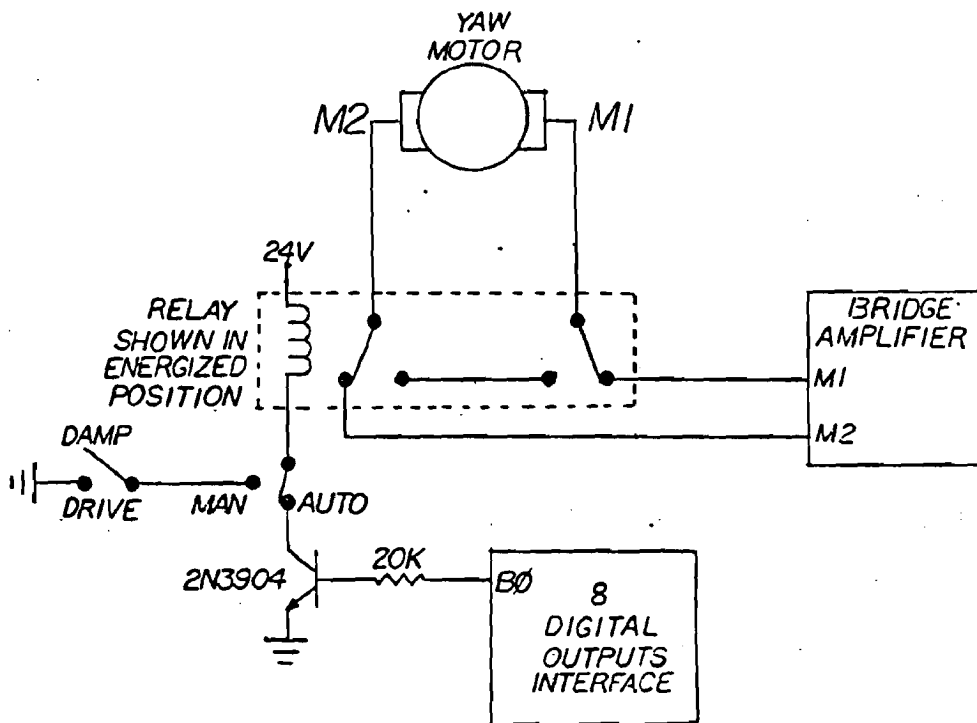
DATE 5-9-78

DRN BY D.H.



ENERGY ALTERNATIVE PROGRAM
 UNIVERSITY OF MASSACHUSETTS
 MANUAL PITCH AND YAW CONTROLS

DRAWING NO. 8
 DATE 5-9-78 DRAWN BY DH



ENERGY ALTERNATIVE PROGRAM

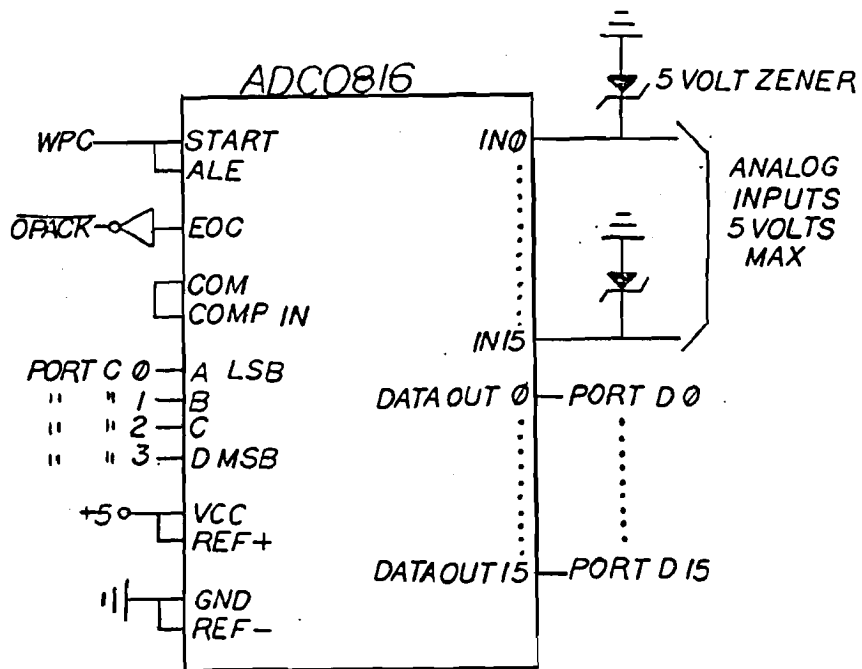
UNIVERSITY OF MASSACHUSETTS

YAW DAMP-DRIVE CONTROLS

DRAWING NO. 9

DATE 5-9-78

CRE BY D.H.



ENERGY ALTERNATIVE PROGRAM

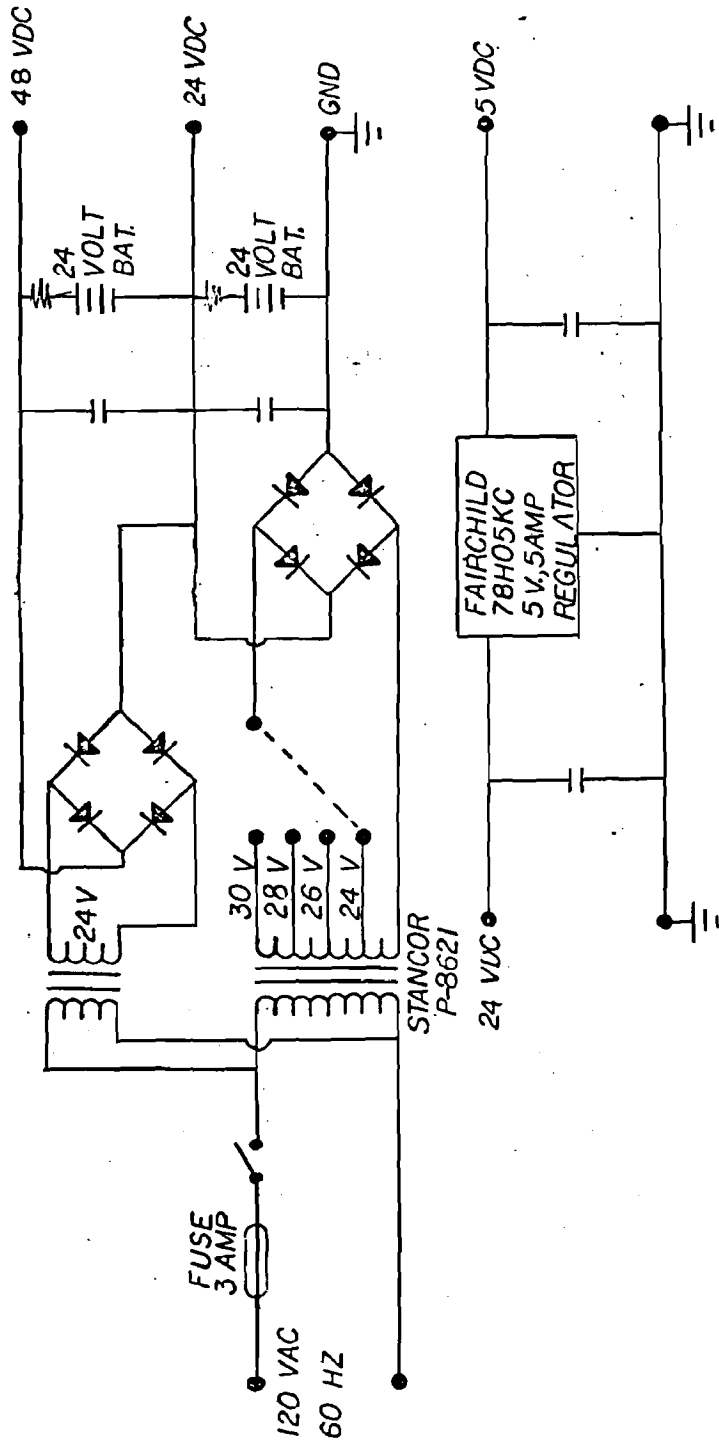
UNIVERSITY OF MASSACHUSETTS

16 ANALOG INPUTS INTERFACE

DRAWING NO. 10

DATE 5-9-78

DRWN BY D.H.



ENERGY ALTERNATIVE PROGRAM

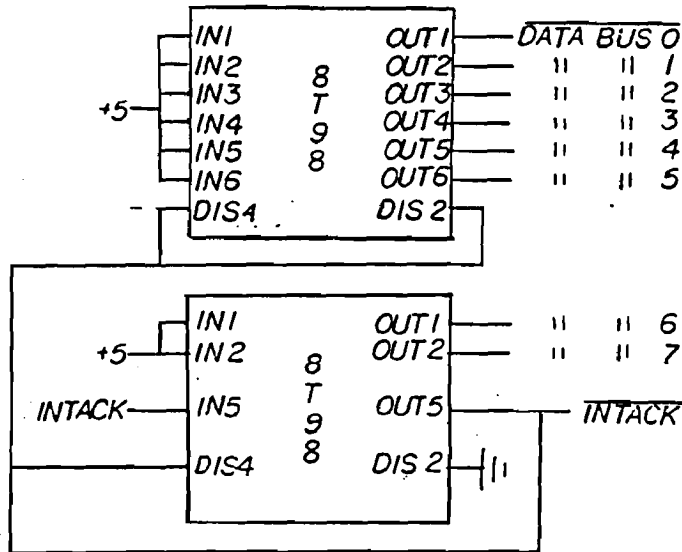
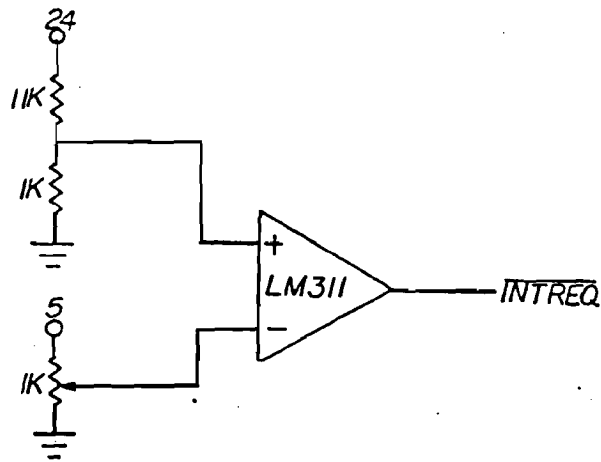
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POWER SUPPLY

DRAWING NO. 11

DATE 5-9-73

BY D.H.



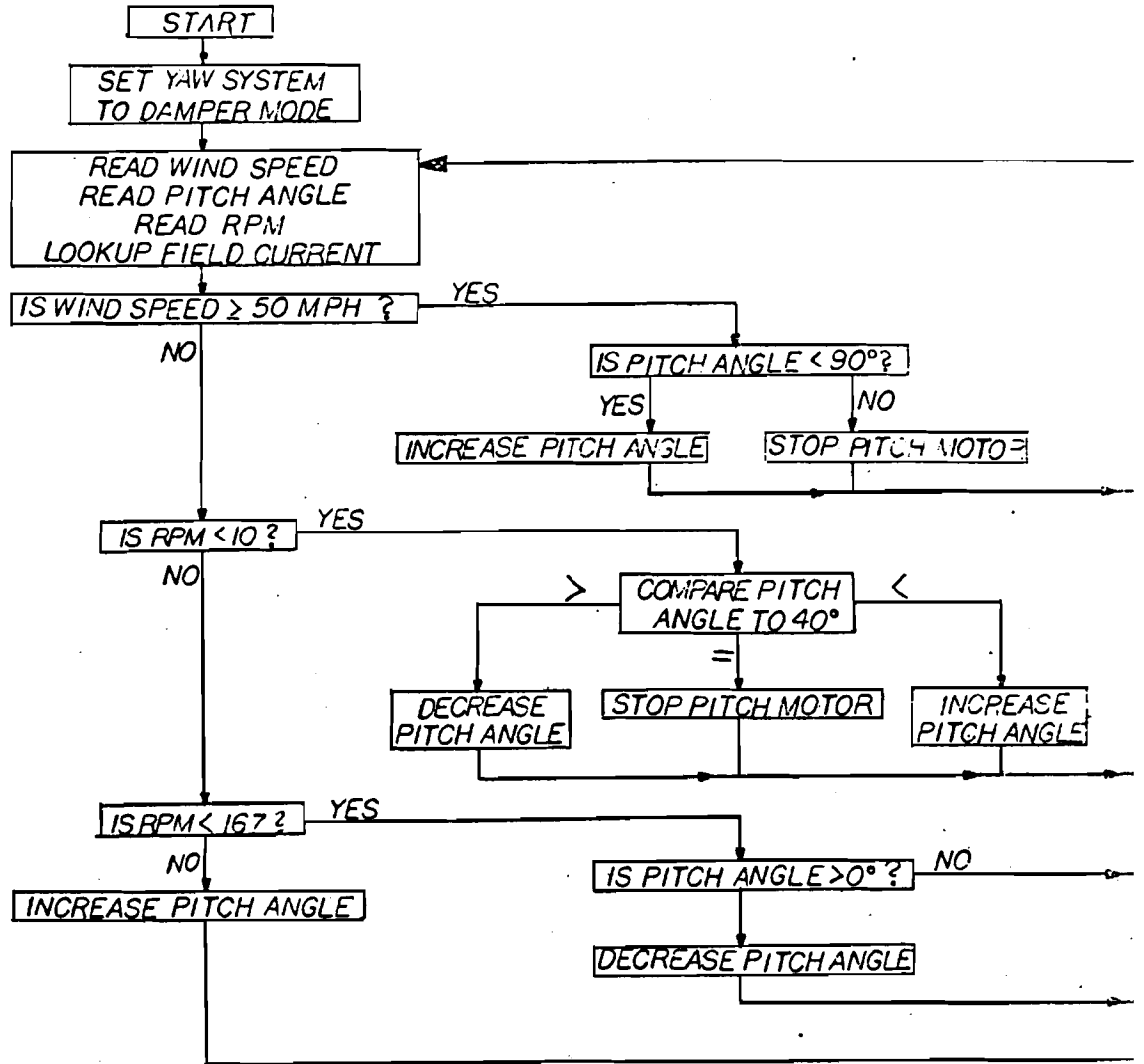
ENERGY ALTERNATIVE PROGRAM

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LOW BATTERY VOLTAGE FEATHER
CIRCUIT

DRAWING NO. 12

DATE 5-9-73 DRAW BY D.H.



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FLOW CHART - SAMPLE PROGRAM

DRAWING NO. 13

DATE 5-9-78

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