# THE DESIGN OF A MICROPROCESSOR BASED CONTROLLER FOR AN ENVIRONMENTAL CHAMBER

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Approved by:

Dr. R.L. Geiger [signature]

May 1986

# ABSTRACT

## THE DESIGN OF A MICROPROCESSOR BASED CONTROLLER FOR AN ENVIRONMENTAL CHAMBER

A need has surfaced to replace the existing hard wired controller of the environmental chamber used in the 'Peanut Project'. This controller has proven itself to be prone to malfunctions, breakdowns and inflexibilty. It is felt that a microprocessor based controller would be best suitable to meet the need. Hardware needed to interface the systems of the environmental chamber to the micro-computer is designed and implemented.

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# I. INTRODUCTION

Microprocessors have proved themselves to be an extremely valuable tool in, amongst various fields, the fields of control, data acquisition, and data processing. In this project a microprocessor is used to satisfy needs in each of these fields. The objective of this project is to replace the existing controller of an environmental chamber so as to make its control at the fingertips of the user via a micro-computer. This is carried out by designing the necessary hardware to interface the micro-computer with the environmental chamber. The designed interfacing hardware allows not only the control of the chamber but also provides the facilities of data acquisition, data storage and data processing.

## II. GENERAL OVERVIEW OF THE PROJECT

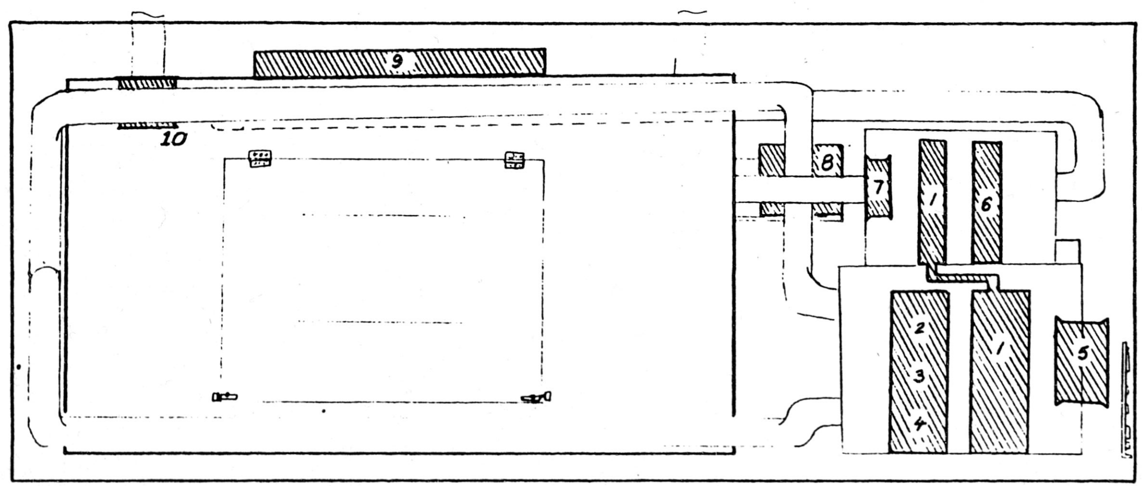
Research is under way, under the guidance of Dr. Geiger and the Plant Science Department at Texas A & M University, to study the electrical properties of fresh and healthy peanuts as compared to to those that are old and have started their process of deterioration, as evidenced by the presence of the growth of toxic molds on their body. Of particular concern to this 'Peanut Project,' is the metabolite of aspergillus flacus mold, alfatoxin, which can prove fatal to humans if internally consumed. The growth of molds on peanut is influenced greatly by the kind of environment the peanuts are in. As a result, in order to study the influence of the presence of molds on the electrical properties of peanuts, it is necessary that these molds be grown in a regulated environment. This is the purpose of the environmental chamber. Good peanuts, innoculated with spores to enhance the growth of molds on them, are placed in the chamber where the two most influential environmental conditions, temperature and relative humidity, are regulated.

Figure 1. shows a schematic of the Environmental Chamber that is being used for this project. The chamber consists of an airconditioner, a humidifier, and several fans and heater coils. The operation of one or more of these at any instant in time performs various functions such as heating, cooling, humidifying, maintaining constant temperature and humidity levels and/or formation of dew.

The operation of this chamber was controlled by a control panel located on the outside of the chamber. The panel consisted of two knobs to set the desired temperature level, two knobs to set the desired temperature level and six switches to manually turn on or off different parts of the system. This hardwired contoller proved to be prone to breakdowns and extremely inflexible. As a result a desire to replace this contoller with a micro-processor based controller surfaced.

Thus the major goal of the project has been to replace the control circuit of the environmental chamber with a microprocessor based controller. The micro-computer not only serves the purpose of controlling the operation of the environmetal chamber, which was the function of the

## MECHANICAL SYSTEMS




1. AIR CONDITIONING COILS
2. MAIN HEATER COIL #1
3. MAIN HEATER COIL #2
4. MAIN HEATER COIL #3
5. MAIN FAN
6. HUMIDITY HEATER COIL
7. HUMIDITY FAN
8. HUMIDIFIER
9. GROW LIGHTS
10. CIRCULATING FAN

FRONT VIEW

FIG. 1

previous control panel, but also allows the storage of accurate and detailed data.

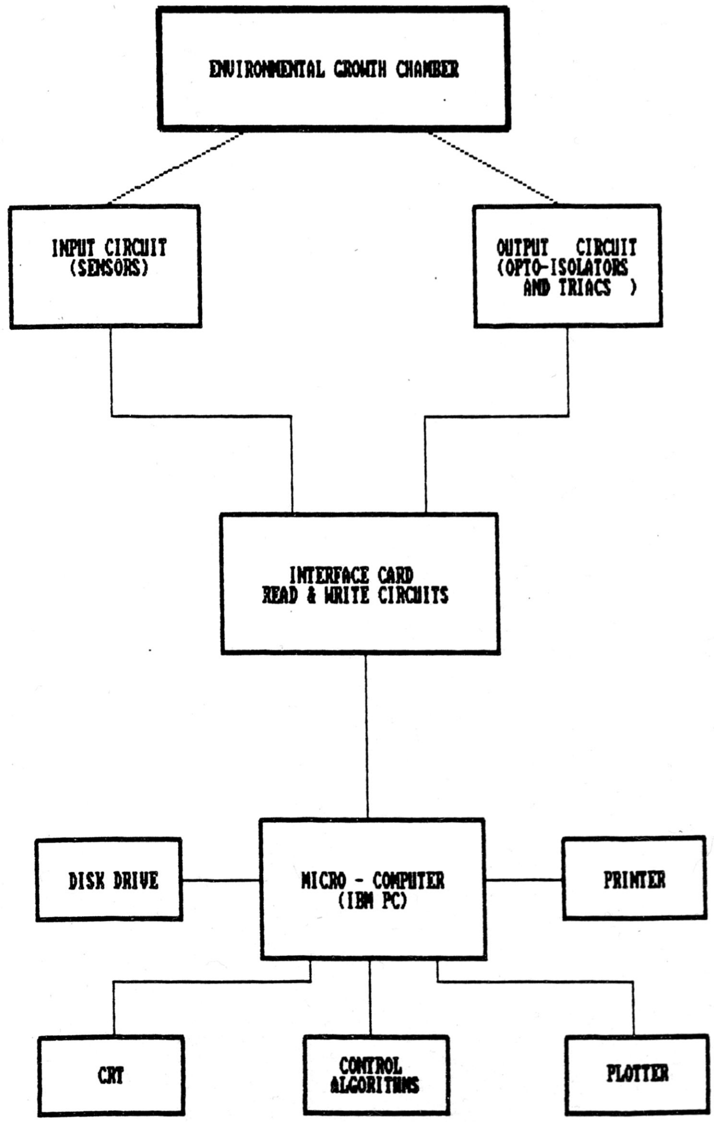
The main objective of the research is to design the required hardware to interface the various systems of the environmental chamber with the micro-computer. The desired control of the chamber is governed by algorithms programmed by Scott Horton who is also involved with the 'Peanut Project.'

# III. GENERAL OVERVIEW OF THE INTERFACE HARDWARE

Figure 2. shows a block diagram of the system. Immediately connected to the environmental chamber are the 'Input' and 'Output' circuits. The input circuit consists of temperature and humidity sensors which provide analog signals that are functions of temperature. The output circuit consists of opto-isolators and triacs which serve as a solid state relay to turn on or off the different systems of the environmental chamber.

The 'Input' and 'Output' circuits are connected to an interface card which will eventually be placed inside the body of the micro-computer. At the moment this card is a wire wrapped card that sits outside the micro-computer. It is connected to the input/output port of the micro-computer by a special connector that has also been made for the project. Eventually this card will be replaced by an etched board which will be housed directly on to the input/output port of the micro-computer. This card consists of the 'Read' and 'Write' circuits.

Figure 2: BLOCK DIAGRAM OF THE GENERAL OVERVIEW OF THE INTERFACE HARDWARE



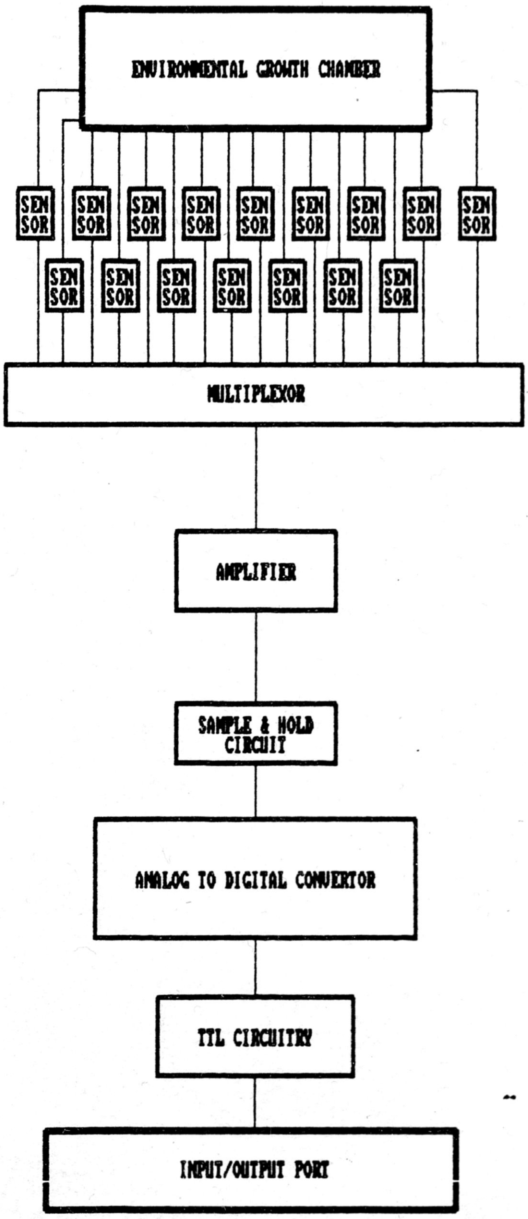
The micro-computer that has been used for this project is an IBM PC mainly because of the availability of its technical documents. The computer is connected to such peripheral devices such as CRT, disk drive, and printer/plotter. The control of the environmental chamber is carried out by the control algoritms programmed in the computer.

## IV. 'READ' CIRCUIT

### A. Temperature Sensors

The sensors that are used to monitor the temperature inside he environmental chamber are the AD590 sensors. The AD590 is a two-terminal integrated circuit temperature transducer which produces an output current proportional to absolute temperature. It acts as a high impedance, constant current regulator passing 1 microampere/K. Specific details and application information are provided in the appendix.

Figure 3: BLOCK DIAGRAM OF THE READ CIRCUIT



## B. Humidity Sensors

The AD590 sensors are used to monitor the humidity of the chamber as well. In order to monitor the humidity two sensors are used. One sensor measures the air temperature. The other sensor is wrapped with a wick whose other end is immersed in water. Based on the readings of the two sensors and their application in a defined equation, the humidity can be determined.

Provision has been made for the implementation of 16 sensors. Their use as temperature sensors or humidity sensors is determined by the user through the program algorithm. Currently only one temperature and one humidity sensor are in use (a total of three sensors are in use).

## C. Amplifier Circuit

The signal provided by the temperature transducers are fairly small. The input in to the comparator of the analog to digital convertor has to be in the range between 0V and 5V. Therefore this signal has to be amplified. Figure 6. shows the circuit diagram of the amplifier circuit. The input of the circuit is the multiplexor output of the analog-to-digital convertor chip. The output of this circuit is connected to the input of the comparator on the convertor chip.

Presented in the circuit diagram are three operational amplifiers. The first and last stage of the amplifier are buffers. The first stage establishes a stable reference voltage for the second stage non-inverting amplifier. The signal is amplified by a factor of 10 in the second stage. The third stage serves as a limiter that limits the output between 0V and 5V to meet the input requirements of the comparator input of the analog-to-digital convertor chip.

D. Analog to Digital Convertor

The Analog to Digital Convertor is the heart of the 'Read' circuit. It converts the analog signals provided by the sensor in to a binary digital code. In the block diagram of the 'Read' circuit, it is broken up in to three components. It is composed of an 8-bit analog-to-digital convertor, a sample and hold circuit, and a 16 channel multiplexor providing for sixteen possible inputs. Its digital output is directly proportional to the analog input given by:

Qout = Vin/Vref

The schematic circuit diagram of the 'Read' circuit is shown in figure 4. It shows the place of the analog-to-digital convertor in the circuit. Figure 5 is circuit schematic specifically of the analog-to-digital convertor.

The maximum clock frequency specified for the analog-to-digital convertor is 1280 Khz. The clock signal available at the input/output port of the IBM PC is 4.77 MHz. In order to decrease this frequency a binary counter is used in the divide by four mode.

## E. TTL Circuitry

The circuit schematic of the 'Read' Circuit, figure 4, shows that most of the circuit is composed of TTL circuitry. This is used to enable the analog-to-digital convertor and start the conversion process when the Input/output port read signal (which is low true) goes

**Figure 4: READ CIRCUIT**

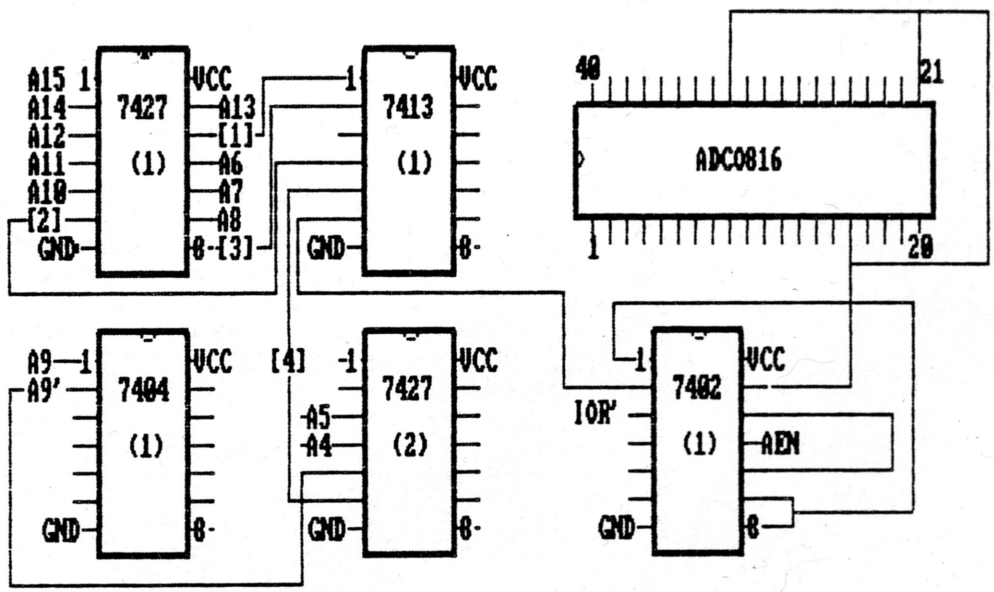


Figure 5.1: ANALOG TO DIGITAL CONVERSION CIRCUIT

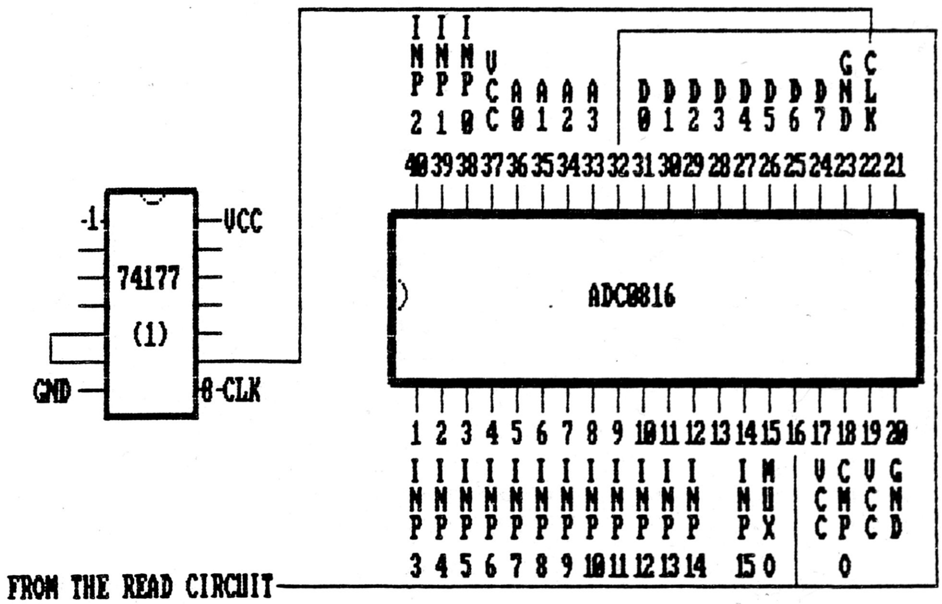
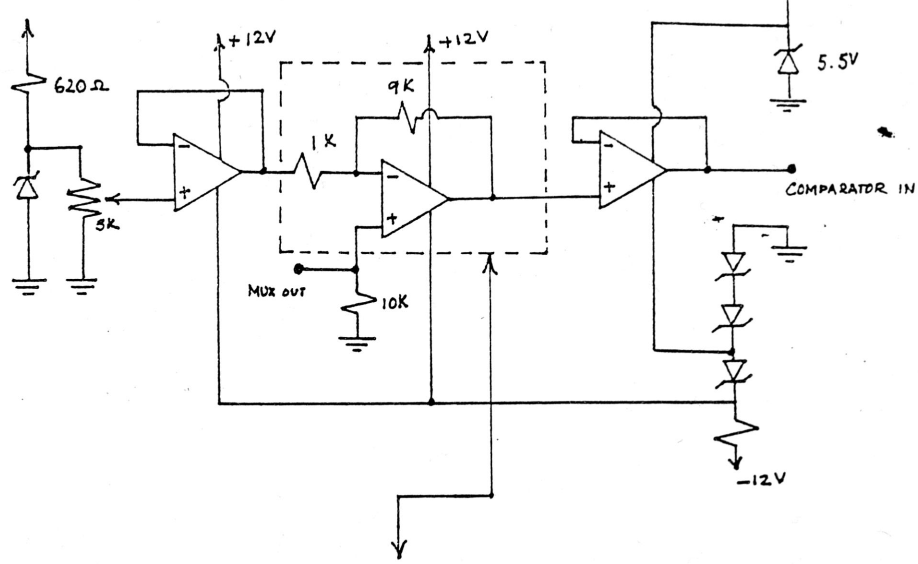
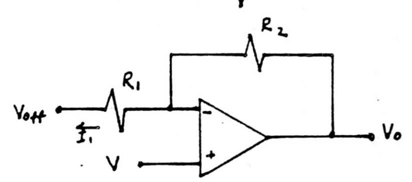


FIGURE 5.2 SENSOR SIGNAL AMPLIFIER CIRCUIT




$$V = 10V_T - 26.93$$

$$V_o = \frac{V}{R_1} R_2 + V = V\left(1 + \frac{R_2}{R_1}\right)$$

$$I = \frac{V - V_{off}}{R_1}$$

$$V_o = \left(\frac{V - V_{off}}{R_1}\right) R_2 + V = V\left(1 + \frac{R_2}{R_1}\right) - V_{off}\frac{R_2}{R_1}$$

Let $1 + \frac{R_2}{R_1} = 10$

$\frac{R_2}{R_1} = 9$

let $R_2 = 9k$.

$R_1 = 1k$

$\frac{R_2}{R_1}(-V_{OFF}) = -26.93$

$-V_{OFF}(9) = -26.93$

$V_{off} = 3.0V$

low, the address enable signal is low and when the correct address exists on the address bus.

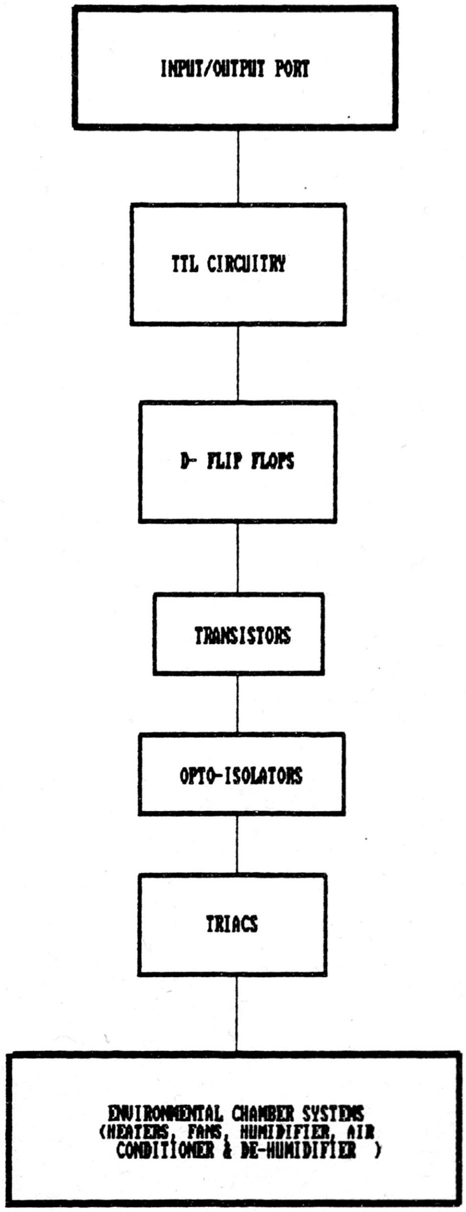
## V. 'Write Circuit'

A Block diagram of the 'Write' circuit is shown in figure 6.

### A. D Flip-flops

Data that is outputted to the output port of the computer is present at the port for a very brief moment. As a result it is necessary to freeze this data in to the D flip-flops to have the data constantly available over periods of time that the data available on the data bus is not for this system. Provisions are made to control 16 different systems. The microprocessor outputs two bytes of data to the interface card. Each byte controls eight different systems. Each bit of the byte is used to either turn on or off a particular system. The data latched in to the flip-flops changes only when

Figure 6: BLOCK DIAGRAM OF THE WRITE CIRCUIT



a clock signal is generated by the TTL circuitry. A detailed circuit schematic of the 'Write' circuit showing the D flip-flops is shown in figure 7.

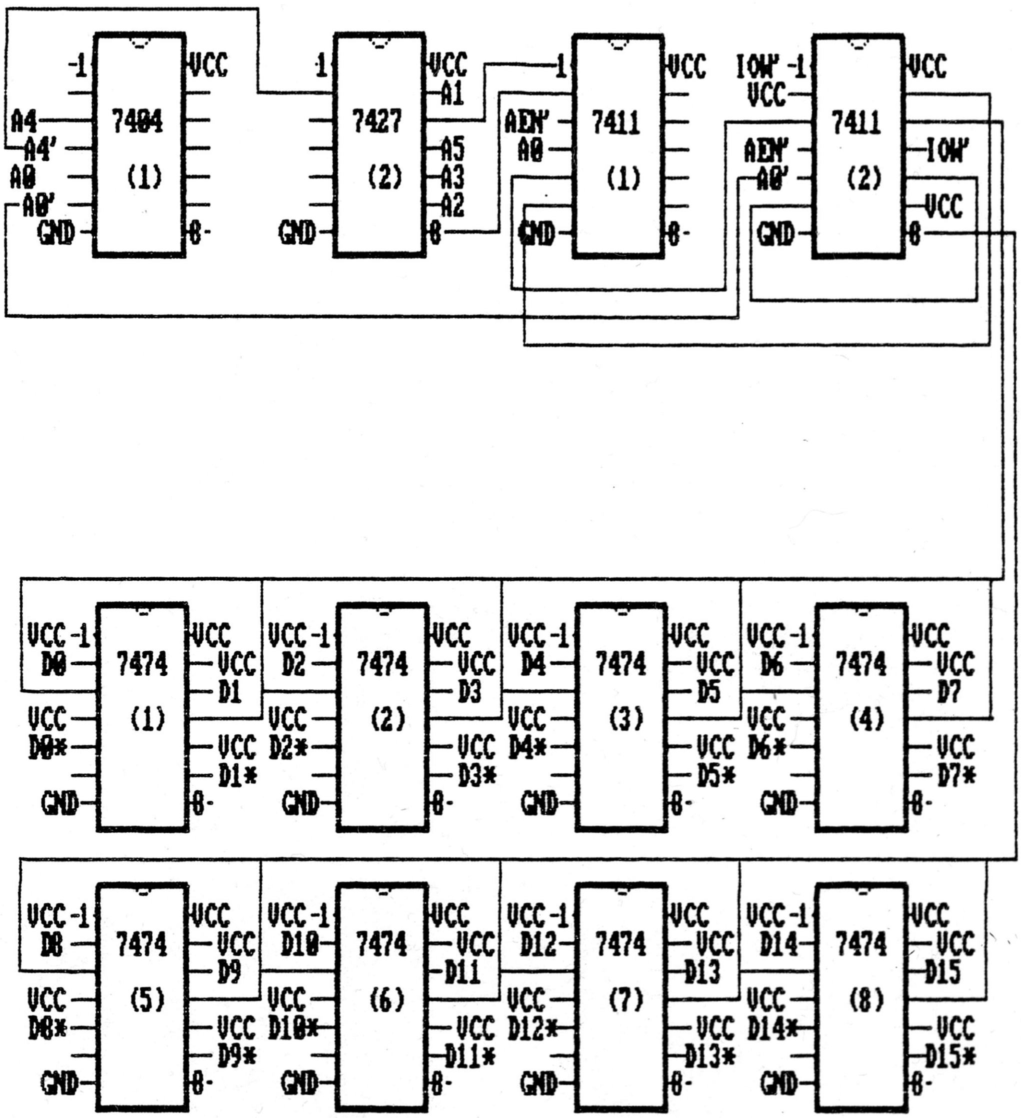
## B. TTL Circuitry

The role of the TTL circuitry in the 'Write' circuit is parallel to that of the TTL circuitry of the 'Read' Circuit. Data is latched on to the D flip-flops only when the Input/output write signal (which is low true) goes low, the adrress enable signal is low and the correct output port is addressed by the micro-processor. The TTL circuitry provides provides a clock signal to the appropriate set of D flip-flops (depending on the output port that is addressed) when these conditions are met.

## C. Transistors, Optoisolators and Triacs

Each bit of the two bytes of data from the microprocessor, which is latched in to the D flip-flops, is used to either turn on or off a particular system of the environmental chamber. Output of the D flip-flops is

**Figure 7: WRITE CIRCUIT**



amplified to the adequate level by transistors and is fed in to the optoisolators. The optoisolator which is a light emmitting diode is used to isolate the large power consuming systems of the chamber from the micro-computer. This prevents any damage to the micro-computer due to any power surges that may result due to the operation of the chamber systems. Each optoisolator drives a triac which is essentially a solid state relay. It provides a conducting path when a constant current of atleast 50 mA is provided to its gate.

## VII. Input/Output Port

The Interface card is connected to the micro-computer via the input/output port of the IBM PC. It is through this port that the microprocessor communicates with the interface card and the environmental chamber. A diagram with the different signal and pin definitions of the port is shown in figure 6.

Input Port Addresses: Hex 0200 to Hex 020F

Output Port Addresses: Hex 0210 to Hex 0211

## VI. DESCRIPTION OF SYSTEM BUS SIGNALS USED

### CLK

This is a clock signal with a frequency of 4.77 MHz. Its period is 210 ns with a high time of 70 ns and a low time of 140 ns.

### A0 through A19

Address bits A0 through A19 are output-only signals that are used to address system-bus attached memory and I/O. For the case of addressing I/O ports only bits A0 through A15 are used. As a result only these lines are decoded by the TTL circuitry.

### D0 through D7

These eight lines are bidirectional data lines used to transmit data between the 8088 microprocessor, memory and I/O ports.

IOR (I/O Read)

This is signal is an output-only signal. It is used to indicate to the I/O ports that the present microprocessor intiated bus cycle is an I/O port read cycle and that the address on the address on the address is an I/O port address. The I/O port should respond by placing its read data on the system bus. This signal active low.

IOW (I/O Write)

This signal is a low-level active output-only signal. It indicates the address bus that contains an I/O port address and that data bus that contains data to be written in to the I/O port.

AEN (Address Enable)

This signal is an output -only active-high signal issued by the DMA control logic. It indicates that a DMA bus cycle is in progress. On the system bus, its purpose is to disable I/O port address decodes during DMA cycles so that DMA memory addresses are not used as I/O port addresses during DMA cycles. This is possible since IOW and IOR may be active with memory addresses on the address bus during DMA cycles.

+5 V DC

The +5 volt dc power level is availble on two pins of the card edge connectors on the bus and it is regulated to +/- 5%.

+12 V DC

The +12 volt dc power level is available at one pin of the card edge connector on the bus and it is regulated to +/- 5%.

-5 V DC

The -5 volt dc power level is availble on one pin of the card edge coneectors on the bus and is regulated to +/- 10%.

-12 V DC

The -12 volt dc power level is available on one pin of the card edge connectors on the bus and is regulated to +/- 10%.

GND (Ground)

System dc and frame ground is provided at three pins on the card edge connectors of the bus.

# VIII. CONCLUSION

The need for a reliable and flexible controller for the environmental chamber that is in use in the 'Peanut' Project. Hardware necessary to interface the IBM PC micro-computer to the sensors and the systems of the environmental chamber has been designed and troubleshooted. Implementation of this controller will follow during summer.

The benefits of this controller over the existing one can only be appreciated when one comes upon the realization that the chamber can be operated in numerous ways depending on the control algorithm that is programmed in to the microprocessor. The true versatility of this controller can be realized when the contol software written by Scott Horton is put in to use.

As a result of this hardware more precise temperature and humidity settings are possible than those that are possible by the existing hardware. Any recalibration using the present circuitry requires the lengthy task of opening the control panel and manually adjusting the physical parameters such as resistance until the performance is as desired. Recalibration using this hardware is possible merely by changing some control equations in the program. This hardware allows not only the measurement of accurate data but also its storage in disks. It opens up the possibilty of manipulating the data and making it more presentable in the form of plots.

# IX. REFERENCES


1. Bibbero, "Microprocessors in Instruments and Control", pp.104-145
2. Lewis C. Eggebrecht, "Interfacing to the IBM Personal Computer", Indianapolis, 1983
3. A.K. Kochhar and N.D. Burns, "Microprocessors and their Manufacturing Applications"
4. Stout, "Microprocessor Applications Handbook"
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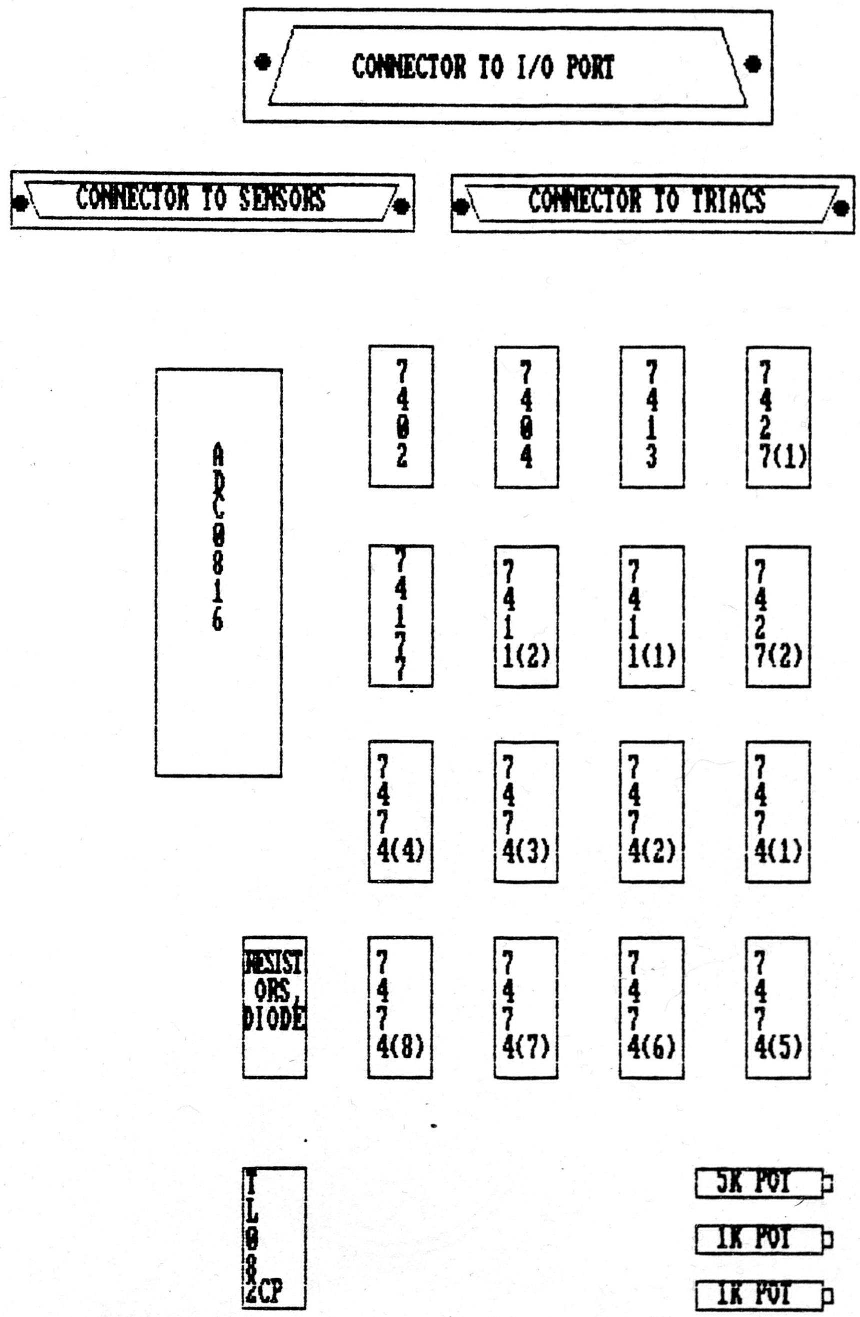
# APPENDIX I

## LAYOUT OF THE INTERFACE CARD

## LAYOUT OF THE INTERFACE CARD



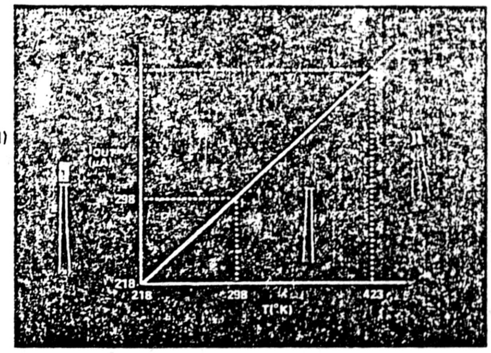
# APPENDIX II

## INFORMATION ON AD590

ANALOG DEVICES

# Two-Terminal IC Temperature Transducer

**FEATURES**
- Linear Current Output: 1μA/°K
- Wide Range: -55°C to +150°C
- Probe Compatible Ceramic Sensor Package
- Two-Terminal Device: Voltage In/Current Out
- Laser Trimmed to ±0.5°C Calibration Accuracy (AD590M)
- Excellent Linearity: ±0.3°C Over Full Range Range (AD590M)
- Wide Power Supply Range: +4V to +30V
- Sensor Isolation from Case
- Low Cost S2.10 (100+, AD5901H)




**PRODUCT DESCRIPTION**

The AD590 is a two-terminal integrated circuit temperature transducer which produces an output current proportional to absolute temperature. For supply voltages between +4V and +30V the device acts as a high impedance, constant current regulator passing 1μA/°K. Laser trimming of the chip's thin film resistors is used to calibrate the device to 298.2μA output at 298.2°K (+25°C).

The AD590 should be used in any temperature sensing application below +150°C in which conventional electrical temperature sensors are currently employed. The inherent low cost of a monolithic integrated circuit combined with the elimination of support circuitry makes the AD590 an attractive alternative for many temperature measurement situations. Linearization circuitry, precision voltage amplifiers, resistance measuring circuitry and cold junction compensation are not needed in applying the AD590.

In addition to temperature measurement, applications include temperature compensation or correction of discrete components, biasing proportional to absolute temperature, flow rate measurement, level detection of fluids and anemometry. The AD590 is available in chip form making it suitable for hybrid circuits and fast temperature measurements in protected environments.

The AD590 is particularly useful in remote sensing applications. The device is insensitive to voltage drops over long lines due to its high impedance current output. Any well-insulated twisted pair is sufficient for operation hundreds of feet from the receiving circuitry. The output characteristics also make the AD590 easy to multiplex: the current can be switched by a CMOS multiplexer or the supply voltage can be switched by a logic gate output.

**PRODUCT HIGHLIGHTS**

1. The AD590 is a calibrated two terminal temperature sensor requiring only a dc voltage supply (+4V to +30V). Costly transmitters, filters, lead wire compensation and linearization circuits are all unnecessary in applying the device.
2. State-of-the-art laser trimming at the wafer level in conjunction with extensive final testing insures that AD590 units are easily interchangeable.
3. Superior interference rejection results from the output being a current rather than a voltage. In addition, power requirements are low (1.5mW's @ 5V @ +25°C). These features make the AD590 easy to apply as a remote sensor.
4. The high output impedance (>10MΩ) provides excellent rejection of supply voltage drift and ripple. For instance, changing the power supply from 5V to 10V results in only a 1μA maximum current change, or 1°C equivalent error.
5. The AD590 is electrically durable: it will withstand a forward voltage up to 44V and a reverse voltage of 20V. Hence, supply irregularities or pin reversal will not damage the device.
6. The device is hermetically sealed in both a ceramic sensor package and in to TO-52 package. MIL-STD-883 processing to level B is available and, for large unit volumes, special accuracy requirements over limited temperature ranges can be satisfied by selections at final test. The device is also available in chip form.



Route 1 Industrial Park; P.O. Box 280; Norwood, Mass. 02062
Tel: 617/329-4700 TWX: 710/394-6577
West Coast 714/842-1717 Mid-West 312/894-3300 Texas 214/231-5094

# SPECIFICATIONS (typical @ +25°C and $V_S$ = 5V unless otherwise noted)

| MODEL | AD590I | AD590J | AD590K | AD590L | AD590M |
|---|---|---|---|---|---|
| **ABSOLUTE MAXIMUM RATINGS** | | | | | |
| Forward Voltage (E+ to E−) | +44V | * | * | * | * |
| Reverse Voltage (E+ to E−) | −20V | * | * | * | * |
| Breakdown Voltage (Case to E+ or E−) | ±200V | * | * | * | * |
| Rated Performance Temperature Range[1] | −55°C to +150°C | * | * | * | * |
| Storage Temperature Range[1] | −65°C to +155°C | * | * | * | * |
| Lead Temperature (Soldering, 10 sec) | +300°C | * | * | * | * |
| **POWER SUPPLY** | | | | | |
| Operating Voltage Range | +4V to +30V | * | * | * | * |
| **OUTPUT** | | | | | |
| Nominal Current Output @ +25°C (298.2°K) | 298.2μA | * | * | * | * |
| Nominal Temperature Coefficient | 1μA/°K | * | * | * | * |
| Calibration Error @ +25°C | ±10.0°C max | ±5.0°C max | ±2.5°C max | ±1.0°C max | ±0.5°C max |
| Absolute Error[2] (over rated performance temperature range) | | | | | |
| Without External Calibration Adjustment | ±20.0°C max | ±10.0°C max | ±5.5°C max | ±3.0°C max | ±1.7°C max |
| With +25°C Calibration Error Set to Zero | ±5.8°C max | ±3.0°C max | ±2.0°C max | ±1.6°C max | ±1.0°C max |
| Nonlinearity | ±3.0°C max | ±1.5°C max | ±0.8°C max | ±0.4°C max | ±0.3°C max |
| Repeatability[3] | ±0.1°C max | * | * | * | * |
| Long Term Drift[4] | ±0.1°C/month max | * | * | * | * |
| Current Noise | 40pA$\sqrt{Hz}$ | * | * | * | * |
| Power Supply Rejection | | | | | |
| $+4V \leq V_S \leq +5V$ | 0.5μA/V | * | * | * | * |
| $+5V \leq V_S \leq +15V$ | 0.2μA/V | * | * | * | * |
| $+15V \leq V_S \leq +30V$ | 0.1μA/V | * | * | * | * |
| Case Isolation to Either Lead | $10^{10}\Omega$ | * | * | * | * |
| Effective Shunt Capacitance | 100pF | * | * | * | * |
| Electrical Turn-On Time[5] | 20μs | * | * | * | * |
| Reverse Bias Leakage Current[6] (Reverse Voltage = 10V) | 10pA | * | * | * | * |
| **PRICE[7]** | | | | | |
| H Package | | | | | |
| (1–24) | $3.60 | $ 4.10 | $ 8.20 | $17.20 | $40.40 |
| (25–99) | $2.80 | $ 3.15 | $ 6.50 | $13.60 | $30.70 |
| (100+) | $2.10 | $ 2.40 | $ 4.90 | $10.30 | $24.50 |
| F Package | | | | | |
| (1–24) | $7.20 | $10.70 | $12.90 | $21.50 | $47.90 |
| (25–99) | $5.80 | $ 7.50 | $10.20 | $17.70 | $38.60 |
| (100+) | $4.60 | $ 6.40 | $ 7.70 | $14.20 | $29.30 |
| **PRICE–PROCESSED TO MIL-STD-883B** | | | | | |
| H Package | | | | | |
| (1–24) | – | $10.70 | $15.70 | $25.70 | $50.90 |
| (25–99) | – | $ 8.70 | $11.60 | $20.50 | $40.80 |
| (100+) | – | $ 6.40 | $ 9.00 | $15.00 | $31.30 |
| F Package | | | | | |
| (1–24) | – | $13.60 | $21.50 | $31.50 | $59.80 |
| (25–99) | – | $11.30 | $17.70 | $25.20 | $48.60 |
| (100+) | – | $ 9.00 | $12.90 | $19.40 | $37.50 |

*Specifications same as AD590I

[1] The AD590 has been used at −100°C and +200°C for short periods of measurement with no physical damage to the device. However, the absolute errors specified apply to only the rated performance temperature range.

[2] See page 8–10 for explanation of error components. Note that ±1°C error is the equivalent of ±1μA error.

[3] Maximum deviation between +25°C readings after temperature cycling between −55°C and +150°C; guaranteed not tested.

[4] Conditions: constant +5V, constant +125°C; guaranteed, not tested.

[5] Does not include self heating effects; see page 8–11 for explanaiton of these effects.

[6] Leakage current doubles every 10°C.

[7] Chips are available to J specifications; minimum order is 25 chips; 25–99 price: $2.52/chip; 100+ price: $1.70/chip; consult local sales office for large volume pricing; consult Chip Catalog for applications detail.

Specifications subject to change without notice.

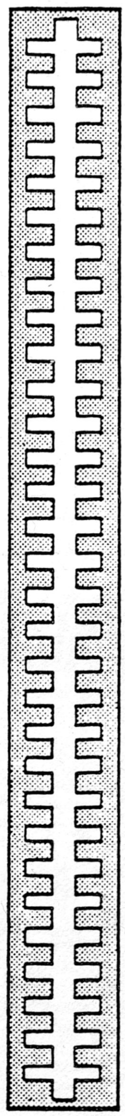

## TEMPERATURE SCALE CONVERSION EQUATIONS

$$°C = \frac{5}{9}(°F - 32) \qquad °K = °C + 273.15$$

$$°F = \frac{9}{5}°C + 32 \qquad °R = °F + 459.7$$

# APPENDIX III

## PIN AND SIGNAL DEFINITIONS FOR INPUT/OUTPUT PORT



| SIGNAL | PIN | PIN | SIGNAL |
|---|---|---|---|
| GND | B1 | A1 | $\overline{\text{I/O CH CK}}$ |
| RESET DRV | B2 | A2 | D0 |
| +5 V DC | B3 | A3 | D1 |
| IRQ2 | B4 | A4 | D2 |
| −5 V DC | B5 | A5 | D3 |
| DRQ2 | B6 | A6 | D4 |
| −12 V DC | B7 | A7 | D5 |
| (NOT USED) | B8 | A8 | D6 |
| +12 V DC | B9 | A9 | D7 |
| GND | B10 | A10 | I/O CH RDY |
| MEMW | B11 | A11 | AEN |
| MEMR | B12 | A12 | A19 |
| IOW | B13 | A13 | A18 |
| IOR | B14 | A14 | A17 |
| DACK 3 | B15 | A15 | A16 |
| DRQ3 | B16 | A16 | A15 |
| DACK 1 | B17 | A17 | A14 |
| DRQ1 | B18 | A18 | A13 |
| DACK 0 | B19 | A19 | A12 |
| CLK | B20 | A20 | A11 |
| IRQ7 | B21 | A21 | A10 |
| IRQ6 | B22 | A22 | A9 |
| IRQ5 | B23 | A23 | A8 |
| IRQ4 | B24 | A24 | A7 |
| IRQ3 | B25 | A25 | A6 |
| DACK 2 | B26 | A26 | A5 |
| T/C | B27 | A27 | A4 |
| ALE | B28 | A28 | A3 |
| +5 V DC | B29 | A29 | A2 |
| OSC | B30 | A30 | A1 |
| GND | B31 | A31 | A0 |

**Pin and signal definitions for the card slots.**

# APPENDIX IV

## TIMING DIAGRAM OF THE I/O WRITE BUS CYCLE

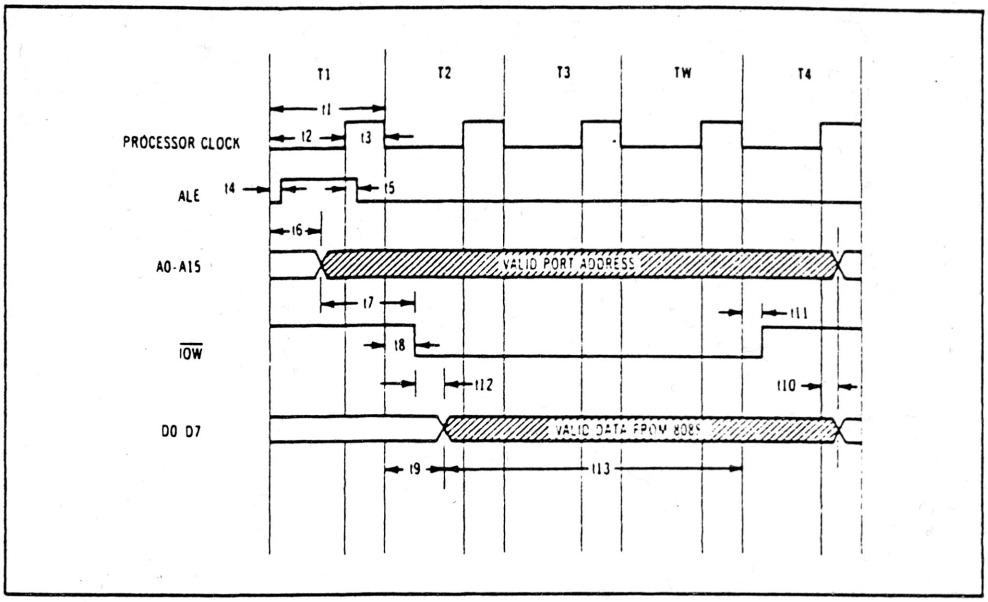



Fig. 6-4. I/O port write bus cycle timings.

**Table 6-4. I/O Port Write Bus Cycle Timings**

| Symbol | Max | Min |
|---|---|---|
| t1 | — | 209.5 |
| t2 | — | 124.5 |
| t3 | — | 71.8 |
| t4 | 15 | — |
| t5 | 15 | — |
| t6 | 128 | 16 |
| t7 | — | 91.5 |
| t8 | 35 | 10 |
| t9 | 122 | 14 |
| t10 | — | 10 |
| t11 | 35 | 10 |
| t12 | 112 | — |
| t13 | — | 506.5 |

*All times are in nanoseconds.

# APPENDIX V

## TIMING DIAGRAM OF THE I/O PORT WRITE BUS CYCLE

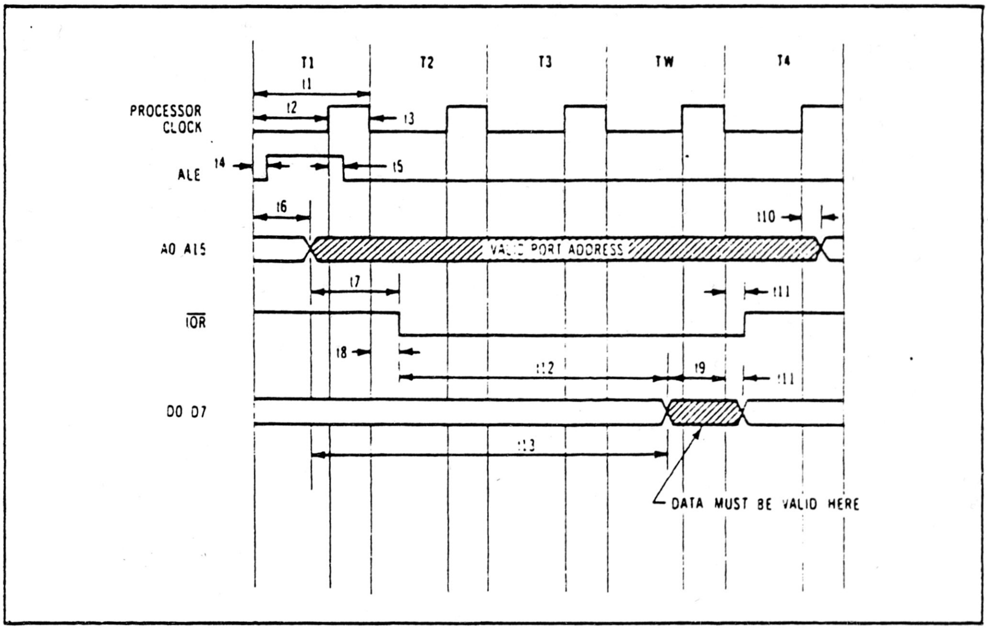



Fig. 6-3. I/O port read bus cycle timings.

**Table 6-3. I/O Port Read Bus Cycle Timings**

| Symbol | Max | Min |
|---|---|---|
| t1 | — | 209.5 |
| t2 | — | 124.5 |
| t3 | — | 71.8 |
| t4 | 15 | — |
| t5 | 15 | — |
| t6 | 128 | 16 |
| t7 | — | 91.5 |
| t8 | 35 | 10 |
| t9 | — | 42 |
| t10 | — | 10 |
| t11 | 35 | 10 |
| t12 | — | 551.5 |
| t13 | — | 668 |

*All times are in nanoseconds.