A Wireless Robotic Manipulator for Semiconductor Manufacturing Equipment

by

Jevin E. Scrivens

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Signature of Author..
Department of Mechanical Engineering
May 26, 1997

Certified by..
Alexander Slocum
d'Arbeloff Associate Professor of Mechanical Engineering
Thesis Supervisor

Accepted by..
Ain A. Sonin
Chairman, Department Committee on Graduate Studies

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Abstract:

Silicon wafer processing is an extremely refined and sensitive operation. Processing often takes place in clean rooms filtered to better than class 1. However even under these precautions, particle contamination still causes failures in the microchips produced in these environments. One source of these contaminants is the production equipment itself. Particularly, the wire carriers connecting the robots can shed micro particles which are deposited onto the wafers in process. The wires within these carriers also possess a considerable failure rate which causes machine down time and contamination of the environment due to the repair operation. These combined factors illustrate the need to minimize the use of wire carriers.

The solution to these problems is the concept of the wireless robot. The wireless robot uses inductive power transfer and optical communication to operate the end effector of the robot. This takes advantage of the fact that for many types of production equipment, the robots only need to execute more complex motions at discrete locations.

In its overall operation, the robot is positioned in front of an operation station where a pair electromagnetic coils would be aligned. The primary coil would be fixed to the station and the secondary coil would be attached to the robotic manipulator. The primary coil would be charged by a high frequency AC supply, and the property of electromagnetic induction would cause a similar voltage to be produced in the secondary coil. This voltage would then be supplied to the electronics of the manipulator as a power source.

Robot control would be achieved through the use of optical transfer rather than a hardwired voltage transfer. This technique is similar to well known processes used in fiber optics, however in this process the transfer median is an air gap rather than a fiber optic cable. This design calls for the use of only one way transmission where the transmitters are on the base and the receptors are on the robot. Two way transmission for feedback is possible and available for future use.

This design also lends itself to a variety of other applications including factory automation robots and other environments in which operation is required in discrete locations or sensitive environments.

Thesis Supervisor: Alexander Slocum
Title: d'Arbeloff Associate Professor of Mechanical Engineering

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To all of my friends, whose frequent talks were my anchor to sanity. And especially to M.K.K., you just don't know how much you have done for me.

Most importantly, I would like to thank my family and friends. To Mom, Dad, Janelle, Jay, and Ted, I owe you everything. All that I am and all that I will be.

Thank you all.

Chapter 1

Introduction

The Wireless Robot is a solution to some of the problems in semiconductor manufacturing. It allows complete omission of wires connecting the mobile wafer manipulators and a stationary base thereby solving the problem by removing the cause.

1.1 Problem

Silicon wafer processing is an extremely refined and sensitive operation. Processing often takes place in clean rooms filtered to better than class 1. Even if mini environments are used around equipment, it is important to minimize contaminant generation inside the equipment. This level of filtration is important because of sensitivity of the wafers. Particle contamination causes failure of microchips produced in these operations. Even a single particle is sufficient to fail a microchip. Even though the air is filtered to remove outside contaminants, there are still a significant number of failures due to contamination. One source of these contaminants is the production equipment itself. Particularly, the wire carriers connecting the robots constantly shed micro particles that are deposited onto the wafers in process. These wire carriers are made of plastic and are designed to organize and direct the wires supplying the robots with power and transferring information between the robots and outside computers.

Another major problem with wire carriers is the failure rate of the wires within them. As the wires are constantly being moved with the robot they ultimately fatigue and break. Causing considerable down time due the compromise of room air cleanliness from the repair operation. These combined factors illustrate the need to minimize the use of wire carriers.

1.2 Solution

An extreme solution to this problem would be the elimination of components causing the contamination. This means removing the moving wires attached to the robot. In normal cases the wire provides both power and control. Power may take the form of either electrical or mechanical energy. Control usually takes the form of electricity. This idea broke the problem down into two components, transmission of control and transmission of power

The solution to these problems is the wireless robot concept. The wireless robot uses inductive power transfer and optical communication to operate the end effector of the robot. This takes advantage of the fact that for many types of production equipment, the robots only need to execute more complex motions at discrete locations.

In theory the manipulator will be placed in front of an operation station, where the robot would then be powered by electromagnetic induction. By having actual power transfer with no physical connection, there is no chance to spark or otherwise create any micro-particle contaminants. The lack of wire harness would also eliminate the possibility of wear in a movable mechanical connection.

Control of the robot would also be accomplished through a non-physical connection. Through the use of infra-red LED's and infra-red logic detectors, digital control of a stepper motor may be obtained.

Chapter 2

Concept Exploration

With the basic operational requirements of the robotic manipulator established, a methodology of achieving those requirements must now be established. This requires the evaluation of several concepts in both power transfer and in control

2.1 Power Transfer

The transfer of power without wires does not necessarily require the development of new technology. The first step is to evaluate some of the current, well established methods that have already been tried and proven in other applications.

The three power transfer methods considered are:

- Battery Power
- Geared power train
- Electromagnetic induction

2.1.1 Battery

The concept of battery power appears to be a sound concept, however, in a manufacturing environment this type of mechanism has several shortcomings. Due to the limited capacity of batteries the actual operation time of the manipulator would be limited. In order to work at all it would have to operate under one of two conditions.

In order to maintain a decent operating time, the manipulator may require the use of very large batteries. However, large batteries are expensive and heavy and this may pose some design problems depending on the operation. Also, as with all rechargeable batteries, regular replacement is required. If the batteries were to operate throughout an entire day then they would have to be extremely large capacity meaning even higher weight and longer recharging.

The other option is to use smaller batteries with frequent recharging cycles. The problem with this concept is that the recharging time takes away from production time. And frequent recharging cycles decrease the life of the battery.

2.1.2 **Geared Power Train**

The second concept is the geared power train. This concept satisfies both power and control issues but loses sight of the overall goal of the project. A mechanical power train in any form (gear, pulley, or chain) entails moving parts. These moving parts will rub together resulting in friction and wear. The wear of the mechanisms will cause particle contamination, which is part of the initial problem.

2.1.3 **Electromagnetic Induction**

The third concept is electromagnetic induction. This concept will prove itself to be the best choice for this application and will also present itself to a variety of other applications. Electromagnetic induction is a well proven technology and is the basis for the common electrical transformer (fig. 2-1).

The transformer is a passive electrical device consisting of two closely coupled coils (called the primary and the secondary) in a magnetic core. An AC voltage applied across the primary coil appears on the secondary. During operation, the primary coil creates a alternating magnetic field which is directed by the core material to pass through the secondary coil. This alternating magnetic field within the secondary coil creates a voltage across the coil.

AC Transformer

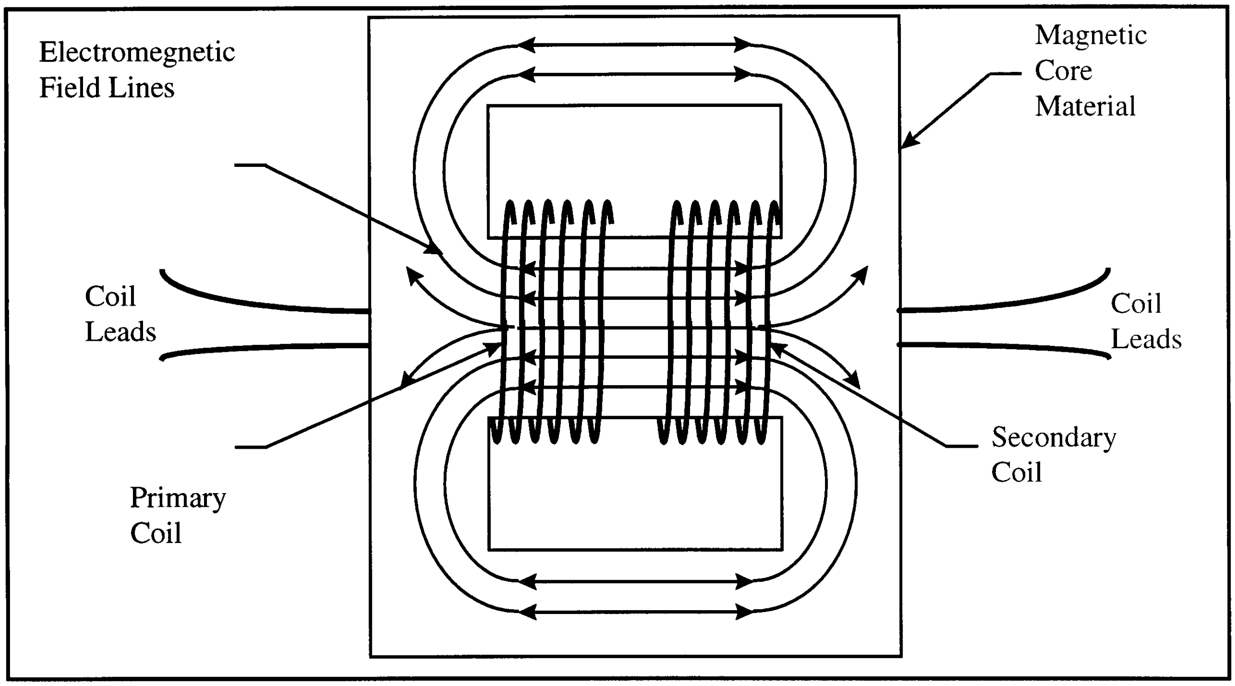


Figure 2-1

In the wireless operation, the power transfer apparatus is very similar to a transformer. Except in this case the core material will be split into two halves and the coil halves do not touch, but are separated by a small air gap. This split core arrangement (fig 2-2) will provide the inductive transfer. One coil half again operates as the primary coil and is located on the stationary base unit. The second coil half is located on the manipulator and operate as the secondary coil. The secondary coil effectively receives the power transmitted by the primary and delivers it as an AC voltage for use by the manipulator circuitry.

Due to the properties of magnetic fields, the small gap does not have extremely negative effects on the power transfer. However large gaps result in considerable loss. With just a small gap, the two coil halves operate effectively as a transformer.

Split Core Transformer

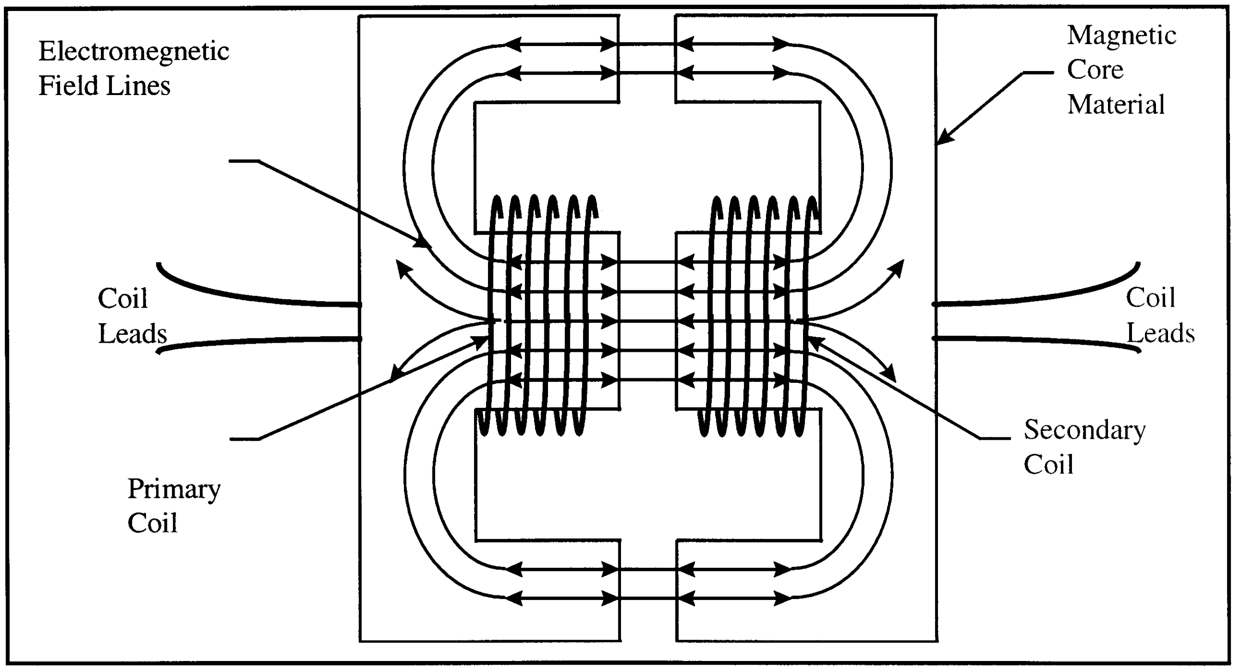


Figure 2-2

2.2 Control

After power has been transferred to the manipulator, there must be some method, also wireless, of controlling the manipulator. The design of the control interface began with the analysis of three wireless data transfer methods:

- Radio transmission
- Power signal modulation
- Infra-red transmission

2.2.1 **Radio Transmission**

To transfer data in a radio signal would require the use of a modulated carrier wave. The carrier wave's amplitude or frequency could be modulated giving an AM of FM signal. However as any car occupant knows, radio signals are subject to a great deal of interference. Interference comes from various outside sources including electrical motors and especially the power transmission. The method of power transfer selected is a high frequency induction system. The basis of induction is the generation of electromagnetic fields, which is also the median of radio transmission. With high intensity magnetic fields being generated in such close proximity, radio reception is subject to a great deal of interference.

2.2.2 **Modulated Power Signal**

Data transfer in the form of the modulated power signal is an interesting concept, however data transfer in this method is a complicated issue. It requires precise study and control of the power signal and power consumption. This type of transfer is better suited for wire connected DC transfers rather than high frequency induction systems. This type of communications configuration is an unnecessary increase in the complexity of the design. Also it's use would not help in proving the technology of the wireless robot.

2.2.3 **Infra-red LED and Detector pair**

Infra-red data transfer is the method chosen to control the robot because of it's simplicity and resilience. Infra-red flashes can be used to transmit digital information without any form of encryption or decryption. The motor used in the manipulator is a stepper motor, which operates under two channel binary communication. The stepper driver is instructed by voltage pulses to either step clockwise or step counter clockwise. The construction of an optical interface for communication is a simple task of wiring the controller to flash an infra-red light instead of connecting directly to the stepper driver. A logic detector is used to detect the light and send a voltage to the stepper driver when detected.

This type of system is not subject to electromagnetic interference and operates on a line of sight basis with low level infra-red light. Hence, it has no effect on surrounding equipment. This system may be subject to interference from ambient IR light sources, however, interface blocks can easily designed to shield the detector form extraneous sources.

Chapter 3

Power System Development

This chapter will discuss the actual development of the power transfer system. As stated in the previous chapter, an inductive transfer system will be used. This chapter will discuss some of the details of that design process.

The initial idea for the power supply was to use a switching power supply. Switching power seemed optimal because of it's relatively high power density compared to normal AC transformers. The AC and switching systems differ in the sense that the AC transformer uses a 60Hz sine wave input while the switching supply uses a square wave and operates at a higher frequency. The advantage of the switching power supply in this particular application is the high frequency nature of it's operation.

The voltage induced on the secondary coil is proportional to the time rate of change of the magnetic field passing through the secondary coil. By oscillation the field at a higher frequency, lower field intensity is needed than if using a lower frequency. Lower field intensity is more desirable because of losses incurred within the magnetic material and especially over the air gap. Higher field intensity also means higher forces imposed on the coils and the system itself.

3.1 Initial Switching Design

Initially the system used was a switching power supply (fig. 3-1), however it did not provide the necessary effectiveness. Later analysis revealed that the switching design was faulty and was effectively sending a fluctuating DC voltage across the coil rather than the required AC voltage.

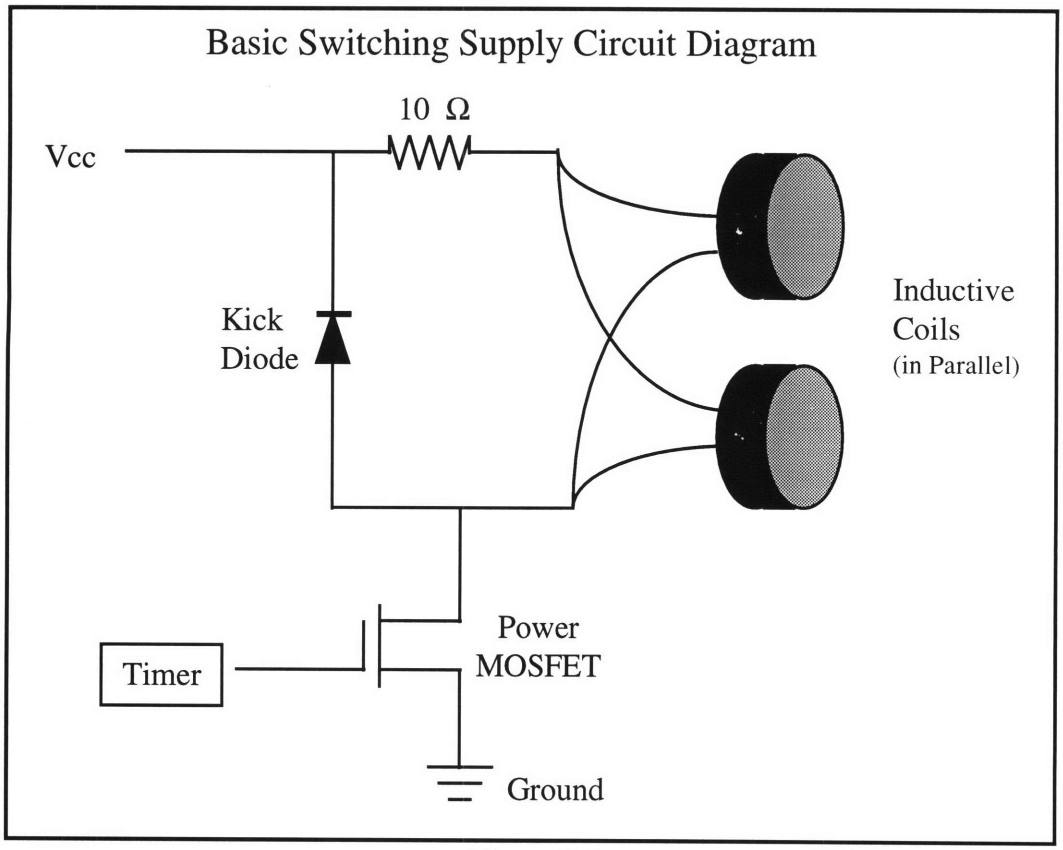


Figure 3-1

3.2 Amplifier Drive Design

Compensation for the errors in the stepper drive, the system was changed to use an 800Hz sine wave generated by a function generator and amplified by a servo amplifier (fig 3-2). This high power output signal was then sent to the primary coils of each station, which were connected to each other in series. From the secondary coil on the robotic manipulator, the transferred power is rectified and filtered through two large parallel capacitors. A DC voltage of 12V is then delivered to the stepper driver satisfying it's voltage requirements.

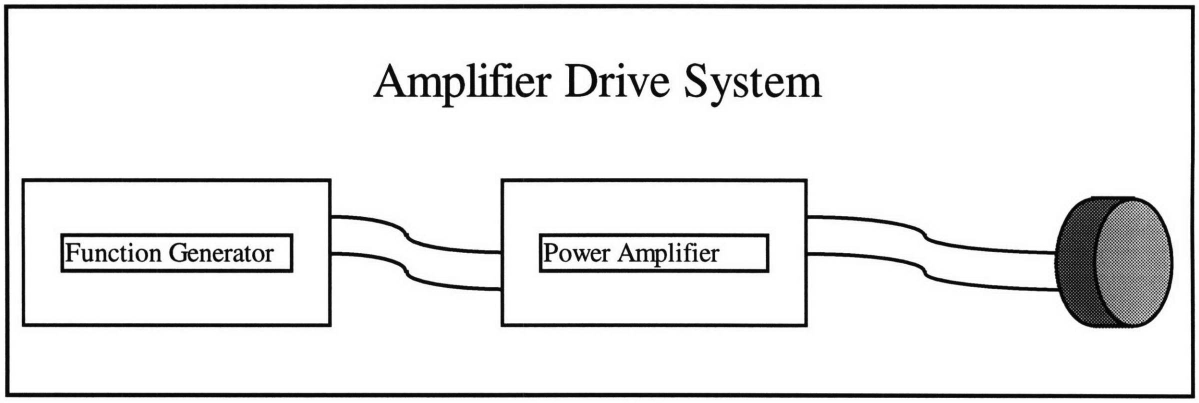


Figure 3-2

3.2.1 Series connection of primary coils

Since the secondary coil is only in front of one primary at a time, the other primary will not have a closed magnetic loop and will therefore have a much lower inductance and will be essentially seen as a resistor to the circuit. When the secondary comes in front of the next primary, it's magnetic path will again be closed. After the inductance increased, the circuit will be seen as a transformer again while first coil is seen as a resistor.

3.2.2 Servo Amplifier Drive

The most efficient design for this system is a switching system operating in the range of 20kHz. The initial power supply design is intended to provide this, however due to design errors it was not capable of the required power transfer.

Once the errors were recognized the intent was to mimic the intended switching drive with the combination of a function generator and an amplifier. However, the bandwidth of the amplifier used was limited to 800Hz and this is the reason for the 800Hz input signal in this system.

3.2.3 Coil design

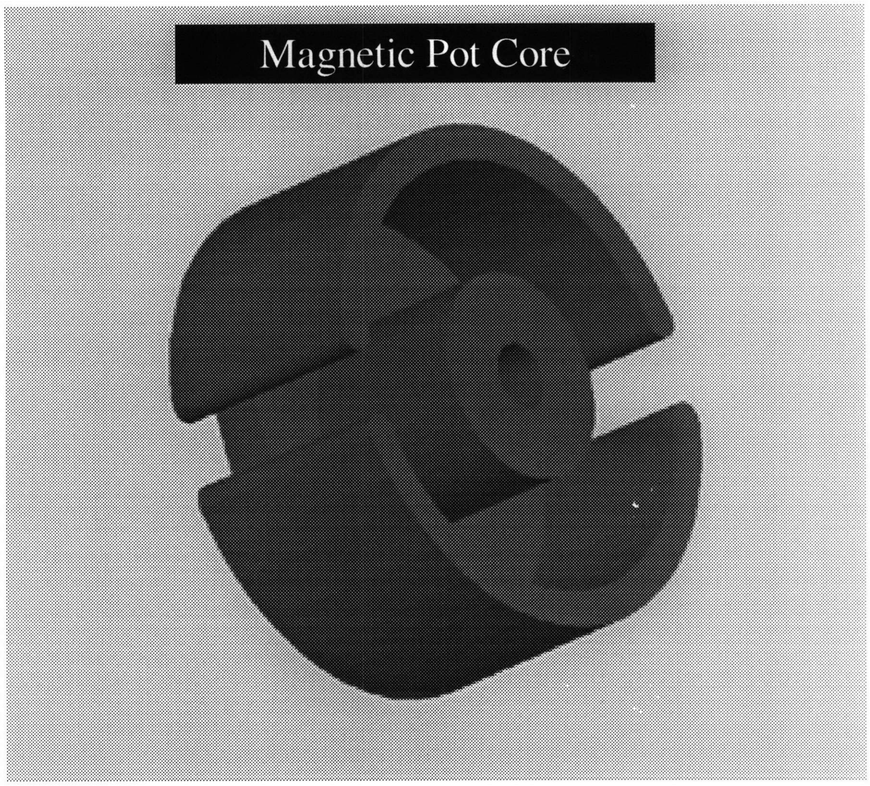


Figure 3-3

The purpose of the power drive is to create an alternating voltage in coil and core assembly, which will effectively induce a voltage of sufficient amperage in a matching coil. First, a pot core configuration was selected and Phillips Magnetics 4229 cores and core material 3C81 were obtained (fig 3-3).

Pot cores of this diameter were chosen because of their large size and suitability to high frequency operation. In this design, a large diameter core was deemed necessary to compensate for any misalignment that may occur in the positioning of the manipulator in relation to the base. In practice the use of a precision motion controller will eliminate that error and an optimal core may be chosen without the need to compensate for positioning error.

Next, the coil assemblies were completed using 100 turn coils (fig 3-4). The assemblies were made with 100 turns in order to roughly optimize the inductive coupling.

A fewer number of turns would not have provided enough inductance for the system, since it is a general rule of thumb that more turns make better transformers. Too many turns may cause saturation of the magnetic field at the current levels required by the stepper driver. Saturation of the field will severely decrease the efficiency of the power transfer.

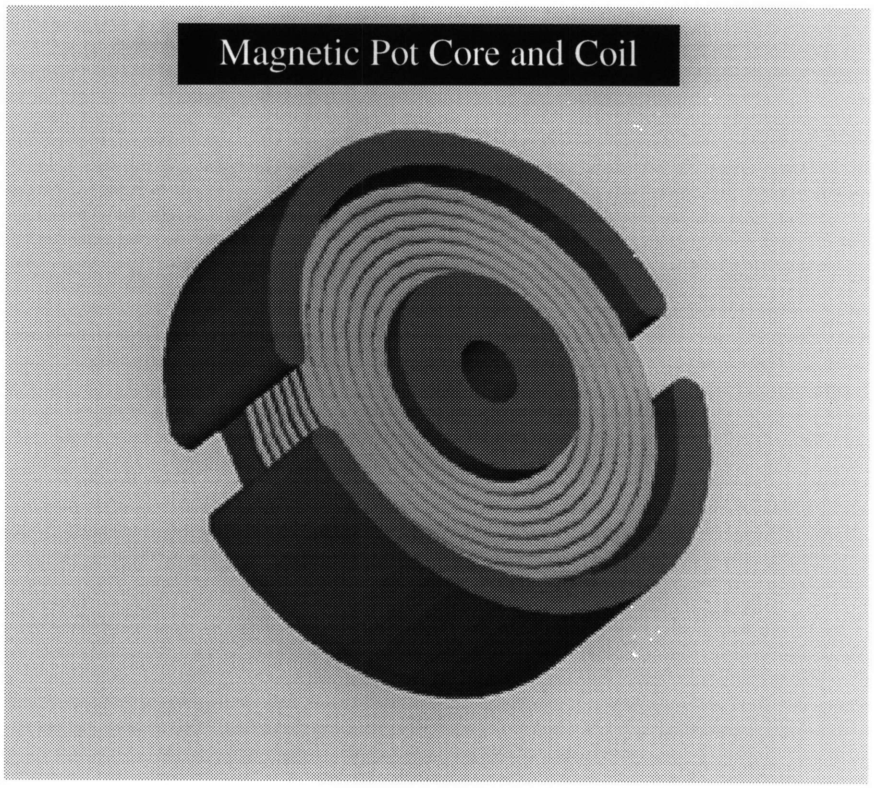


Figure 3-4

Chapter 4

Control System Development

This chapter will discuss the development of the control system, beginning with the motion control board and the interface between the host computer with the motion control interface board.

4.1 Motion Control

Operation of the wireless robot is achieved through the use of a motion control board. In this application, the motion controller needs to operate in both stepper mode and servo mode simultaneously. Stepper mode is required to operate the wireless axis. In order to minimize the complexity of the wireless interface, open loop control was necessary and this could only be achieved through stepper control. The primary axis, the linear track, was already equipped with a servo motor and encoder. Therefore, a motion controller was required to be compatible with both of these existing systems. Another requirement of the motion controller was top possess several uncommitted digital outputs and inputs. These outputs were required to operate the pneumatics at the operation stations and turn on the power supply when required. The search for a motion controller with these characteristics revealed the NuLogic Flex Motion controller. The Flex Motion controller along with it's interface board, the UMI Flex, provided 4 axes of motion control, two of which could be used in stepper mode. It also provided 24 uncommitted digital I/O ports. The Flex Motion is a PC based motion controller for use in Windows 3.1, Windows 95, or Windows NT environments. Programming may be achieved through an included interface program, or the languages of C, Visual C, Visual Basic, or the Lab View environment.

4.2 Wireless Interface

The design of the optical interface is intertwined with configuration of the motion actuators. There are two choices for motor configurations in control systems: servo and stepper. In this design, one way transmission is preferred to eliminate the complexity of a feedback channel. In order to use one way transmission or open loop control, the motor has to operate as a stepper motor. Servo operation requires some sort of position or velocity feedback, while stepper operation requires only one way transmission of step and direction. This little fact narrowed the possibilities of which type of motor could be used so the use of a stepper motor was chosen for this design. With the stepper configuration confirmed, design of the design the appropriate interface could now proceed.

4.2.1 Interface Concept

In normal operation, the stepper driver is directly connected to the motion controller and is controlled by a voltage on the signal lines. This design required the substitution of the signal lines with and infra-red interface (fig 4-1). In basic operation, the controller needs to transmit two channels of information to the driver, step CW and step CCW. As a result of this, two channels of infra-red interface consisting of two IR LED's and two IR receivers are required. In the search for this equipment, there was trouble using normal IR transistors. Simple connection to the system was not possible because decoding circuitry was required. However, IR logic detectors provided the exact functionality required for the operation.

Infra-Red Interface Diagram

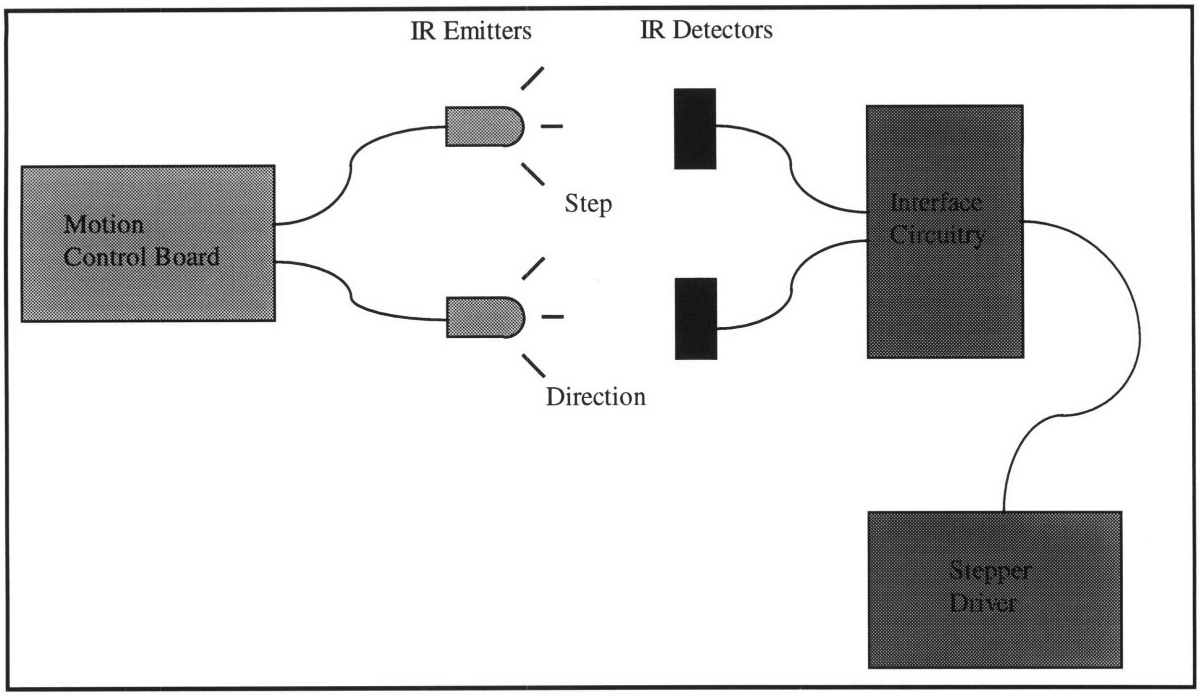


Figure 4-1

The logic detectors (fig. 4-2) operate within TTL level circuitry and when IR light of minimal intensity is detected the output lead is driven to high (5V).

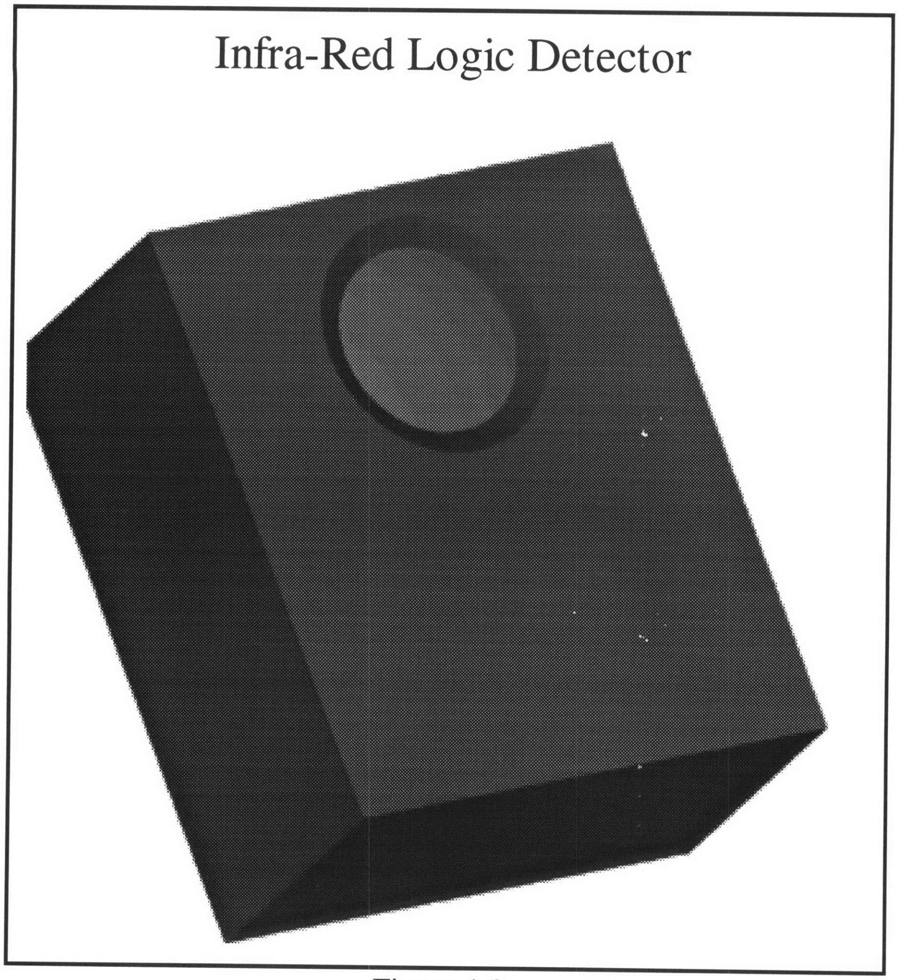


Figure 4-2

4.2.2 Interface Circuit Design

Normally the currents involved in connecting a computer to the stepper driver are minimal, so the computer is capable of handling the direct connection. However in this case the computer is being used to control infra-red LED's. The LED's require higher current values than the stepper driver, so to avoid burning out the motion control board in the computer, an interface was built to buffer the control card from those currents. The buffer consisted of using a TTL level integrated circuit, (in this case an inverter), whose outputs would be directly connected to the infrared LED's.

Interface Circuit Diagram

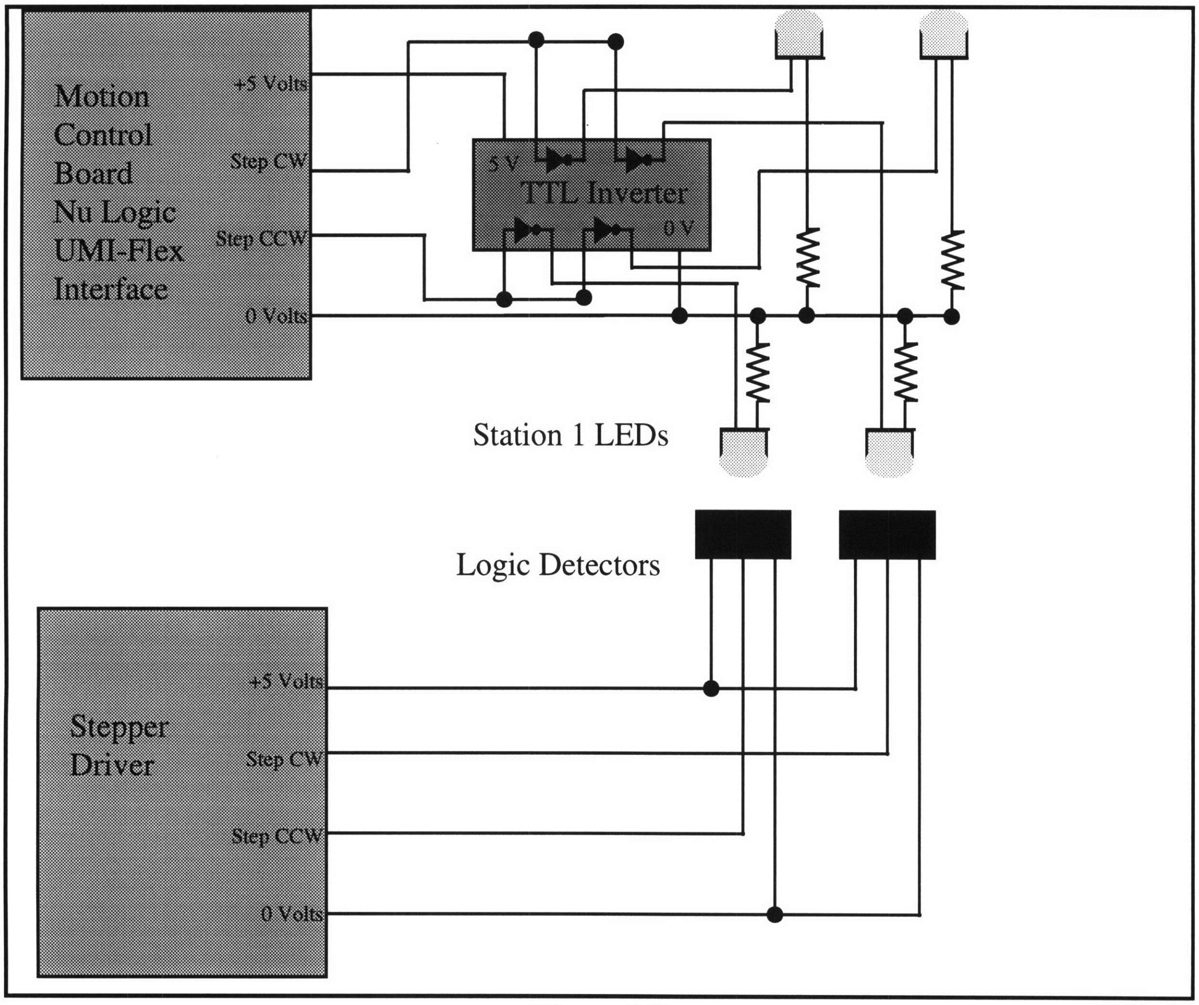


Figure 4-3

The inverter is used in this case because the step outputs from the computer normally on. If the LED's were connected without inversion, then they would also be normally on. This would cause a problem during transition from one station to another because movement would cause the logic detectors to see an off transition and this would register as a step to the stepper driver. This transition would cause unregistered movement of the motor and unpredictability in actuator location. By using the inverter, the LED's are normally off and no change is seen by the driver during transition from one station to the other.

4.3 Supplemental Interfaces

4.3.1 Pneumatic Control Interface

The pneumatics for the wafer lifts are controlled by the digital I/O ports from the motion controller. Within the operation program, the pneumatics are connected to port 3 of the digital I/O. The outputs are connected to minor interface circuitry to gain sufficient power to switch the pneumatic valves.

Pneumatic Interface Circuit Diagram

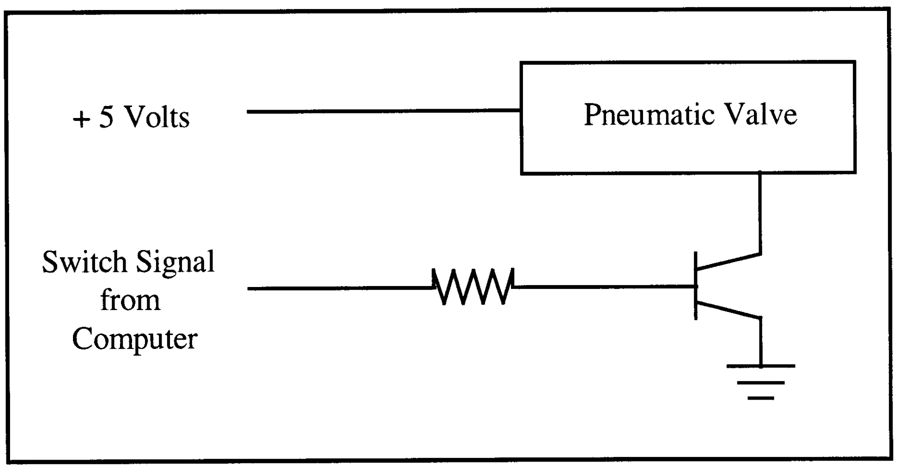


Figure 4-4

4.3.2 Power Control Interface

Switching of the power to the primary coils is also controlled by the computer. The power switch is connected to port 2 of the digital I/O ports. Since the voltage of the power supply is a high frequency alternating voltage, mechanical relays were used to physically connect the control voltage to the amplifier. When the switch is off, the relays are in the normally closed position which are connected to ground. When turned on the relay the two signal lines to the amplifier input, providing the high power voltage to the coils.

Power Control Circuit Diagram

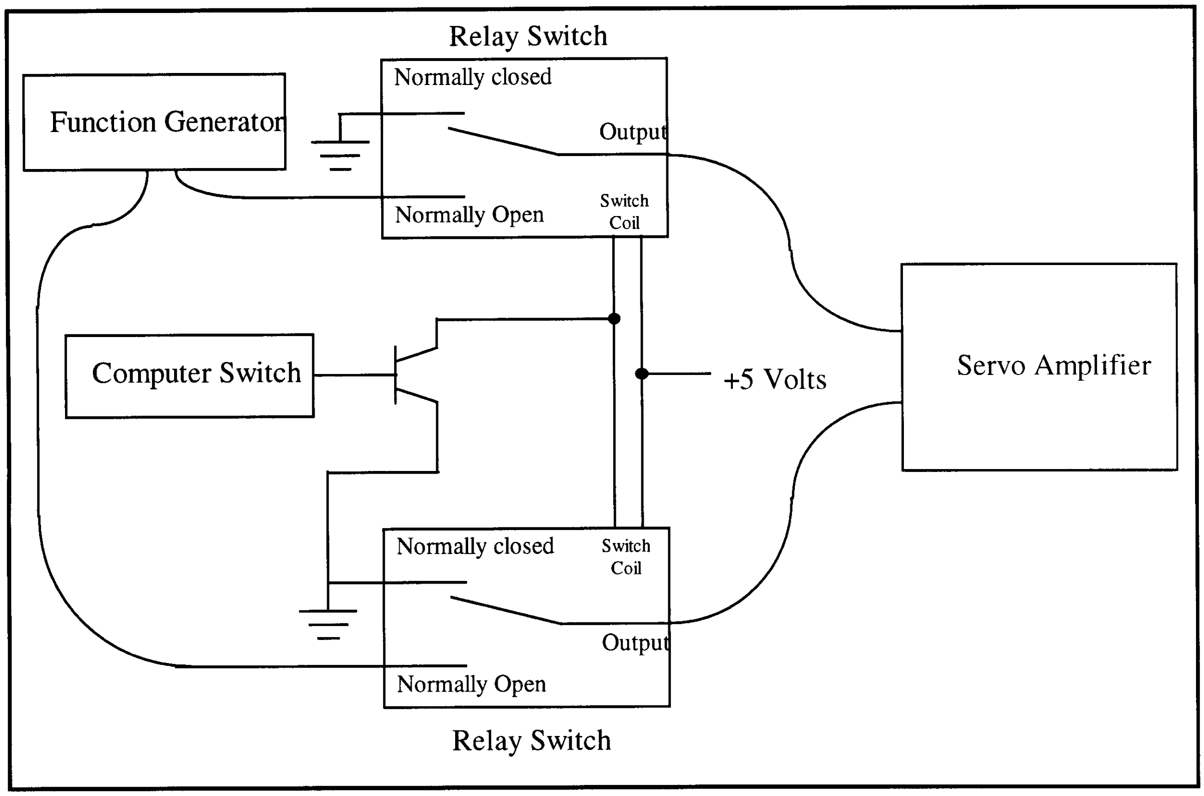


Figure 4-5

Chapter 5

Prototype Development

The aim of this project is to develop a prototype proving that the operation a wireless robot is feasible. To prove wireless operation, the prototype had to perform controlled, repeatable operations at multiple stations. The first application of this technology is in the silicon wafer processing industry. In this application the robot needed to perform as a wafer manipulator, moving silicon wafers from one station to another without moving wires.

5.1 Operation Concept

To demonstrate wireless technology, a prototype needed to be developed. The concept of this prototype called for a wafer manipulator with at least operation stations. During operation, wafers would be continually rotated between the stations keeping a constant flow of material in process. Original concepts included both two axis manipulators and single axis manipulators.

The two axis manipulator systems required the second axis to lift and drop for placing and retrieving wafers. One of the most advanced in the two axis manipulators systems was straight lime motion system (fig. 5-1). This actuator in this system (fig. 5-2), is a geared linkage of three arms which would provide straight line motion derived from a rotary motor.

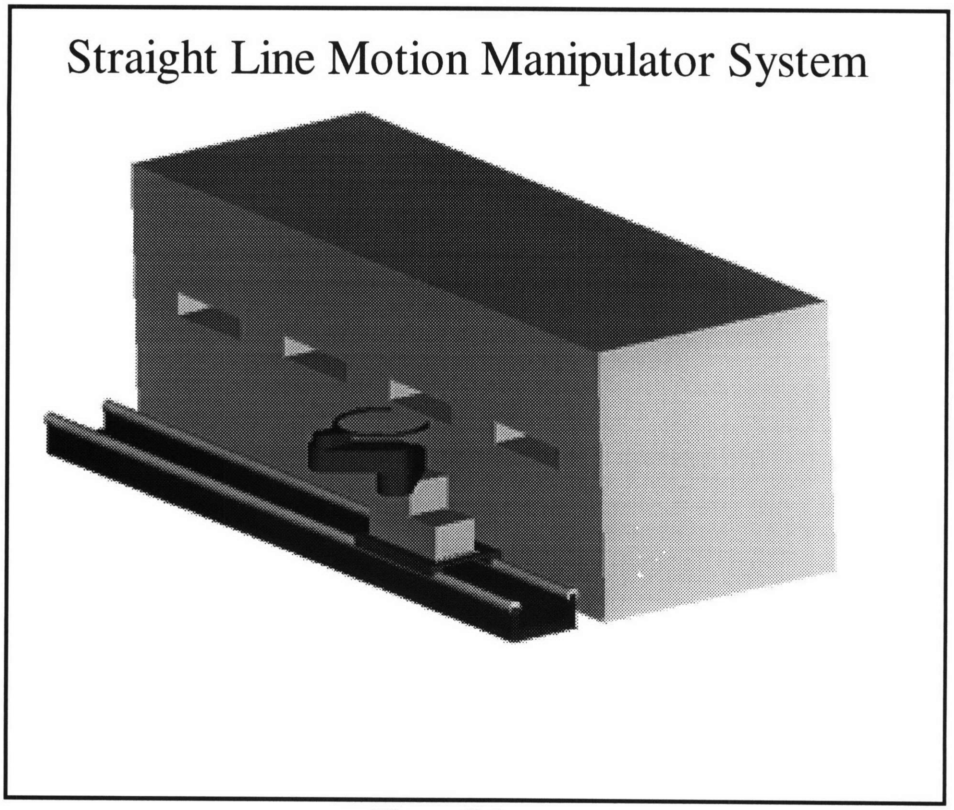


Figure 5-1

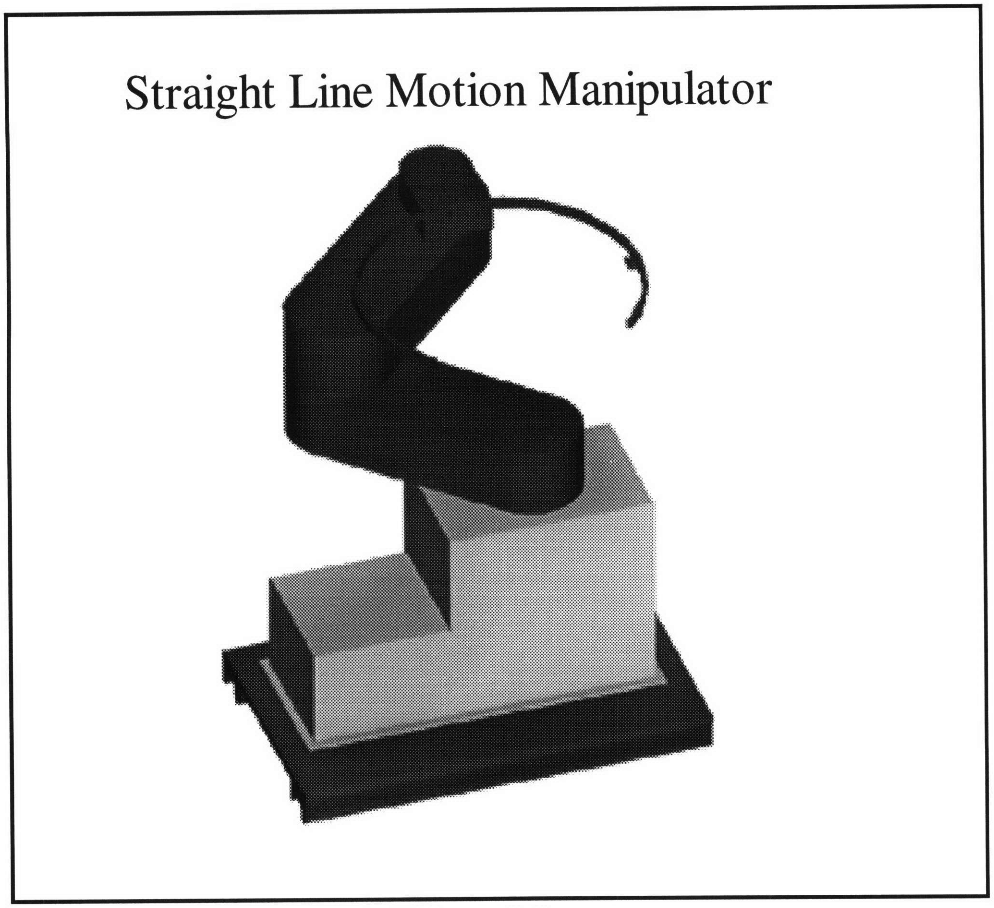


Figure 5-2

The straight line manipulator concept is significant because of it's ability to achieve straight line motion without moving the primary axis. Straight line motion is often required and in some current systems, it's motion is achieved by controlled coupling of the secondary rotary axis and the primary axis. Eventually it was decided that this concept was more complex than necessary for this wireless robot project. The idea is sound and may be more appropriate and necessary in actual production equipment.

The other design concept was the simple rotary system (fig. 5-3). It simply rotated a wafer carrier while the lifting action was achieved through pneumatic manipulators located at each station. In operation, the manipulator rotates the carrier to position over the station and the pneumatic lifts the wafer out of the carrier or drops a wafer into the carrier.

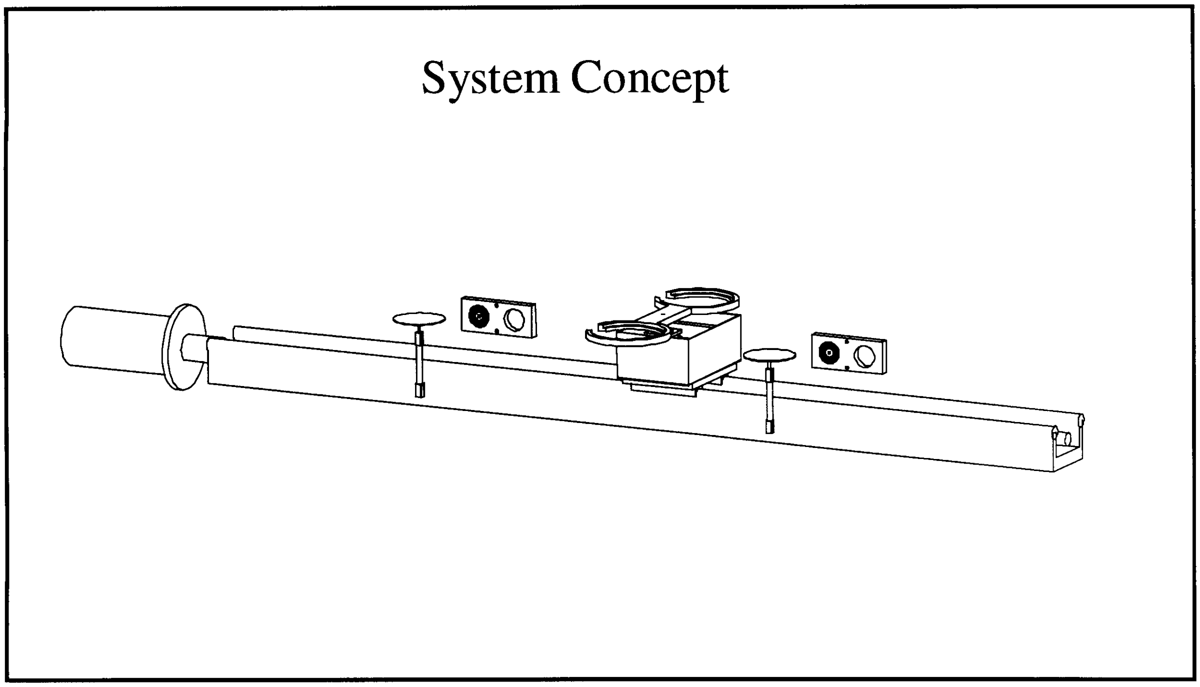


Figure 5-3

5.2 System Design

From the point of concept development, detailed design began with the with the interface. The interface needed to align the primary and secondary pot cores together and as well as the infra-red LED's and logic detectors for step CW and step CCW. In order to achieve this alignment, two similar blocks were designed for transmission and reception. They were both designed to hold two pot cores each because that was the requirement of the previous switching system. The difference between the two designs is that the transmission block (fig. 5-4) holds IR LED's and the reception block holds logic detectors.

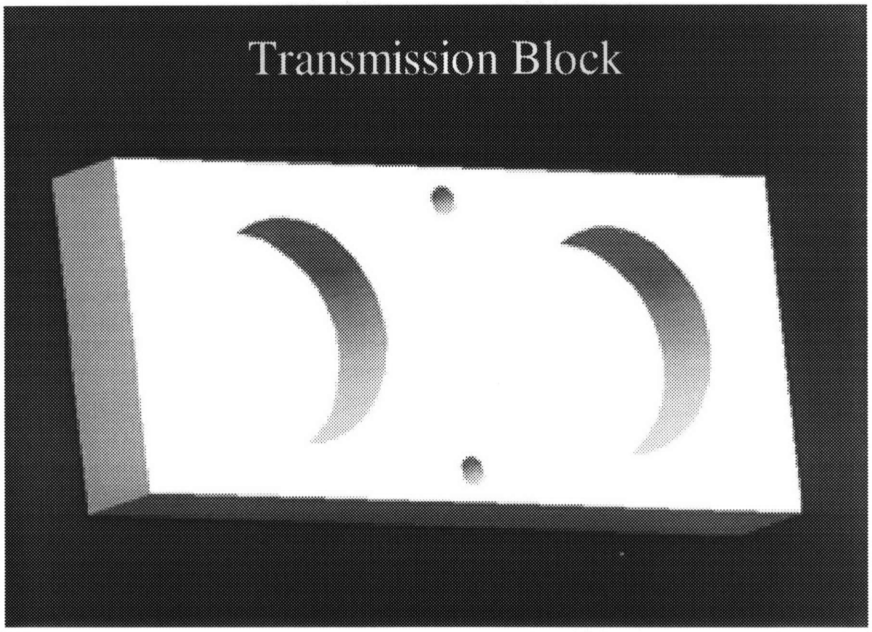


Figure 5-4

With the servo amplifier drive system the interface required only one transfer coil. This left a corresponding coil slot in the reception assembly (fig. 5-5)and transmitter assembly (fig.5-6) open. Using this interface, the coils, LED's, and detectors are automatically aligned with the step CW LED and detector on the top and CCW on the bottom.

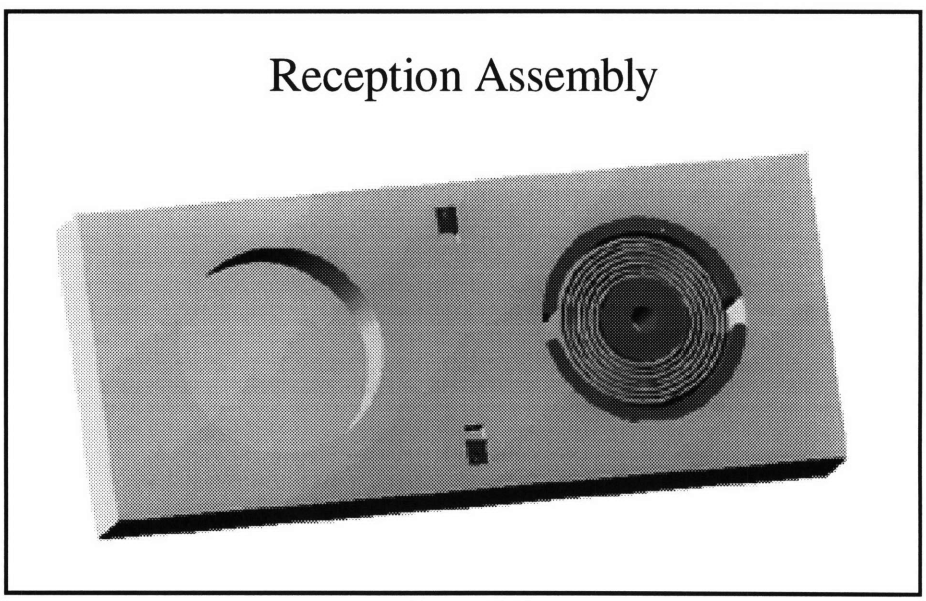


Figure 5-5

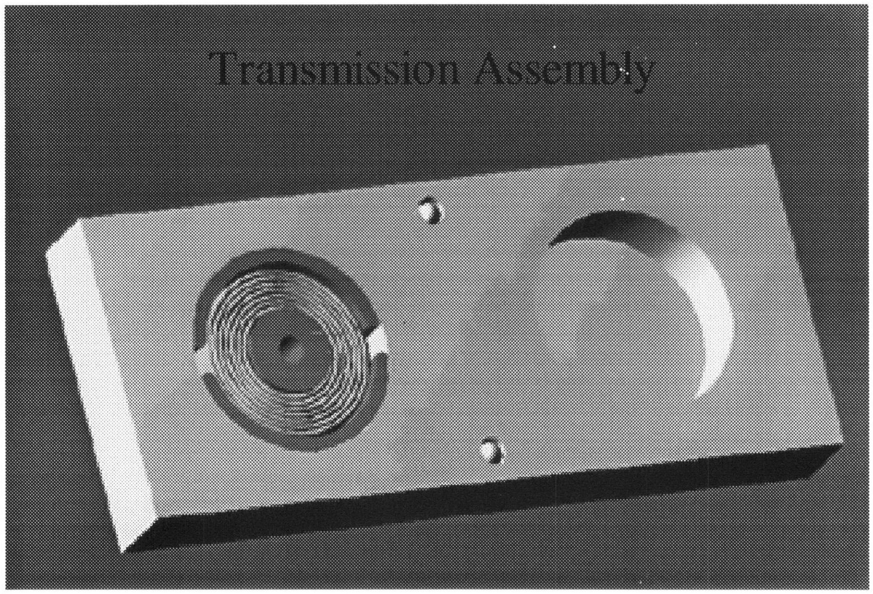


Figure 5-6

The wafer manipulator (fig. 5-7) operates by rotary motion. The motion is simplified by using pneumatic actuators at the operation station to achieve the required lifting action.

Figure 5-7

The stepper motor, stepper driver, and receiver assembly are combined in an aluminum housing to complete the electrical components of the manipulator (fig. 5-8).

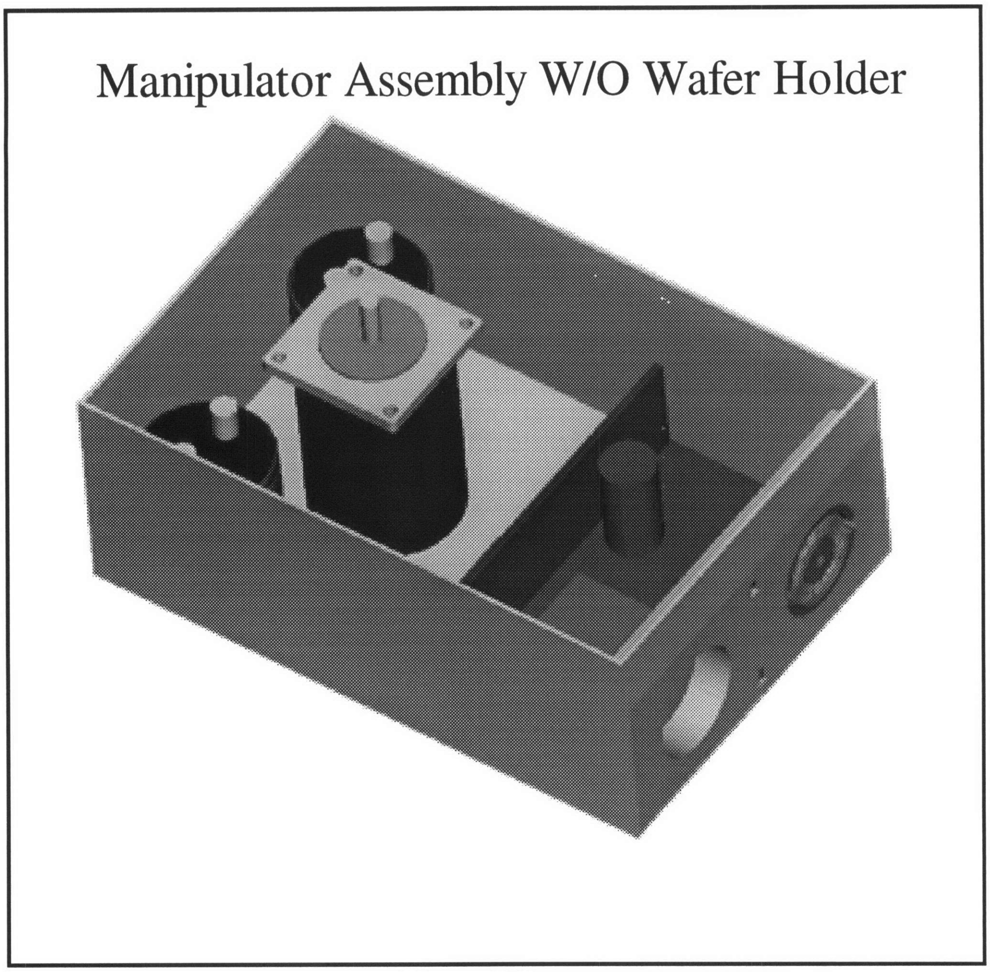


Figure 5-8

The completed manipulator (fig. 5-9) adds the wafer manipulator to the electrical components. The manipulator is designed to hold two wafers simultaneously so that a one wafer may be picked up and another dropped at a station in one operation.

Figure 5-9

In the complete prototype (fig. 5-10) the manipulator assembly is mounted on a 6 foot screw drive linear track. There are two operation stations complete with transmission assembly and corresponding pneumatic actuator.

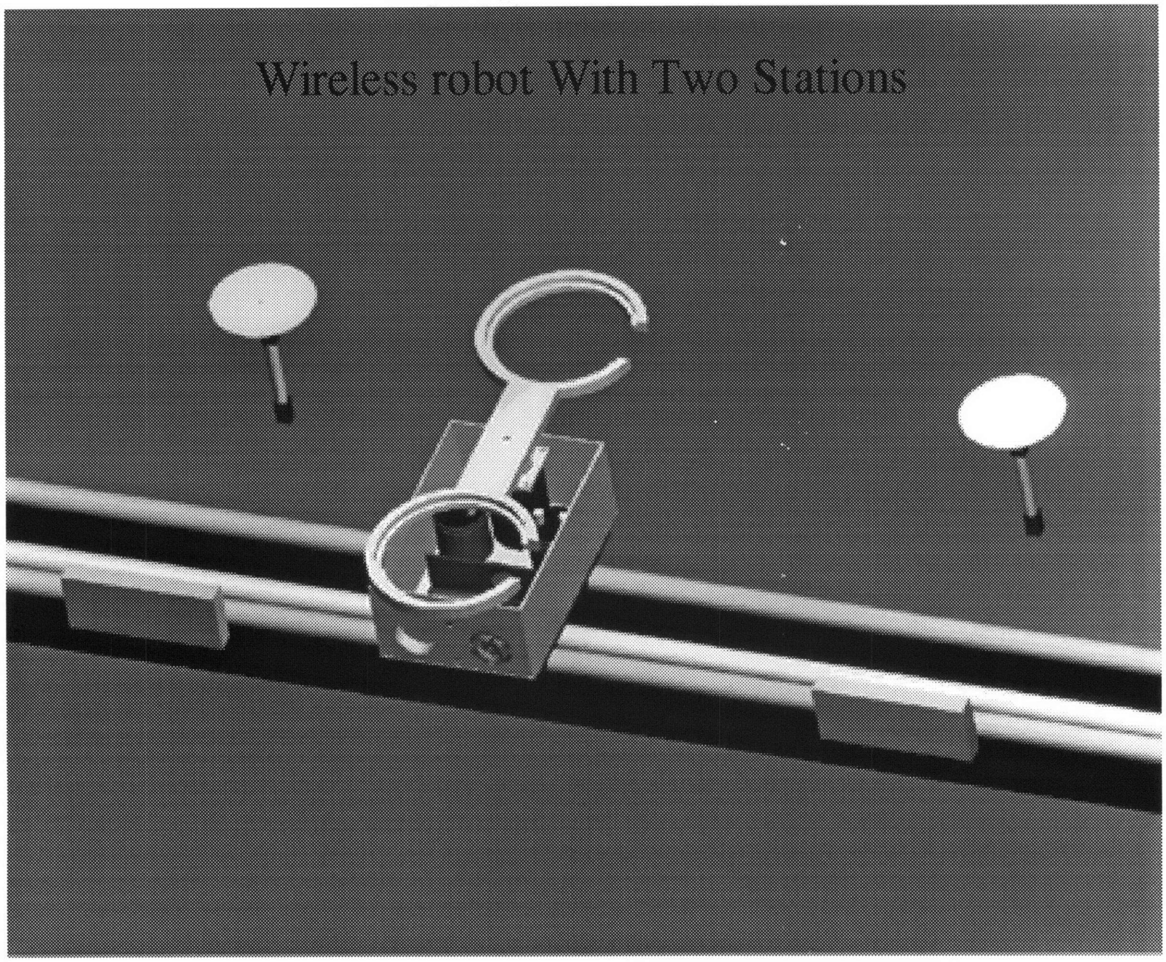


Figure 5-10

Chapter 6

Programming

In any computerized motion control application, some type of programming is required to instruct the computer on which operations to complete. For this project programming was done using the Flex Motion board interface program. This program allows users to send individual commands to the motion controller or create macros which contain the desired commands. This can be manually stepped with the push of a button. The interface utility also allows users to create programs.

Programs are similar to macros in the sense that they contain the desired commands. However, programs differ in that they are run through completely and not stepped. When a program is created, it is stored on the Flex Motion board rather than the host computer. This allows the controller to perform complex operations without performing complex operations on the main CPU. Once a program has been created and stored on the control board, it may be run by simply sending the run command with the corresponding program number.

These programs operate the axes 2 and 6, which are the primary and wireless axes respectively. These two also correspond to the servo and stepper axes, respectively. This setup is used because an original test setup was established on axes 1 and 5, and stepper axes are possible only on axes 5 and 6.

6.1 Initial Control

Initially, operations were carried out by manually stepping through macros containing the desired steps. This method was used to test each type of command needed in the operation of the wireless robot. The end functions required in operation were movement on axis 2 and 5, switching of pneumatic actuators and switching of coil power supply. These operations were completed using the following commands:

load_target_pos	Sets the desired position of the particular axis
start	Starts motion on the selected axes sending them to their desired position
set_port_momo	Changes the voltage of the selected pin in the digital output from the control board to either hi (5 Volts) or low (0 Volts).

After each operation was tested and proved, a macro containing the complete operation of the wireless robot was created. This manual operation macro is OPREATIONS1. This program stepped trough the entire operation process of the wireless robot.

6.2 Program Control

After the successful operation of OPERATIONS1 another macro was then created to operate the robot in program mode. This macro is OPPROG1_2. The macro is essentially the same as OPEARTIONS 1 with the addition of the following commands:

wait	Instructs the computer to wait until a desired condition is met before proceeding to the next command in the program. In these programs the wait condition is the completed motion on a desired axis
load_prog_delay	Waits for a set amount of time before executing the next command in the program.

These commands were added to enable the program proper flow properly and smoothly. The wait commands tell the program to wait for motion to complete on axes 2 and 6. The load_prog_delay was used to give time for the pneumatic actuators to complete their motion. Without these commands the entire program would run in the time that it takes to send all commands, about one or two seconds.

Programming the manipulator to operate properly also involves solving the problem of predicting the position of axis 6, the wireless axis. Since the axis is open loop with no position feedback there is no way to know the position of the manipulator. Because of this, the manipulator must be manually reset at power up. While there is power in the manipulator, it will hold its position and move as instructed. However, during transition from one station to another, the power is interrupted and when it is re-engaged, the manipulator jumps from it's desired position. Repeated trials in positioning revealed that the jump is consistent and predictable. With this information, the operation programs were created with compensation for the step.

Chapter 7

Conclusions and Future Work

This thesis is another step in the development of new manufacturing processes. These developments work towards the goal of creating better methods of manufacturing. This final chapter summarizes this project and offers possible improvements and new applications for future work.

7.1 Achievements of Thesis Work

This prototype was successful in proving the feasibility of wireless robots. In its operation, the wireless manipulator was moved to an operation station and proceeded to unload and load wafers for processing. The robot achieved these tasks through the use of inductive coupling and infra-red transfer. The mobile robot simply contained one pot core and coil, two infra-red logic detectors, a stepper driver, stepper motor, and wafer holder. Although this prototype did not possess any of the extra features that a production unit may possess, it is successful in accomplishing its tasks and proving the feasibility of a wireless robot for semiconductor manufacturing equipment.

7.2 Possible Improvements

Possible improvements for this prototype include the use of another transmission channel to enable and disable the stepper motor. The motor could be disabled while it is between operation stations. Disabling the motor will dramatically reduces the power requirements of the driver. It may also allow the capacitors to hold sufficient charge to maintain the driver logic circuitry during a transition. The maintenance of the logic circuitry may eliminate the jump that occurs when the driver is recharged by the next coil.

The addition of even another channel could be used to reset the position of the manipulator. A limit switch could be used as a home switch for the rotation of the of the wafer holder. A homing program could then be used to find the home position of the manipulator. This would eliminate the need of the manual resetting operation which sets the manipulator to a position known by the computer.

Other possible improvements for this prototype include:

- Install a brake to stop motion during transition
- Enable gearing to resist undesired motion and give more accurate positioning
- Supplement battery to maintain memory in more complicated electronics
- Use a 20kHz power supply

This project was successful in demonstrating the technology of wireless manipulators. The power supply designed for this system was sufficient in delivering the required power to the end effector. However, for future projects, it is recommended that the development of the power transmission system be designed by persons skilled in power electronics.

7.3 Future Applications

The technology demonstrated in project is not limited to semiconductor manufacturing. This technology has the possibility to revolutionize the manufacturing industry.

With the use of wireless robots, manufacturing sites may be able to have an automated delivery system to restock assembly sites. The deliveries would be carried out by robots made small through the lack of need for large batteries for operation. Systems similar to this idea are already in existence. However, in this case the robotic manipulators could be mounted on the mobile robot rather than at each station. This modification would minimize the bulkiness of the complete operation.

The concept of the wireless robot is a technology which enables robotic manipulators to be used without the hindrance of a cumbersome wire tether. The possible uses for this technology apply to almost any robotic manipulator system and other applications yet to be discovered.

Appendix A

Specification Sheets

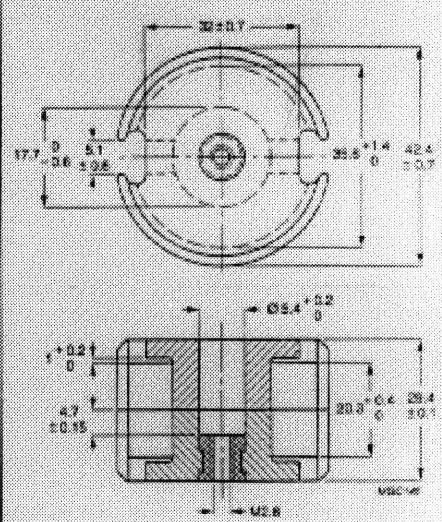
Pot Core Specification Sheet 1/4

P cores and accessories — P42/29

CORE SETS

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.259	mm^{-1}
V_e	effective volume	18200	mm^3
l_e	effective length	68.6	mm
A_e	effective area	265	mm^2
A_{min}	minimum area	214	mm^2
m	mass of set	≈104	g



Dimensions in mm.

Fig.1 P42/29 core set.

Core sets for filter applications

GRADE	A_L (1) (nH)	μ_e	AIR GAP (μm)	TYPE NUMBER (WITH NUT)	TYPE NUMBER (WITHOUT NUT)
3H1	315 ±3%	≈65	≈1100	P42/29-3H1-E315/N	P42/29-3H1-E315
	400 ±3%	≈81	≈830	P42/29-3H1-E400/N	P42/29-3H1-E400
	630 ±3%	≈130	≈450	P42/29-3H1-A630/N	P42/29-3H1-A630
	1600 ±5%	≈325	≈150	P42/29-3H1-A1600/N	P42/29-3H1-A1600
	9500 ±25%	≈1930	≈0	–	P42/29-3H1
3B7	315 ±3%	≈65	≈1100	P42/29-3B7-E315/N	P42/29-3B7-E315
	400 ±3%	≈81	≈830	P42/29-3B7-E400/N	P42/29-3B7-E400
	630 ±3%	≈130	≈450	P42/29-3B7-E630/N	P42/29-3B7-E630
	1000 ±3%	≈205	≈270	P42/29-3B7-A1000/N	P42/29-3B7-A1000
	1600 ±5%	≈325	≈150	P42/29-3B7-A1600/N	P42/29-3B7-A1600
	10300 ±25%	≈2090	≈0	–	P42/29-3B7

Note

1. Clamping force 550 ±100 N.

Figure A-1

Pot Core Specification Sheet 2/4

P cores and accessories P42/29

Core sets for general purpose transformers and power applications

GRADE	A_L [(1)] (nH)	μ_e	AIR GAP (μm)	TYPE NUMBER
3C81	315 ±3%	≈65	≈1100	P42/29-3C81-E315
	400 ±3%	≈81	≈800	P42/29-3C81-E400
	630 ±3%	≈130	≈500	P42/29-3C81-A630
	1000 ±3%	≈205	≈270	P42/29-3C81-A1000
	1600 ±5%	≈325	≈150	P42/29-3C81-A1600
	11500 ±25%	≈2340	≈0	P42/29-3C81
3C85	315 ±3%	≈65	≈1100	P42/29-3C85-E315
	400 ±3%	≈81	≈800	P42/29-3C85-E400
	630 ±3%	≈130	≈500	P42/29-3C85-A630
	1000 ±3%	≈205	≈270	P42/29-3C85-A1000
	1600 ±5%	≈325	≈150	P42/29-3C85-A1600
	8500 ±25%	≈1750	≈0	P42/29-3C85
3F3	315 ±3%	≈65	≈1100	P42/29-3F3-E315
	400 ±3%	≈81	≈800	P42/29-3F3-E400
	630 ±3%	≈130	≈500	P42/29-3F3-A630
	1000 ±3%	≈205	≈270	P42/29-3F3-A1000
	1600 ±5%	≈325	≈150	P42/29-3F3-A1600
	7700 ±25%	≈1600	≈0	P42/29-3F3

Note

1. Clamping force 550 ±100 N.

Properties of core sets under power conditions

GRADE	B (mT) at	CORE LOSS (W) at		
	H = 250 A/m; f = 25 kHz; T = 100 °C	f = 25 kHz; $\hat{B}$ = 200 mT; T = 100 °C	f = 100 kHz; $\hat{B}$ = 100 mT; T = 100 °C	f = 400 kHz; $\hat{B}$ = 50 mT; T = 100 °C
3C81	≥315	≤3.7	≤	−
3C85	≥315	≤2.9	≤3.4	−
3F3	≥315	−	≤2.0	≤3.5

Figure A-2

Pot Core Specification Sheet 3/4

Material grade specification 3C81

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤10 kHz; 0.1 mT	2700 ±20%	
μ_a	100 °C; 25 kHz; 200 mT	5500 ±20%	
B	25 °C; 10 kHz; 250 A/m	≈420	mT
	25 °C; 10 kHz; 250 A/m	≈330	
P_V	100 °C; 25 kHz; 200 mT	≤185	kW/m³
ρ	DC; 25 °C	≈1	Ωm
T_C		≥210	°C
density		≈4800	kg/m³

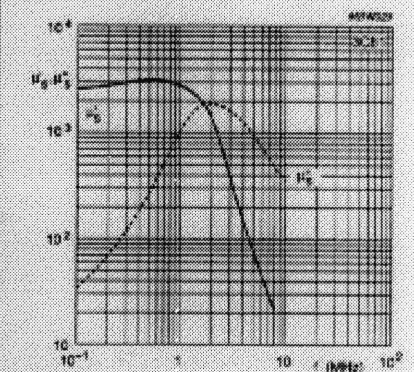


Fig.1 Complex permeability as a function of frequency.

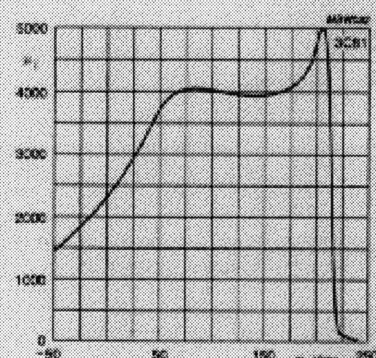


Fig.2 Initial permeability as a function of temperature.

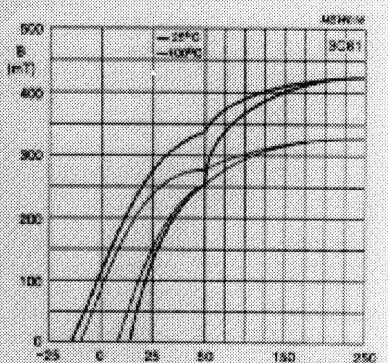


Fig.3 Typical B-H loops.

Figure A-3

Pot Core Specification Sheet 4/4

Philips Components

Material grade specification 3C81

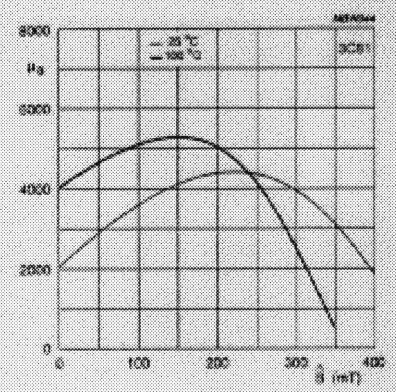


Fig.4 Amplitude permeability as function of peak flux density.

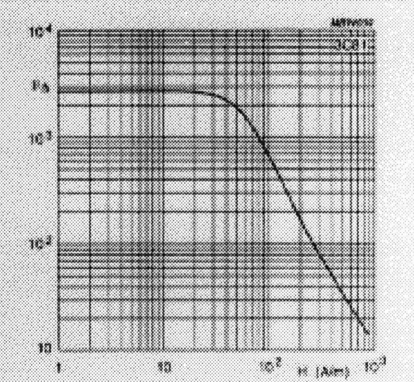


Fig.5 Incremental permeability as a function of magnetic field strenght.

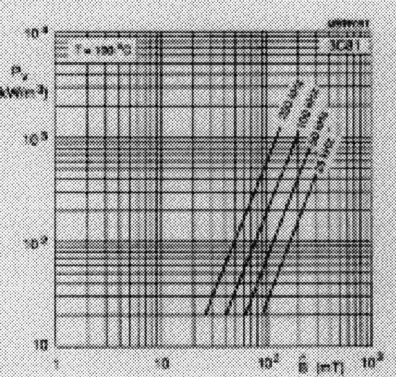


Fig.6 Specific power loss as a function of peak flux density with frequency as aparameter

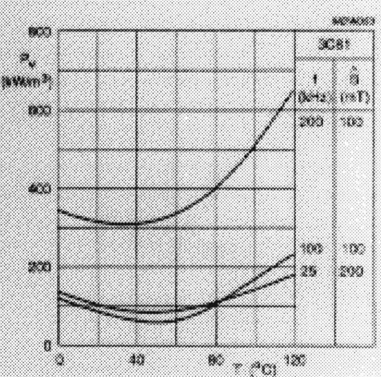


Fig.7 Specific power loss for several frequency/flux density combinations as a function of temperature

1995 Aug 25 97

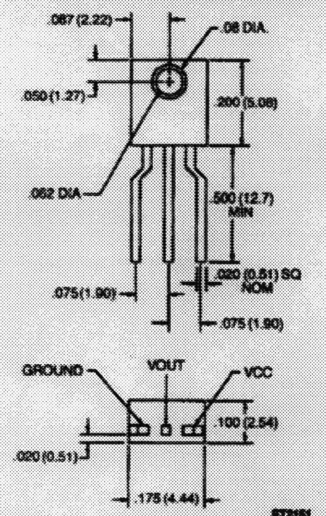
Figure A-4

Logic Detector Specification Sheet 1/4

OPTELECTRONICS

OPTOLOGIC™

QSE156/157/158/159



NOTES:
1. DIMENSIONS ARE IN INCHES (mm).
2. TOLERANCE IS ±.010 (.25) UNLESS OTHERWISE SPECIFIED.

The QSE15X family are OPTOLOGIC™ ICs which feature a Schmitt trigger at output which provides hysteresis for noise immunity and pulse shaping. The basic building block of this IC consists of a photodiode, a linear amplifier, voltage regulator, Schmitt trigger and four output options. The TTL/LSTTL compatible output can drive up to ten TTL loads over supply currents from 4.5 to 16.0 volts. The dark red epoxy packaging system is designed to optimize the mechanical resolution, coupling efficiency, cost, and reliability.

- High noise immunity.
- Direct TTL/LSTTL interface.
- Steel lead frames for improved solder mounting.
- Reception angle of ±25°.

Figure A-5

Logic Detector Specification Sheet 2/4

QT OPTOELECTRONICS

OPTOLOGIC™

ABSOLUTE MAXIMUM RATINGS (T_A = 25°C Unless Otherwise Specified)

Supply Voltage, V_{CC}	18 volts
Storage Temperature	−40°C + 100°C
Operating Temperature	−40°C to + 85°C
Soldering:	
Lead Temperature (Iron)	240°C for 5 sec. [2,3,4,5]
Lead Temperature (Flow)	260°C for 10 sec. [2,3,6]
Power Dissipation	100 mW[1]
Duration of Output short to V_{CC}	1.00 sec.
Voltage at Output	35 volts
Sinking Current	50 mA
Sourcing Current (QSE156, QSE157)	10 mA
Irradiance	3.0 mW/cm²

ELECTRICAL CHARACTERISTICS (T_A = −40°C to + 85°C) (V_{CC} = 4.5 to 16 volts)

PARAMETER	SYMBOL	MIN.	TYP.	MAX.	UNITS	TEST CONDITIONS
Operating Supply Voltage	V_{CC}	4.5		16.0	V	
Positive Going Threshold Irradiance[8]	Ee (+)	0.025		0.250	mW/cm²	T_A = 25°C
Hysteresis Ratio	Ee(+)/Ee(−)	1.10		2.00		
Supply Current	I_{CC}	—		12.0	mA	Ee = 0 or .3 mW/cm² [9]
Peak to peak ripple which will cause false triggering		—		2.00	V	f = DC to 50 MHZ
QSE156 (BUFFER TOTEM POLE)						
High Level Output Voltage	V_{OH}	V_{CC}−2.1		—	V	Ee = .3 mW/cm², I_{OH} = −1.0 mA[9]
Low Level Output Voltage	V_{OL}	—		0.40	V	Ee = 0, I_{OL} = 16 mA
QSE157 (INVERTER TOTEM POLE)						
High Level Output Voltage	V_OH	V_{CC}−2.1		—	V	Ee = 0, I_{OH} = −1.0 mA
Low Level Output Voltage	V_{OL}	—		0.40	V	Ee = .3 mW/cm², I_{OL} = 16 mA[9]
QSE158 (BUFFER OPEN COLLECTOR)						
High Level Output Current	I_{OH}	—		100	µA	Ee = .3 mW/cm², V_{OH} = 30 V[9]
Low Level Output Voltage	V_{OL}	—		0.40	V	Ee = 0, I_{OL} = 16 mA
QSE159 (INVERTER OPEN COLLECTOR)						
High Level Output Current	I_{OH}	—		100	µA	Ee = 0, V_{OH} = 30 V
Low Level Output Voltage	V_{OL}	—		0.40	V	Ee = .3 mW/cm², I_{OL} = 16 mA [9]

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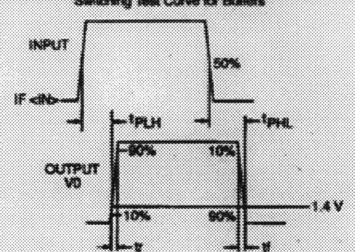
Figure A-6

Logic Detector Specification Sheet 3/4

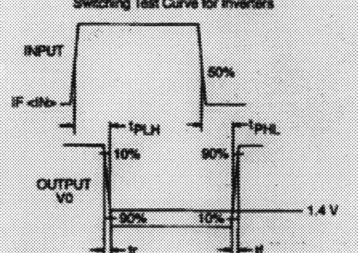
QT OPTOELECTRONICS | **OPTOLOGIC™**

PARAMETER	SYMBOL	MIN.	TYP.	MAX.	UNITS	TEST CONDITIONS
QSE156, QSE157						
Output rise, fall times	tr, tf	—		70	nS	Ee=0 or .3 mW/cm², f=10K Hz DC=50%, R_L=10 TTL loads[6]
Propagation delay	tphl, tplh		6.0		µS	
QSE158, QSE159						
Output rise, fall times	tr, tf	—		100	nS	Ee=0 or .3 mW/cm², f=10K Hz DC=50%, R_L=300Ω[6]
Propagation delay	tphl, tplh		6.0		µS	

Switching Test Curve for Buffers



Switching Test Curve for Inverters



1. *Derate power dissipation linearly 4.00 mW/°C above 25°C.*
2. *RMA flux is recommended.*
3. *Methanol or isopropyl alcohols are recommended as cleaning agents.*
4. *Soldering iron tip 1/16" (1.6 mm) minimum from housing.*
5. *As long as leads are not under any stress or spring tension.*
6. *Irradiance measurements are made with an AlGaAs LED emitting light at a peak wavelength of 880 nm.*

3-47

Figure A-7

Logic Detector Specification Sheet 4/4

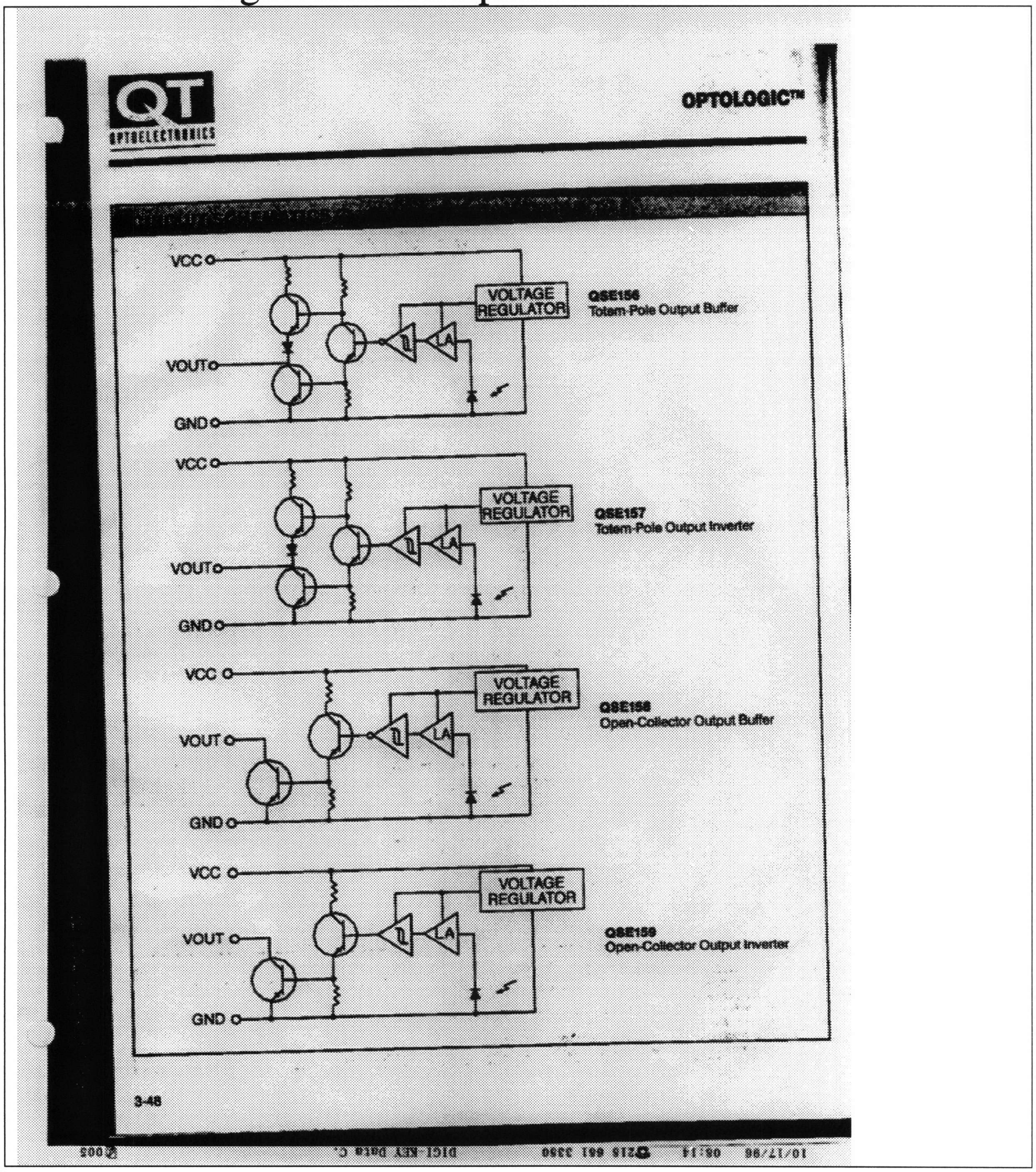
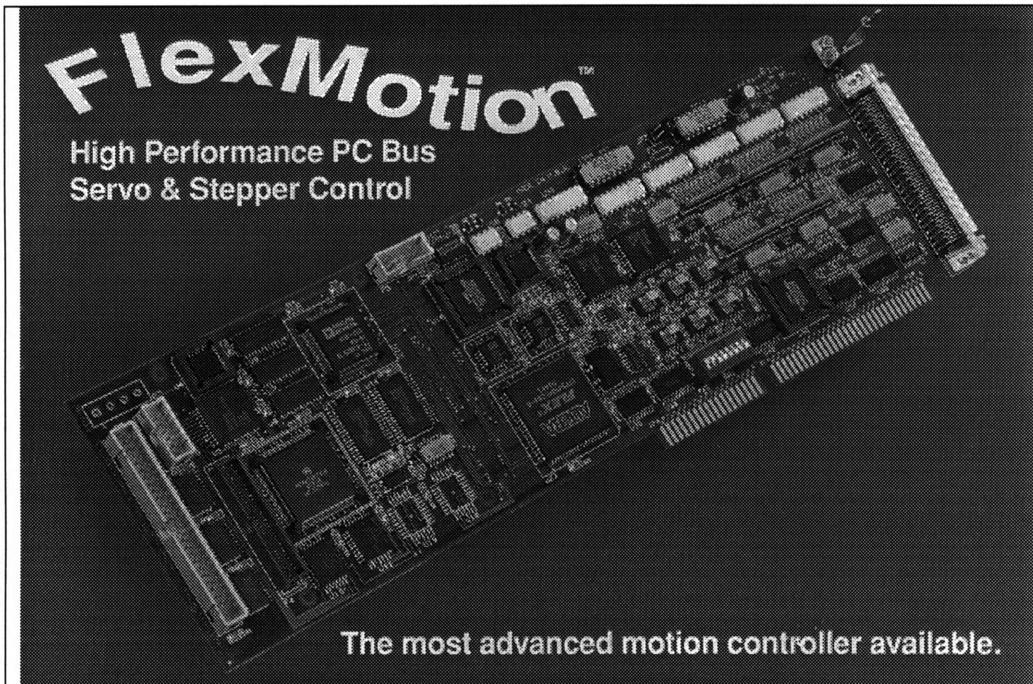


Figure A-8

Flex Motion Controller Specification Sheet 1/6



Features

- Up to 10 Servo Axes in a single PC ISA bus slot
- Motorola 68331 32 Bit Real-Time Multi-Tasking CPU
- Analog Devices ADSP2111 Digital Signal Processor
- 16 Mhz Encoder Feedback with Differential or Single Ended Inputs
- 3-D Linear, Circular, Helical & Spherical Interpolation, Point to Point & Jogging Control
- Electronic Gearing, Camming & Master / Slave
- PID & PIV-Feed Forward Servo Loop DSP Filters
- S-Curve Acceleration & Deceleration with fully programmable jerk control parameters.
- Cubic Spline Trajectory Calculation & Control
- Continuous Contour & User Profile Execution
- Blending Control for Multi-Segment Smoothing
- 16 Bit D/A Servo Command Output Resolution
- 60 µSec per axis Servo Update Rate
- Surface Mount Technology & Reliability
- Optoisolated Limits, Home, Enable, Breakpoint & Position Capture I/O per axis
- 24 Bits of Opto 22 compatible non-dedicated digital I/O, 8 Outputs, 16 Bit I/O, Byte Selectable
- 8 Analog A/D Inputs for joystick, sensors, transducers or servo feedback
- Flash Memory Architecture with Program & Parameter Storage during power down
- Full Command Set with error checking, status & FIFO data packet communications
- Double buffered 32 Bit Position, Velocity & Acceleration Values with On-The-Fly updating
- Expansion connector for additional servo or stepper axes, I/O or OEM/User Customization
- High Speed Position Capture for Registration
- pcRunner Windows Software, High-Level C & Basic Drivers and DLLs all included free on disk
- Also available for PCI bus

nuLogic®

Infinite Trajectory Control Processing™

Figure A-9

Specifications

Servo Loop Performance

PID Update Rate Per Axis:	62 µSec (Six to Ten Axis Configuration)
6 Axis PID Update Rate:	375 µSec Total
Position Accuracy:	
Encoder Feedback:	± 1 Quadrature Count
Analog Feedback:	± 1 LSB (0.0049 V @ ±10 V Range)
Long Term Velocity Accuracy:	Oscillator Based, .002% (+0.00004%/°C)
Double Buffered Servo Axis Parameter Ranges:	
Position Range:	2,147,483,647 counts/move
Velocity Range:	0 to 16,000,000 counts/sec
Accel./Decel.:	512 to 134,217,728 counts/sec^2
Following Error Range:	0 to 32,768 counts
Gear Ratio:	1:32768
DSP Based Servo Filter Modes:	PID, PIV-FF, Notch, S-Curve, Dual Loop
Notch Value:	Filter Q Range, Filter Center Freq. 5 - 500 Hz
S-Curve Value:	Per Axis S-Curve Jerk Value (counts/sec^3)
Feed Forward Values:	Acceleration & Velocity Feed Forward
Kp,Ki & Kd Gain:	0 to 65,535
Integration Sum Limit:	0 to 65,535
Derivative Sample Period Multiplier:	Td: 1 to 255
Servo Command Analog Output:	
Resolution & Range:	16 Bits, ±10 Volts, 0.000305 Volts/LSB
Torque & Velocity Limits:	Independent +V & -V Limits

Stepper Axis Performance

Position Accuracy:	
Open Loop Stepper:	1 Full, Half or Microstep
Encoder Feedback:	± 1 Quadrature Count
Analog Feedback:	± 1 LSB (0.0049 V @ ±10 V Range)
Long Term Velocity Accuracy:	Oscillator Based .002% (+0.00004%/°C)
Double Buffered Stepper Axis Parameter Ranges:	
Position Range:	2,147,483,647 steps/move
Velocity Range:	0 to 1,500,000 steps/sec
Accel./Decel.:	1 to 15,000,000 steps/sec^2
Following Error Range:	0 to 32,768 counts
Gear Ratio:	1:32768
Step Pulse Output:	
Maximum Pulse Rate:	1.5 Mhz(Full,Half & Microstep), 50% Duty
Step Pulse Width:	330 nSec @ 1.5 Mhz, 0.5 Sec @ 1 Hz
Step Output Signals:	Step & Direction or CW/CCW Programmable Output Polarity Open Collector TTL, 60 mA Max.Sink

General Purpose Analog & Digital I/O

Digital I/O:	24 Bits of Non-Dedicated Digital I/O 50 Pin Opto 22 I/O Box Connector Output 1-8, Eight Uncommitted Outputs I/O 1-16, Sixteen Uncommitted I/O Selected in banks of Eight I/O
Analog I/O:	
Analog Inputs:	Eight A/D Input Lines 12 Bit A/D Resolution, 10 µSec Convert. ±10 V Range, Measure to 0.0049 V/LSB Assignable per Axis for Loop Feedback
Analog Outputs:	Direct Servo DAC Control 16 Bit DAC Resolution, ±10 Volt Range
E-Stop Input: ¥	Optocoupled Input, 24 V Maximum Hardware Disable all Motion Outputs Kill Motion Control all Axes

General Purpose Counter & Timer I/O

Counter/Timer I/O:	4 Timer Inputs, 1 Counter/Accumulator 4 Timer Outputs, 2 PWM Outputs TTL Level Inputs & Outputs
Timer Functions:	Timer Capture on Input Signal Programmable Timer Compare Registers Output Transition on Timer Match
Counter Function:	Count Input Pulses & Accumulate Count
PWM Functions:	User Programmable PWM Outputs Prog. 0.5 - 32 kHz, 0 - 100 % Duty Cycle
Clock Source:	Internal or External Timer Clock Sources

Multi-Axis Functionality & Performance

Axis Operation Modes:	Single Axis Point-To-Point Positioning S-Curve Mechanical Jerk Control Feedrate (Velocity) Control Torque Limit Control Coordinated Multi-Axis Motion Linear & Circular Interpolation 2/3 Axis Vector w/ Coordinated N^{th} Axis Blended Multiple Move Sequences Continuous Motion Contouring Electronic Gearing, Camming & Following Multi-Axis Cubic Spline Interpolation
Multi-Axis Performance:	Sync'ed DSP Clock, < 1 PID Period

FlexMotion

Per Axis Outputs

Breakpoint Output: ¥	Programmable Output Polarity OptoCoupled Mapped To Encoder Channels 1,2,3,4
Amplifier Enable/Inhibit:	User Programmable Output Polarity Open Collector 100 mA Maximum Sink Current Mapped To Axis x,y,z,θ,ψ,φ

Per Axis Inputs

High Speed Position Latch: ¥	User Programmable Input Polarity OptoCoupled Minimum Pulse Width 83 nSec Capture Latency < 100 nSec Accuracy < 1 count, Reset Rate 1.0 kHz Mapped To Encoder Channels 1,2,3,4
Encoder Inputs:	Normal, Dual Loop (Position/Velocity, Fine/Course), Gearing, Master/Slave
Max. Input Frequency:	16 Mhz Encoder Freq. Channels 1,2 1 Mhz Encoder Freq. Channels 3,4 2 Mhz Encoder Freq. Channels 5,6
Encoder Input Options:	Differential: A,A* B,B* Index,Index* Single Ended: A, B, Index Pulse & Direction Feedback Inputs
Encoder Signal Data:	Minimum Index Pulse Width 83 nSec TTL, Line Driver or ±12 Volt Inputs User Selectable Termination Resistors
Forward & Reverse Limits: ¥	User Programmable Input Polarity Optocoupled Stop On Limit & Prevent Motion Modes
Home Switch Input: ¥	User Programmable Input Polarity Optocoupled Stop on Home, Find Home & Find Edge

Power Requirement & General Configuration

Power Input Requirements:	ISA Bus or External Power Connector + 5 Volts, 1.0 A Typ. + 12 Volts, 300 mA Typ. - 12 Volts, 250 mA Typ.
Isolated Voltage Input: ¥	Jumper Select, Internal/External Source External +ISO Voltage & ISO Return Internal +5 Volts & Digital Return for ISO Pluggable Pull-Up DIP Resistors +ISO Voltage 5 V min., 24 V max.

Bus Interface, Expansion & Cabling

Watchdog Timer Function:	Processor based Watchdog Timer Reset Dead-Man S/W Code Monitor for Kill
Communications Interface:	16 Bit ISA Bus Standard, PC/AT Config. On-Board RS-232 Port
Motion & I/O Interconnect:	Industry Std. 100 Pin Dual Ribbon Cable 50 Pin, Opto 22 Compatible Digital I/O 10 Pin RS-232
Expansion Modules:	Servo, Stepper, Encoder, I/O, Sensor 64 Pin Hi-Density, Low-Profile Expansion
Command/Data Configuration:	Variable Packet Based Communication FIFO Command Buffering, Stored Programs Command Id, Axis, Data, Check Sum High Performance Data Handshaking Direct Addressing of Status Send, Read & Status I/O Map Addresses Full DOS & Windows Device Drivers Windows DLL Function Library C & Basic Libraries, Visual Basic Code Advanced LabVIEW VI Libraries
Cable Assembly Included:	100 Pin -> Dual 50 Pin Ribbon Cables w/ Standard Header Connectors 2 Meter Length Standard
¥ Optocoupled Signals:	All Signals with this Marking, ¥ are Optically Isolated. Optocoupled signal line with 2.2 kΩ in series to +ISO Voltage for Inputs and 2.2 KΩ Pullups To +ISO Voltage for Outputs. With ISO Return(Gnd)

Flex Motion Controller Specification Sheet 4/6

FlexMotion Commands

Setup & Configuration

- Force Power Up Reset
- Force Reset Using Watchdog Timeout
- Run On-Board Self Test
- Set ISA Bus Interface
- Set Interrupt Condition Mask
- Set Axis Operation Mode
- Define Vector Space
- Define Axis Resources
- Enable Encoder Channels
- Enable Axis Operation
- Read Return Data Buffer
- Read Error Message Buffer
- Save Current Parameters as Defaults

Motion Trajectory Control

- Set Position Mode
- Set Trajectory Mode
- Set Blending Factor
- Reset Position Counter (zero/value)
- Set Target Position
- Set Velocity
- Set Rotary Count Modulus
- Set Counts Per Revolution
- Set Acceleration
- Set Accel. Jerk Factor (S-Curve)
- Set Deceleration
- Set Decel. Jerk Factor (S-Curve)
- Set Velocity Filter TC/RS Threshold
- Set Following Error Trip Value
- Set Move Complete Criteria
- Set Move Complete Pulse Width
- Load Arc Segment Data
- Load Spline Point Data

Motion Trajectory Status

- Read Per Axis Hardware Status
- Read Run/Stop Status
- Read Motor Off Status
- Read Position Value
- Read Velocity (Instantaneous)
- Read Velocity (Filtered)
- Read Torque/Velocity Value
- Read Step Count Value
- Read Following Error (Instantaneous)
- Read Encoder Value
- Read Captured Position
- Acquire Sample Data

Servo Loop PID & FF Filter Control

- Set Filter Kp Value
- Set Filter Ki Value
- Set Filter Kd Value
- Set Filter Td Value
- Set Filter ILim Value
- Set Notch Filter Value
- Set All PID & FF Values
- Set Accel. Feed Forward Value
- Set Velocity Feed Forward Value

Start/Stop Motion Control

- Start Axis/Axes/Vector
- Blend Axis/Axes/Vector
- Decel. Stop Axis/Axes/Vector
- Halt Stop Axis/Axes/Vector
- Kill Stop Axis/Axes/Vector

Maser/Slave, Gearing & Cam Control

- Set Gearing Master
- Set Gear Ratio
- Set-Up Camming Array
- Begin Cam Gear Array Storage
- Load Camming Point
- Set-Up Spline Array
- Begin Spline Point Array Storage
- Load Spline Point
- End Array Table Storage
- Enable Gearing

General Purpose I/O Control

- Set I/O Port Direction
- Set I/O Port Polarity
- Set I/O Port Output Value
- Read I/O Port Value
- Configure I/O Pin
- Load Timer Compare Value
- Read Timer Capture Value
- Configure Timer I/O Clocks
- Set Timer I/O PWM Output
- Set DAC Output Direct
- Enable A/D Converters
- Read A/D Value

Motion Axis Initialization

- Find Home Input
- Find Index Input
- Read Index Found Status

Stepper Motor Control

- Set Step Output Mode
- Set Steps Per Revolution
- Set Base Velocity Value
- Set Acceleration Factor

Motion I/O Control

- Set Limit Switch Polarity
- Enable Limit Inputs
- Read Limit Input Status
- Set Home Polarity
- Enable Home Inputs
- Read Home Input Status
- Set Software Limit Values
- Enable Software Limits
- Read Software Limit Status
- Set User Status Bit Value
- Set High Speed Position Capture
- Enable Hi Speed Position Capture
- Read High Speed Capture Status
- Set Position Breakpoint Values
- Enable Position Breakpoint
- Set Position B.P. Repeat/Modulus
- Read Position Breakpoint Status
- Set Velocity Breakpoint Value
- Read Velocity Breakpoint Status
- Set Anticipation Time B.P. Value
- Read Anticipation Time B.P. Status
- Set Breakpoint Outputs
- Config. Amp. Enable/Inhibit Outputs
- Set Amp. Enable/Inhibit Outputs

On-Board Programming

- Begin Program Storage
- Set Line Label
- Jump To Label On Condition
- End Program Storage
- Begin Program Execution
- Pause/Resume Program Execution
- Pause Execution Until Condition
- Stop Program Execution
- Add Var#N,Var#N
- Subtract Var#N,Var#N
- Multiply Var#N,Var#N
- Divide Var#N,Var#N
- Move Var#N,Var#N
- Move Constant, Var#N
- Logical AND Var#N,Var#N
- Logical OR Var#N,Var#N
- Logical XOR Var#N,Var#N
- Logical NOT Var#N

FlexMotion™

Figure A-12

Flex Motion Controller Specification Sheet 5/6

Motion & I/O Connector Pinout

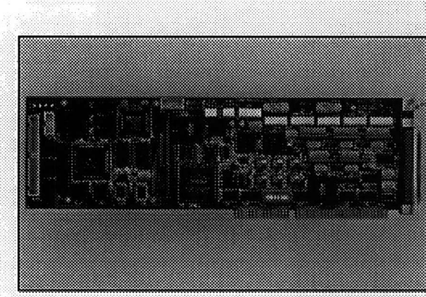
The **FlexMotion** board provides reliable connectors for all of the motion & I/O signals available. The three primary connectors on the board are 100 pin Motion I/O, 50 pin Opto22 compatible digital I/O and High Density Expansion. The High Density Expansion connector provides access to add-on option products including additonal axes of servo and stepper motion control, extended I/O and other custom capabilities.

The 100 pin high density connector includes six axes of motion signals and all of the associated motion specific I/O. The 100 pin ribbon cable assembly splits into two 50 Pin IDC header connectors, one with four axes of motion and the other with two axes. The 50 pin IDC headers connect to UMI breakout modules or nuDrive Amplifer units. An alternate 100 pin ribbon cable assembly maintains all signals to a six axis UMI breakout module for simplified wiring of all motion signals.

The 50 pin Opto22 compatible digital I/O connector is an industry standard interface for use with screw terminal breakout blocks or Opto22 G4 module racks. The Opto22 G4 module racks provide a large assortment of signal conditioning and interface options.

50 pin Opto22 compatible digital I/O

1	I/O Bit #24	GND (Return)	2
3	I/O Bit #23	GND (Return)	4
5	I/O Bit #22	GND (Return)	6
7	I/O Bit #21	GND (Return)	8
9	I/O Bit #20	GND (Return)	10
11	I/O Bit #19	GND (Return)	12
13	I/O Bit #18	GND (Return)	14
15	I/O Bit #17	GND (Return)	16
17	I/O Bit #16	GND (Return)	18
19	I/O Bit #15	GND (Return)	20
21	I/O Bit #14	GND (Return)	22
23	I/O Bit #13	GND (Return)	24
25	I/O Bit #12	GND (Return)	26
27	I/O Bit #11	GND (Return)	28
29	I/O Bit #10	GND (Return)	30
31	I/O Bit #9	GND (Return)	32
33	I/O Bit #8	GND (Return)	34
35	I/O Bit #7	GND (Return)	36
37	I/O Bit #6	GND (Return)	38
39	I/O Bit #5	GND (Return)	40
41	I/O Bit #4	GND (Return)	42
43	I/O Bit #3	GND (Return)	44
45	I/O Bit #2	GND (Return)	46
47	I/O Bit #1	GND (Return)	48
49	+5V	GND (Return)	50



100 Pin Motion Interface Connector Pinout

1	+5V (Isolated)	X:Forward Limit	2
3	X:Home Input	X:Reverse Limit	4
5	X:High Speed Input	X:Breakpoint Output	6
7	Y:Home Input	Y:Forward Limit	8
9	Y:High Speed Input	Y:Reverse Limit	10
11	ψ:Forward Limit	Y:Breakpoint Output	12
13	ψ:Home Input	ψ:Reverse Limit	14
15	α:Forward Limit	α:Reverse Limit	16
17	α:Home Input	E-Stop	18
19	GND (Isolated)	Enc1:Phase A*	20
21	Enc1:Phase A	Enc1:Phase B*	22
23	Enc1:Phase B	Enc1:Index*	24
25	Enc1:Index	Enc2:Phase A*	26
27	Enc2:Phase A	Enc2:Phase B*	28
29	Enc2:Phase B	Enc2:Index*	30
31	Enc2:Index	GND (Return)	32
33	Enc5:Phase A	Enc5:Phase A*	34
35	Enc5:Phase B	Enc5:Phase B*	36
37	Enc5:Index	Enc5:Index*	38
39	Enc6:Phase A	Enc6:Phase A*	40
41	Enc6:Phase B	Enc6:Phase B*	42
43	Enc6:Index	Enc6:Index*	44
45	GND (Return)	Analog GND	46
47	X:Command Vout	Y:Command Vout	48
49	ψ:Command Vout	α:Command Vout	50
51	+5V (Isolated)	Z:Forward Limit	52
53	Z:Home Input	Z:Reverse Limit	54
55	Z:High Speed Input	Z:Breakpoint Output	56
57	θ:Home Input	θ:Forward Limit	58
59	θ:High Speed Input	θ:Reverse Limit	60
61	GND (Isolated)	θ:Breakpoint Output	62
63	A/D Analog Ref.	A/D Input-1	64
65	A/D Input-2	A/D Input-3	66
67	A/D Input-4	A/D Input-5	68
69	A/D Input-6	A/D Input-7	70
71	A/D Input-8	A/D Return	72
73	Z:Command Vout	Analog Ground	74
75	θ:Command Vout	Enc3:Phase A*	76
77	Enc3:Phase A	Enc3:Phase B*	78
79	Enc3:Phase B	Enc3:Index*	80
81	Enc3:Index	Enc4:Phase A*	82
83	Enc4:Phase A	Enc4:Phase B*	84
85	Enc4:Phase B	Enc4:Index*	86
87	Enc4:Index	GND (Return)	88
89	ψ:Step/CW Output	ψ:Dir/CCW Output	90
91	ψ:Amplifier Inhibit	+5 Volts	92
93	α:Step/CW Output	α:Dir/CW Output	94
95	α:Amplifier Inhibit	GND (Return)	96
97	X:Amplifier Inhibit	Y:Amplifier Inhibit	98
99	Z:Amplifier Inhibit	θ:Amplifier Inhibit	100

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Figure A-13

Flex Motion Controller Specification Sheet 6/6

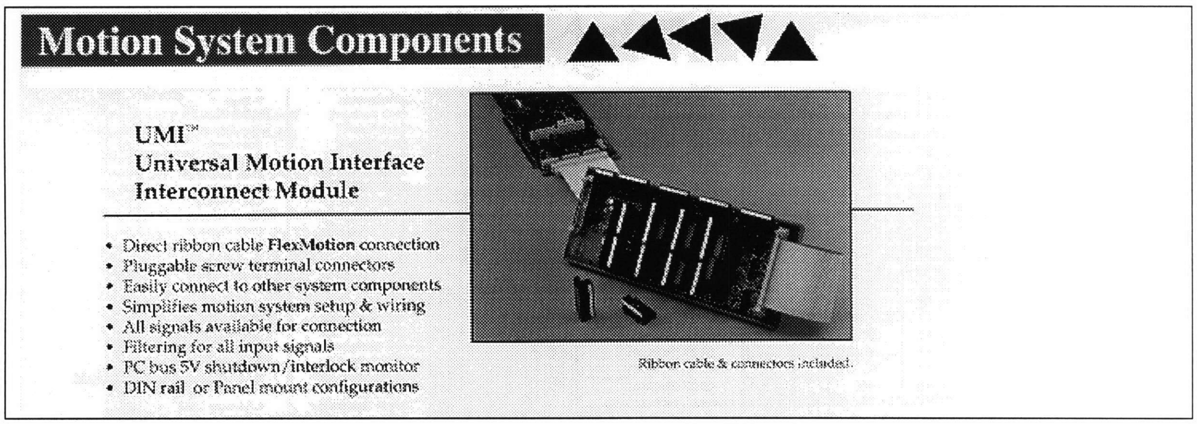


Figure A-14

Stepper Driver Specification Sheet 1/4

TM3000 STEP MOTOR DRIVER

- Requires 12-28VAC or 10-40VDC
- 0.3 - 5.0 Amperes/phase Operating Current
- 0.15 - 2.5 Amperes/phase Standstill Motor Current
- Open Frame Circuit Board Mounts on Snaptrack
- Higher Torque/Speed Output
- Improved Start-Stop Speeds
- Reduced Power Requirements
- Positive or Negative Going Clock Input
- Full and Half-Step Operation
- Motor Turn-Off Provisions
- TTL-CMOS Compatible Inputs
- No RFI or EMI Problems

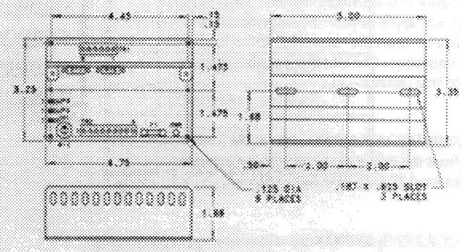


FIGURE 1: DIMENSIONS OF TM3000

GENERAL DESCRIPTION

The ANAHEIM AUTOMATION TM3000 is a low cost, bilevel step motor driver to be used with 4-phase step motors. The TM3000 comes mounted on easy to use snaptrack, available in lengths up to 6 feet.

BILEVEL DRIVE

The basic function of a step motor driver is to control the motor winding currents. Motor performance is determined by how fast the driver can increase and decrease the winding currents. A rapid rise in winding current is achieved by applying a high voltage directly to a motor winding. This rapid rise of current is also referred to as the "kick" or operating current. When a desired current level is reached, the high voltage is turned off and a low voltage is applied to maintain a suitable holding current level. When a motor winding is turned off, a rapid decrease in winding current is achieved by routing the energy in the collapsing field back to the power supply through a high voltage path. The high voltage supply furnishes the energy necessary to maintain motor output torque at high step rates thus providing high mechanical power output. The low voltage supply provides much of the current needed at low step rates and all of the holding current.

Bilevel drivers do not use high frequency switching techniques as chopper drivers do. Consequently, they do not create the EMI, RFI, and motor heating problems that are associated with chopper drivers.

EXCITATION MODE SELECTION

Users have a choice of dual-phase, Full-step operation or Half-step operation. Dual-phase, Full-step operation occurs by energizing two phases at a time, rotating a typical motor 1.8 degrees per step. Half-step operation occurs by alternately energizing one, and then two, phases at a time, rotating the motor 0.9 degrees per step. Full-step operation is only for applications that specifically require that mode, such as when retrofitting existing full-step systems.

MOTOR ON/OFF

The Motor On/Off feature allows de-energizing a motor without disturbing the positioning logic. After re-energizing the motor, a routine can continue. This reduces motor heating and conserves power, especially in applications where motors are stopped for long periods.

CLOCK, CCW AND DIRECTION

Pulses applied to the CLOCK input cause the motor to step in the clockwise direction if the DIRECTION Control input is a logic "1" (or No connection), and in the counterclockwise direction if the DIRECTION Control input is a logic "0". Pulses applied to the CCW input cause the motor to step in the counterclockwise direction. Positive or negative going pulses may be used (see Table 2).

PHASE INPUTS

The TM3000 has the ability to accept phase inputs to control each of the 4 motor phases. For example, a microcontroller can be used to control the motor phases. Terminals 1,2, 3, and 4 of TB2 are used as the inputs for Phase 1, Phase 2, Phase 3, and Phase 4 respectively. Either Positive True Phase Inputs or Negative True Phase

MODEL	DESCRIPTION
TM3000	DRIVER w/ TRACK
TM3000-T1	DRIVER w/ TRACK and 100VA TRANSFORMER
TM3000-T2	DRIVER w/ TRACK and 200VA TRANSFORMER
TM3000-1	DRIVER w/ MOUNTING PLATE
TM3000-1-T1	DRIVER w/ MOUNTING PLATE and 100VA TRANSFORMER
TM3000-1-T2	DRIVER w/ MOUNTING PLATE and 200VA TRANSFORMER

TABLE 1: ORDERING INFORMATION

A N A H E I M A U T O M A T I O N

910 E. Orangefair Lane, Anaheim, CA 92801
(714) 992-6990 • FAX: (714) 992-0471

Figure A-15

Stepper Driver Specification Sheet 2/4

Inputs may be used (see Table 2 and Figure 1).

MOTOR CONNECTIONS
Figure 2 is a hookup diagram for typical driver applications. Wiring connected to inputs must be separated from motor connections and all other possible sources of interference.

IMPORTANT NOTE: When the wiring from the driver to the step motor extends beyond 25 feet, consult the factory.

CURRENT SETTING
The potentiometer on the driver is used to set the motor current. See Table 3. The pot should be set according to the motor's rated current. This will produce a standstill current of 70% of the rated current and a kick current of 1.4x the rated motor current.
Example: For a motor rated at 2.0 amps per phase, the POT should be set between 50 and 60.

POWER REQUIREMENTS
The TM3000 can be powered up by an AC or DC voltage (see specifications). For AC operation, the driver may be purchased with a transformer (see Table 1). A single transformer may be used to power up several drivers.

HEATING CONSIDERATIONS
The temperature of the heatsink should never be allowed to rise above 60 degrees Celsius. If necessary, air should be blown across the heatsink to maintain suitable temperatures.

TM3000-1
The TM3000 is available with a mounting plate for those who do not use "track" systems. The model number for this driver with the mounting plate is the TM3000-1. Dimensions are shown in figure 3.

OPERATING MODE JUMPER SELECTION	JP1	JP2	JP3
POSITIVE GOING CLOCK INPUT	1 TO 2	2 TO 3	1 TO 2
NEGATIVE GOING CLOCK INPUT	1 TO 2	1 TO 2	1 TO 2
POSITIVE TRUE PHASE INPUTS	2 TO 3	2 TO 3	2 TO 3
NEGATIVE TRUE PHASE INPUTS	1 TO 2	1 TO 2	2 TO 3
STANDARD PRODUCT (READY TO SHIP)	1 TO 2	1 TO 2	1 TO 2

TABLE 2: JUMPER SELECTIONS.

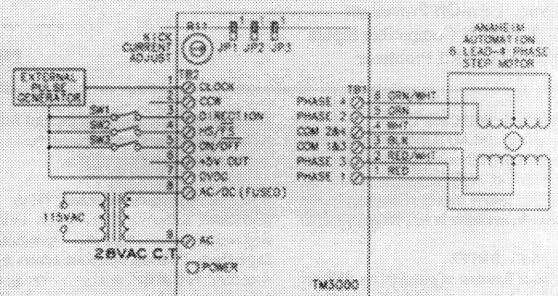


FIGURE 2: HOOKUP DIAGRAM.

POT	RATED MOTOR CURRENT	ACTUAL STANDSTILL CURRENT	KICK CURRENT
0	0.21	0.15	0.3
10	0.55	0.385	0.77
20	0.89	0.62	1.24
30	1.22	0.855	1.71
40	1.56	1.09	2.18
50	1.89	1.33	2.66
60	2.23	1.56	3.12
70	2.56	1.8	3.6
80	2.9	2.03	4.06
90	3.24	2.27	4.54
100	3.57	2.5	5

TABLE 3: POTENTIOMETER/CURRENT SETTING.

Figure A-16

Stepper Driver Specification Sheet 3/4

SPECIFICATIONS

CONTROL INPUTS: (Terminals 1-5, TB2)
TTL-CMOS Compatible
Logic "0"=0 to 0.8 Vdc
Logic "1"=3.5 to 5.0 Vdc
Terminals 1-4 are pulled up or down (depending on Jumpers) through 10k ohm resistors. Terminal 5 is pulled up through a 10k ohm resistor.

CLOCK, CCW:
(Terminals 1 and 2 of TB2)
15 microseconds minimum pulse width, positive or negative going (see Table 2).

DIRECTION CONTROL:
(Terminal 3 of TB2)
Logic "1"(open)-clockwise
Logic "0"-counterclockwise

MODE SELECT:
(Terminal 4 of TB2)
Logic "1"(open)-half-step
Logic "0"-dual full-step

MOTOR ON/OFF:
(Terminal 5 of TB2)
Logic "1"(open)-motor energized
Logic "0"-motor de-energized

OUTPUT CURRENT RATING: (TB1)
5.0 Amperes per phase maximum operating current; 2.5 Amperes per phase maximum standstill current, over the operating voltage and temperature range. Motor phase ratings of 0.5 Amperes minimum are required to meet the minimum kick level.

+5VDC OUTPUT: (Terminal 6, TB2)
100mA maximum

POWER REQUIREMENTS: (Terminals 8 & 9, TB2)
12 Vac(min)-28 Vac(max)
10 Vdc(min)-40 Vdc(max)
Use Terminal 8 for DC input with Terminal 7 as the 0Vdc reference.

OPERATING TEMPERATURE:
Heatsink - 0° to 60°C

FUSE: 5 Amp Fast Blow, 5mm

PIN	DESCRIPTION
1	PHASE 1 (RED)
2	PHASE 3 (RED/WHT)
3	COM PHASE 1 & 3 (BLK)
4	COM PHASE 2 & 4 (WHT)
5	PHASE 2 (GRN)
6	PHASE 4 (GRN/WHT)

TABLE 4: PIN ASSIGNMENTS FOR TB1

PIN	DESCRIPTION
1	CLOCK INPUT (PHASE 1)
2	CCW INPUT (PHASE 2)
3	DIRECTION CONTROL (PHASE 3)
4	HALFSTEP/FULLSTEP (PHASE 4)
5	MOTOR ON/OFF
6	+5VDC OUTPUT
7	0VDC
8	AC/DC POWER INPUT (FUSED)
9	AC POWER INPUT

TABLE 5: PIN ASSIGNMENTS FOR TB2

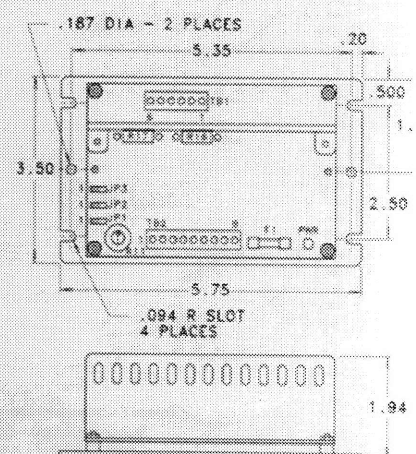


FIGURE 3: DIMENSIONS OF TM3000-1

Figure A-17

Stepper Driver Specification Sheet 4/4

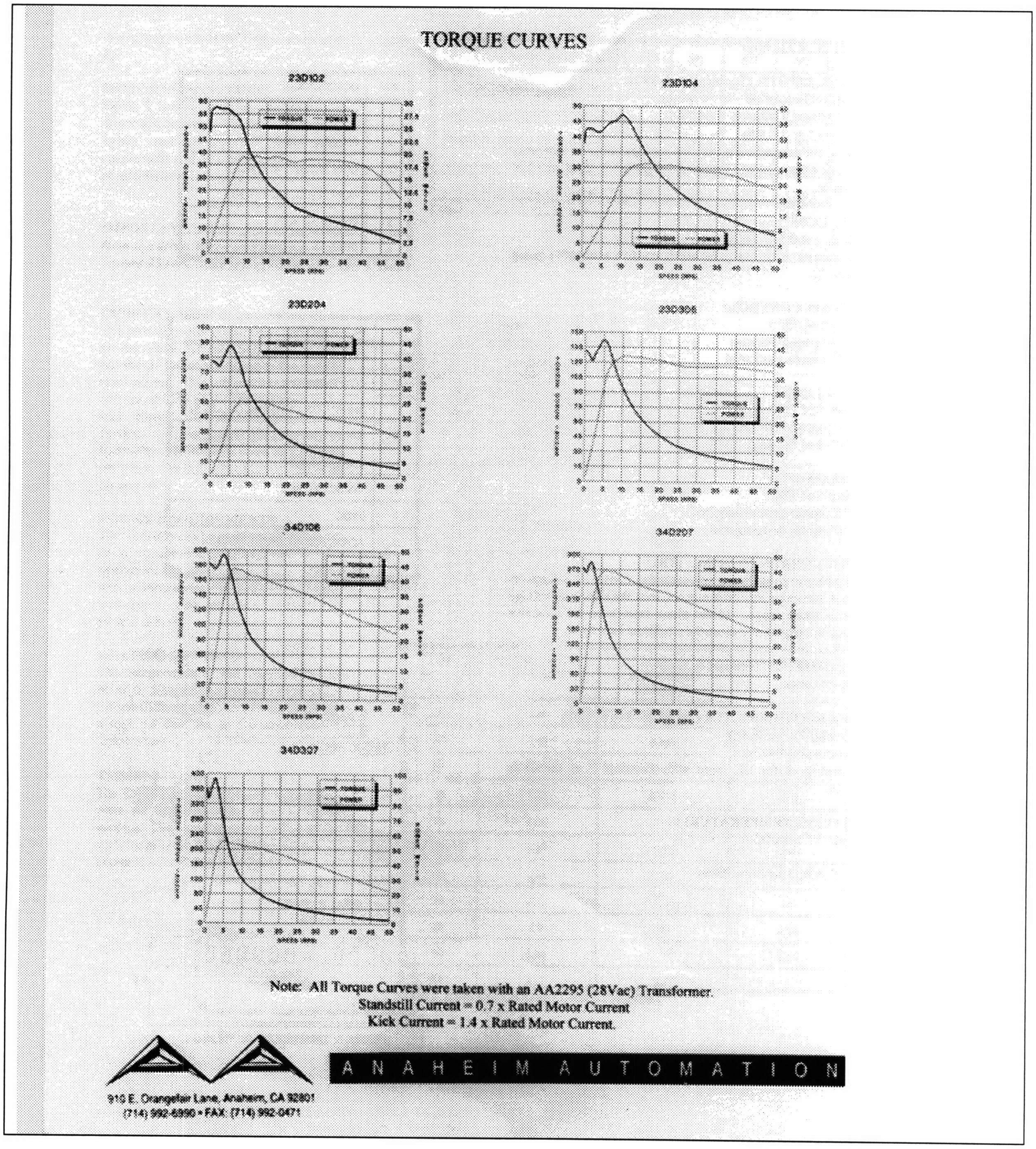
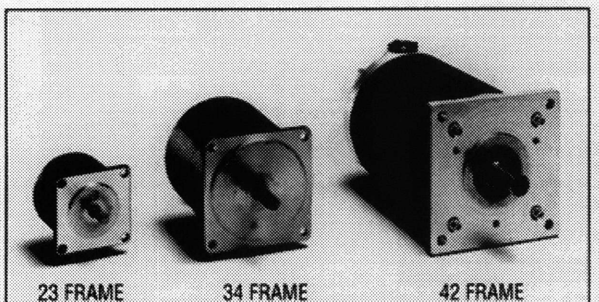


Figure A-18

Stepper Motor Specification Sheet 1/4

ANAHEIM AUTOMATION STEP MOTORS
FRAME SIZES 23, 34 AND 42



- **200 Steps per Revolution**
- **Ideal for Half-step and Mini-Step**
- **Fast Damping for Better Control**
- **High Torque/Small Package**
- **High Reliability Based on Close Tolerance Construction**
- **Low Noise**
- **High Slew Rate**
- **Competitively Priced**

GENERAL SPECIFICATIONS

STEP ANGLE: 1.8° (200 steps/rev.)
STEP ACCURACY: ± 5% of one step, non-cumulative (± 3% accuracy available)
AMBIENT TEMPERATURE: -20°C to 50°C
MAXIMUM CASE TEMPERATURE: 100°C
INSULATION: NEMA Class B
INSULATION RESISTANCE: 1000 MΩ at 500 Vdc @ 25°C

APPLICATIONS

- Clutch/brake replacements
- Accurate pump flow control
- Machine tool controls
- Precision X-Y and rotary table positioning
- Tape readers
- Plotters
- Robotics
- Medical applications
- Factory automation
- Whenever precise positioning is required in open-loop systems, (even in formerly closed-loop applications)

MAKE HOOK-UPS EASY WITH COLOR-CODED MOTOR CABLE

16 gauge, 6 conductor cable with PVC insulation has color-coded conductors, the same as the leads on Anaheim Automation step motors (red, red/white, green, green/white, black, and white), so motor hook-ups are a snap. This shielded cable is available in 25 feet increments. Part Number AA129010-S.

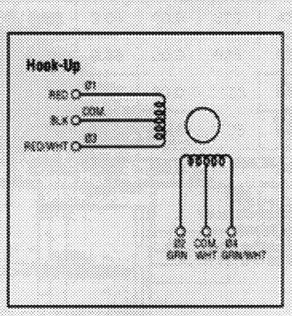
NOTES:
Ask for 6-9005-1 for Technical Data Information. A catalog of our full line of drivers and controllers is available on request.

STEP MOTOR PART NUMBER CODE

23	D	1	02	S
frame size	accuracy 5%	# of stacks	Current both phases energized I/Øx2	*Shaft Option

*S = Single shaft, D = Double shaft

Hook-Up



Six Wire Hook Up		
	Ø1	Red
	Ø3	Red/White
Common	Ø1 & Ø3	Black
	Ø2	Green
	Ø4	Green/White
Common	Ø2 & Ø4	White

A N A H E I M A U T O M A T I O N

910 E. Orangefair Lane, Anaheim, CA 92801
(714) 992-6990 FAX: (714) 992-0471

Figure A-19

Stepper Motor Specification Sheet 2/4

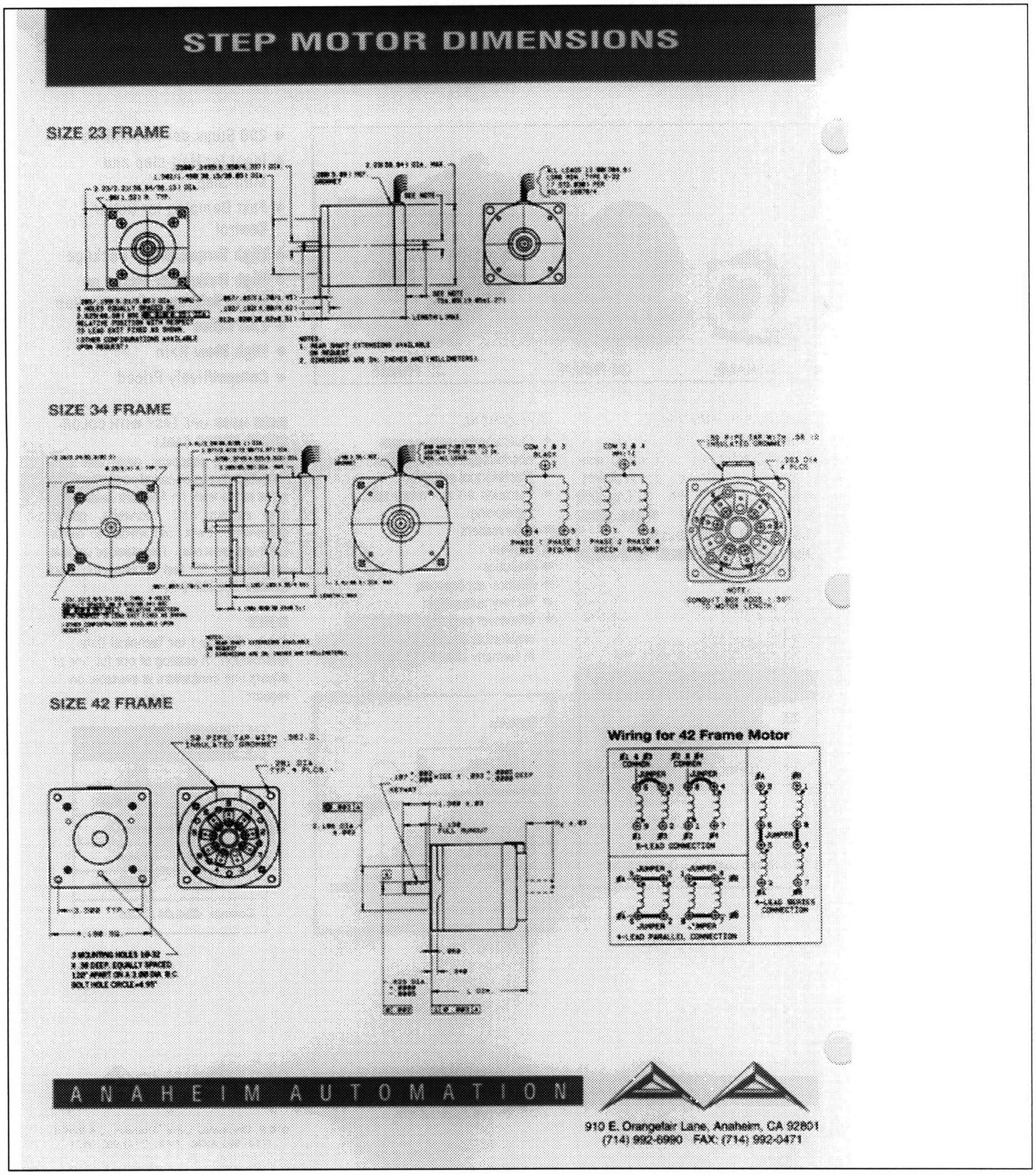


Figure A-20

Stepper Motor Specification Sheet 3/4

SPECIFICATIONS
4ø HYBRID, 1.8° ± 5% STEP ANGLE

Model Numbers	Step Angle (degrees)	Voltage per Phase (V/phase)	Current per Phase (A/phase)	Resistance per Phase (Ω/phase)	Inductance per Phase (mH/phase)	Typical Residual Torque (oz. in.)	Min. Holding Torque (oz. in.)*	Slew (Dynamic) Torque (oz. in.)	Nominal Rotor Inertia (oz. in. sec² x10⁻³)	Torque to Inertia Ratio (x 10³)	Shaft Diameter (in.)	Maximum Motor Length (in.)	Weight (lbs.)
23D102	1.8°	5.1	1.0	5.10	10.0	5.0	53	35	1.5	33.1	.250	2.00	1.3
23D104	1.8°	3.0	2.0	1.50	2.50	5.0	53	35	1.5	33.1	.250	2.00	1.3
23D108	1.8°	1.3	3.9	0.33	0.63	5.0	53	35	1.5	33.1	.250	2.00	1.3
23D204	1.8°	4.7	1.8	2.60	5.70	8.0	100	65	3.0	33.3	.250	3.25	2.0
23D209	1.8°	1.7	4.7	0.37	0.80	8.0	100	65	3.0	33.3	.250	3.25	2.0
23D306	1.8°	3.4	2.9	1.16	2.90	10.0	150	100	4.5	33.3	.250	4.00	2.75
23D309	1.8°	2.2	4.6	0.48	1.20	10.0	150	100	4.5	33.3	.250	4.00	2.75
34D106	1.8°	2.9	3.0	0.95	3.80	5.0	150	110	9.75	15.4	.375	2.45	3.25
34D109	1.8°	1.9	4.8	0.39	1.60	5.0	150	110	9.75	15.4	.375	2.45	3.25
34D207	1.8°	3.5	3.5	1.00	4.25	10.0	300	200	19.50	15.4	.375	3.7	5.5
34D209	1.8°	2.5	4.6	0.55	2.70	10.0	300	200	19.50	15.4	.375	3.7	5.5
34D213	1.8°	2.1	6.5	0.32	1.25	10.0	300	200	19.50	15.4	.375	3.7	5.5
34D307	1.8°	4.5	3.5	1.29	7.00	15.0	450	300	28.50	15.8	.375	5.3	7.8
34D311	1.8°	2.9	5.5	0.52	2.90	15.0	450	300	28.50	15.8	.375	5.3	7.8
34D314	1.8°	2.2	7.0	0.31	1.70	15.0	450	300	28.50	15.8	.375	5.3	7.8
42D112	1.8°	2.3	6.1	0.38	3.04	20.0	625	425	54.60	11.5	.625	4.74	9.0
42D119	1.8°	1.5	9.5	0.16	0.88	20.0	625	425	54.60	11.5	.625	4.74	9.0
42D212	1.8°	3.6	6.1	0.59	5.94	30.0	1125	840	110.5	10.2	.625	6.99	15.7
42D219	1.8°	2.1	9.2	0.30	2.00	30.0	1125	840	110.5	10.2	.625	6.99	15.7
42D225	1.8°	1.8	12.7	0.14	1.00	30.0	1125	840	110.5	10.2	.625	6.99	15.7

Add suffixes S or D: S = single ended shaft
D = double ended shaft

*Both windings energized at rated current.
Operation below rated current will reduce torque and may degrade step accuracy.

Conduit box, keyways, and encoder-ready options are available on request.

Linear actuators in frame sizes 23 and 34 are also available.

Values shown above are for reference information and are correct to the best of our knowledge at time of publication. However, values are subject to change without notice. Parameters to be used as part of an application should be verified with the factory or its representative.

All tests were done in half step mode.
RPS = Revolutions per Second

ANAHEIM AUTOMATION
910 E. Orangefair Lane, Anaheim, CA 92801
(714) 992-6990 FAX: (714) 992-0471

Figure A-21

Stepper Motor Specification Sheet 4/4

WIRING INSTRUCTIONS

BEFORE wiring your step motor(s), it is recommended that some initial checks are performed. These checks involve taking resistance readings. You will need to use an ohm-meter that can resolve 0.1Ω or better.

MOTOR CHECK

Set ohm-meter to highest scale available. Do a resistance check between each motor lead (6 total) and the motors face plate. The resistance in each case should be infinite. Tie both common leads together and connect meter from leads to face plate. Slowly rotate motor one complete revolution, and make sure reading is infinite. If any of the leads appear to be grounded to the case, DO NOT wire the motor to the driver. If the motor passes this check, wire the motor to the driver as follows:

BLD/BLEN-3/BLDEN/DPS/DPD Series

RED	TERMINAL 1	(Ø1)
RED/WHITE	TERMINAL 2	(Ø3)
BLACK	TERMINAL 3	(COM Ø1 & 3)
WHITE	TERMINAL 11	(COM Ø2 & 4)
GREEN	TERMINAL 12	(Ø2)
GREEN/WHITE	TERMINAL 13	(Ø4)

DPT Series

RED	TERMINAL 1	(Ø1)
RED/WHITE	TERMINAL 2	(Ø3)
BLACK	TERMINAL 3	(COM Ø1 & 3)
WHITE	TERMINAL 4	(COM Ø2 & 4)
GREEN	TERMINAL 5	(Ø2)
GREEN/WHITE	TERMINAL 6	(Ø4)

The connections above are silk-screened on the Driver Pack cover for easy reference.

IMPORTANT NOTE: When wiring from the motor to the driver exceeds 25 feet, consult the factory for proper safety guidelines. Wiring connected to inputs must be separated from motor connections and all other possible sources of interference, ie: 110VAC power lines or other motor/induction loads.

MOTOR/DRIVE CHECK

Once the motor is wired to the driver, **RE-CHECK TO MAKE SURE EACH WIRE IS CONNECTED TO THE PROPER TERMINAL.** Set ohm-meter to lowest scale available. Read the resistance between terminal 1 and 3. The resistance reading will be determined by the motors per phase resistance and the wiring between the drive and motor. Now read the resistance between terminals 2 and 3, this reading should be the same as terminals 1 and 3 (+/- 0.1Ω). Finally, read between terminal 1 and 2. The reading will be approximately 1.5 times the phase readings.

Next, read the phase resistance between terminals 11 and 12, and 11 and 13 (BLD/BLDEN-3 & BLDEN) or 14 and 15, and 14 and 16 (DPL). You should get the same readings as above (+- 0.1Ω) Finally, read between terminal 12 and 13 (BLD/BLDEN-3 & BLDEN) or terminals 15 and 16 (DPL). As above, the reading will be 1.5 times the phase readings.

IF ANY OF THE READINGS APPEAR TO BE INCORRECT, DISCONNECT THE MOTOR FROM THE DRIVER. DO NOT APPLY POWER TO DRIVER PACK. CONTACT ANAHEIM AUTOMATION (714) 992-6990 OR YOUR LOCAL REPRESENTATIVE/DISTRIBUTOR FOR FURTHER ASSISTANCE.

If all readings are correct, you will need to set the Kick Current potentiometer to the required setting for each motor used in the system. DPF, DPT, DPD, DPW and DPS Series Driver Packs have a silk-screened scale for ease of setting. Find the motors current per phase rating and set arrow to that point on the scale. It is not necessary to use or operate all drivers in a multiaxis Driver Pack.

GENERAL SAFETY CONSIDERATIONS

The following safety considerations must be observed during all phases of operation and service. Failure to comply with these precautions violates safety standards of design, manufacture, and intended use of products. Anaheim Automation assumes no liability for the customers' failure to comply with these requirements.

Even well-built equipment operated and installed improperly can be hazardous. Safety precautions must be observed by the user with respect to the load and operating environment. The customer is responsible for proper selection, installation and operation of the equipment.

Warning

Dangerous voltage capable of causing death, may be present in this equipment. Use caution when handling, testing, and adjusting during installation, set-up and operation.

Grounding

All equipment and motors must be securely mounted and adequately grounded. Failure to ground properly may cause damage to the equipment or injury to the user.

Atmosphere

Do not operate electrical equipment in the presence of flammable gases, dust, moisture, or vapor. For outdoor use, equipment must be protected against the elements by an enclosure, while still allowing adequate air flow. Moisture may cause an electrical shock hazard or induce equipment breakdown. Due consideration should be given to the avoidance of or protection from liquids or vapors.

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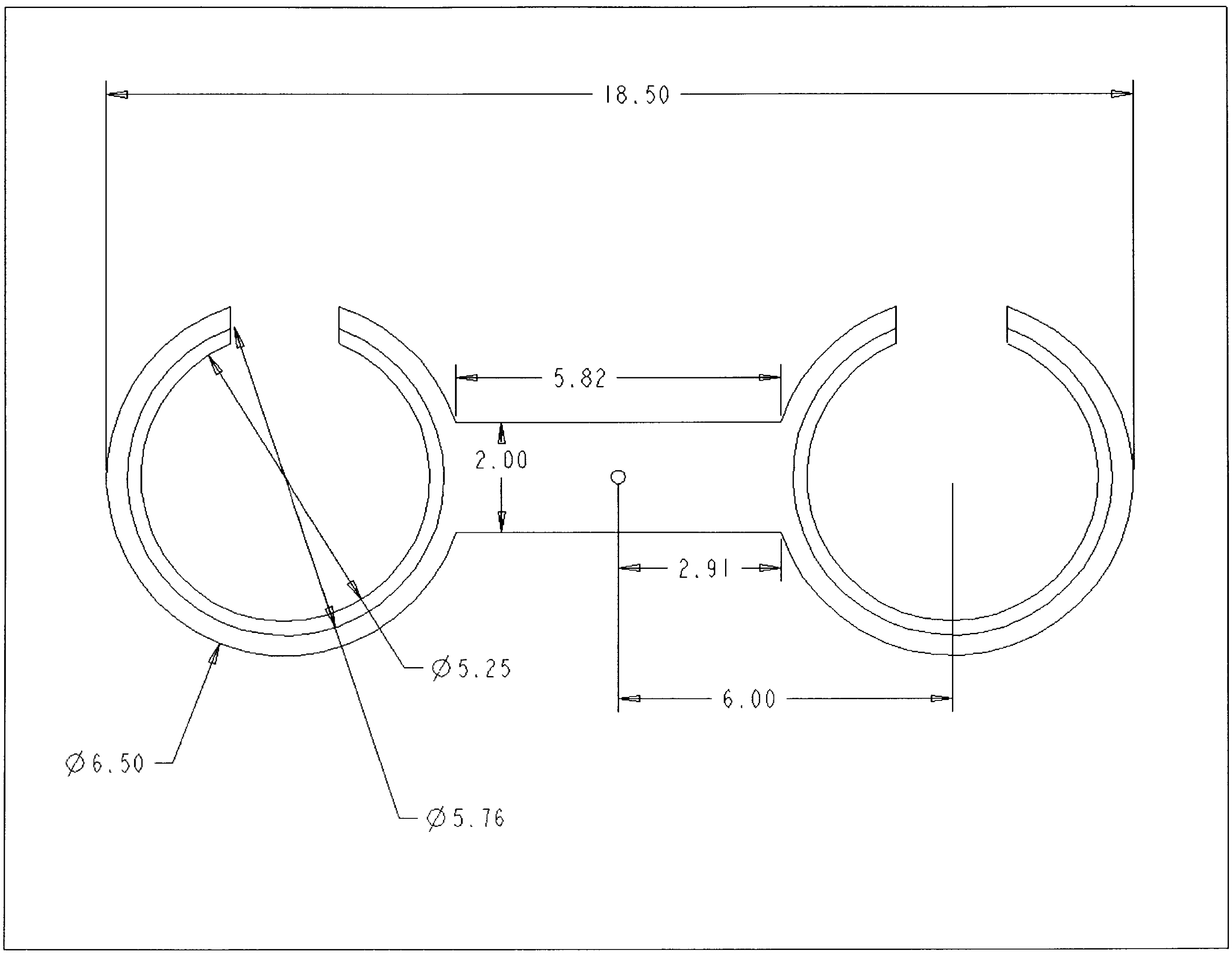
BULLETIN SM-9609-SK

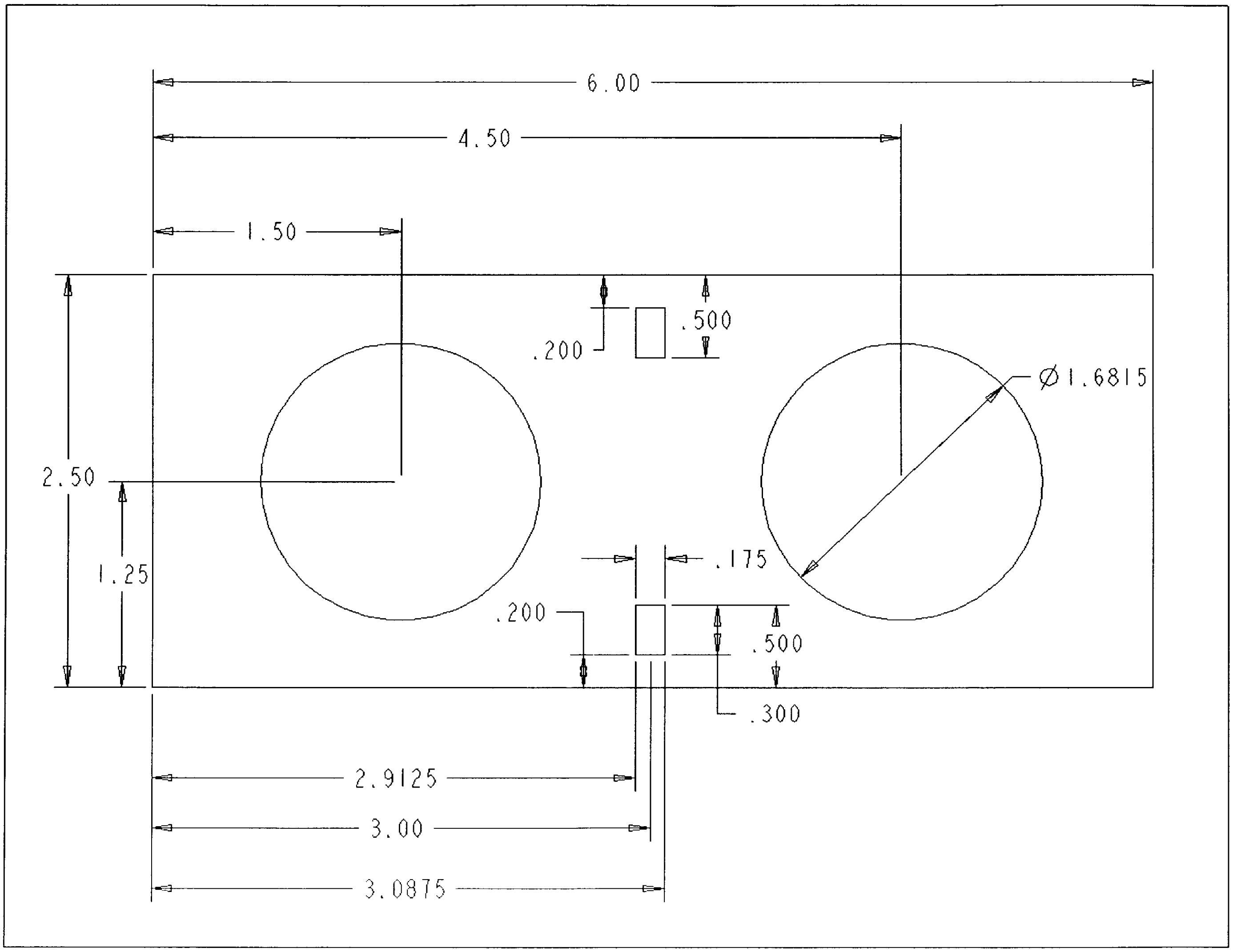
Figure A-22

Appendix B

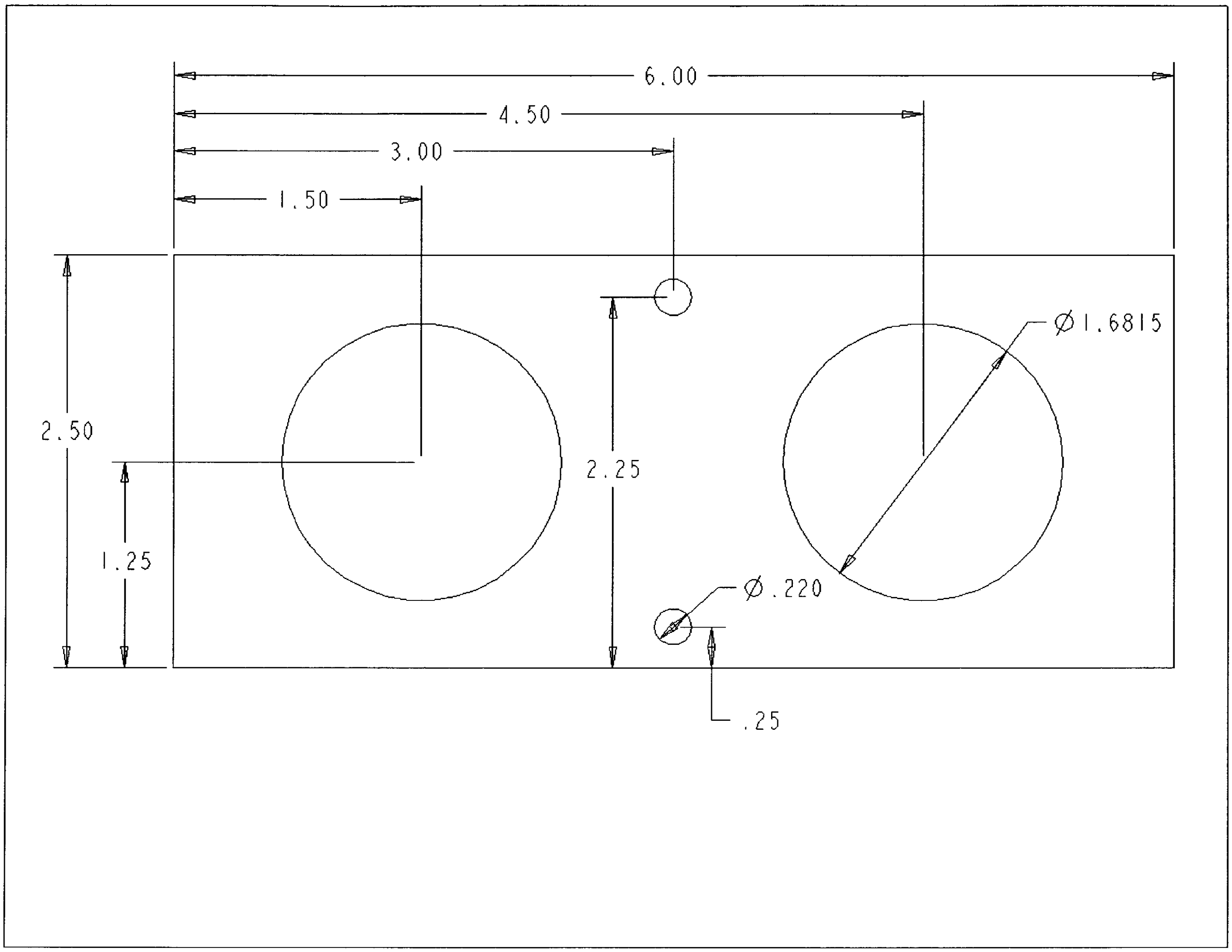
Part Drawings



SCALE : 0.111 TYPE : PART NAME : END_EFFECTOR SIZE : A



SCALE : 0.500   TYPE : PART   NAME : RECEPTION_BLOCK   SIZE : A



SCALE : 0.500 TYPE : PART NAME : TRANSMISSION_BLOCK SIZE : A SCALE 1.500

Appendix C

Programs

BASMOV2.MAC
Basic move on Axis 2
Board ID = 1, load_target_pos, dev = 02, Retn Vect = FF, 4, 0180
Board ID = 1, start, dev = 00, Retn Vect = FF, 4
Board ID = 1, read_pos, dev = 02, Retn Vect = FF
Board ID = 1, load_target_pos, dev = 02, Retn Vect = FF, 7, F000
Board ID = 1, start, dev = 00, Retn Vect = FF, 4
Board ID = 1, read_pos, dev = 02, Retn Vect = FF

BASMOV5.MAC
Basic move on Axis 5 no read_pos
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 64
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 0
Board ID = 1, start, dev = 00, Retn Vect = FF, 20

Set1256.MAC
Setup and enable axes 1 2 5 6
Board ID = 1, kill, dev = 0, Retn Vect = FF, 007e
Board ID = 1, enable_axes, dev = 0, Retn Vect = FF, 0000
Board ID = 1, config_axis, dev = 1, Retn Vect = FF, 2100, 3100
Board ID = 1, config_axis, dev = 2, Retn Vect = FF, 2200, 3200
Board ID = 1, config_axis, dev = 5, Retn Vect = FF, 2500, 4500
Board ID = 1, config_axis, dev = 6, Retn Vect = FF, 2600, 4600
Board ID = 1, set_axis_mode, dev = 5, Retn Vect = FF, 0001
Board ID = 1, set_axis_mode, dev = 6, Retn Vect = FF, 0001
Board ID = 1, config_step_mode_pol, dev = 5, Retn Vect = FF, 4
Board ID = 1, config_step_mode_pol, dev = 6, Retn Vect = FF, 4
Board ID = 1, load_loop_params, dev = 1, Retn Vect = FF, 64, 0, 400, 400, 2, 0, 0, 0
Board ID = 1, load_loop_params, dev = 2, Retn Vect = FF, 64, 0, 400, 400, 2, 0, 0, 0
Board ID = 1, enable_axes, dev = 0, Retn Vect = FF, 0366
Board ID = 1, enable_encs, dev = 20, Retn Vect = FF, 007e

Setio.MAC
Setup and enable I/O port 1
Board ID = 1, set_port_dir, dev = 2, Retn Vect = FF, 0
Board ID = 1, set_port_pol, dev = 2, Retn Vect = FF, FF
Board ID = 1, set_port_pol, dev = 3, Retn Vect = FF, FF

Cfgmov5.MAC
Configuration and speed set for Axis 5
Board ID = 1, load_vel, dev = 05, Retn Vect = FF, 3, 2000
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 2, 2000
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 0
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, load_vel, dev = 05, Retn Vect = FF, 0, A000

Operations1.MAC

Operation macro w/pneumatics on Axis 5 station 1

```
rem     MOVE TO STATION 1
Board ID = 1, load_target_pos, dev = 02, Retn Vect = FF, 4, 0180
Board ID = 1, start, dev = 00, Retn Vect = FF, 4
rem     ROTATE TO START POSITION
Board ID = 1, set_port_momo, dev = 2, Retn Vect = FF, 100
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 64
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
rem     GET WAFER FROM STATION 1
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 100
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 0
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 001
rem     PLACE WAFER AT STATION 1
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, C8
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 100
rem     TURN FOR TRANSPORT AND DROP PLATE1
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 64
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 001
rem     MOVE TO STATION 2
Board ID = 1, load_target_pos, dev = 02, Retn Vect = FF, 7, F000
Board ID = 1, start, dev = 00, Retn Vect = FF, 4
rem     POSITION RESET AFTER TRANSPORT
Board ID = 1, reset_pos, dev = 05, Retn Vect = FF, 0, 66
rem     GET WAFER FROM STATION 2
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 200
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, C8
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 002
rem     PLACE WAFER AT STATION 2
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 0
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 200
rem     POSITION FOR TRANSPORT AND DROP PLATE 2
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 64
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 002
rem     MOVE TO STATION 1
Board ID = 1, load_target_pos, dev = 02, Retn Vect = FF, 4, 0180
Board ID = 1, start, dev = 00, Retn Vect = FF, 4
rem     RESET AFTER TRANSPORT
Board ID = 1, reset_pos, dev = 05, Retn Vect = FF, 0, 66
rem     ROTATE BACK TO 0
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 0
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
```

OpProg1_2.MAC

Wireless Operation program reset for step back startup
Board ID = 1, begin_store, dev = 98, Retn Vect = FF
rem MOVE TO STATION 1
Board ID = 1, load_target_pos, dev = 02, Retn Vect = FF, 4, 0180
Board ID = 1, start, dev = 00, Retn Vect = FF, 4
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 400, 200
rem ROTATE TO START POSITION
Board ID = 1, set_port_momo, dev = 2, Retn Vect = FF, 100
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 64
Board ID = 1, load_delay, dev = 0, Retn Vect = 0, 0, 1F4
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 2000, 200
rem GET WAFER FROM STATION 1
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 100
Board ID = 1, load_delay, dev = 0, Retn Vect = 0, 0, 7D0
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 0
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 2000, 200
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 001
Board ID = 1, load_delay, dev = 0, Retn Vect = 0, 0, 7D0
rem PLACE WAFER AT STATION 1
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, C8
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 2000, 200
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 100
Board ID = 1, load_delay, dev = 0, Retn Vect = 0, 0, 7D0
rem TURN FOR TRANSPORT AND DROP PLATE1
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 64
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 2000, 200
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 001
Board ID = 1, load_delay, dev = 0, Retn Vect = 0, 0, 7D0
rem MOVE TO STATION 2
Board ID = 1, load_target_pos, dev = 02, Retn Vect = FF, 7, F000
Board ID = 1, start, dev = 00, Retn Vect = FF, 4
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 400, 200
rem POSITION RESET AFTER TRANSPORT
Board ID = 1, reset_pos, dev = 05, Retn Vect = FF, 0, 62
rem GET WAFER FROM STATION 2
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 200
Board ID = 1, load_delay, dev = 0, Retn Vect = 0, 0, 7D0
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, C8
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 2000, 200
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 002
Board ID = 1, load_delay, dev = 0, Retn Vect = 0, 0, 7D0

```
rem     PLACE WAFER AT STATION 2
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 0
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 2000, 200
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 200
Board ID = 1, load_delay, dev = 0, Retn Vect = 0, 0, 7D0
rem     POSITION FOR TRANSPORT AND DROP PLATE 2
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 64
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 2000, 200
Board ID = 1, set_port_momo, dev = 3, Retn Vect = FF, 002
Board ID = 1, load_delay, dev = 0, Retn Vect = 0, 0, 7D0
rem     MOVE TO STATION 1
Board ID = 1, load_target_pos, dev = 02, Retn Vect = FF, 4, 0180
Board ID = 1, start, dev = 00, Retn Vect = FF, 4
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 400, 200
rem     RESET AFTER TRANSPORT
Board ID = 1, reset_pos, dev = 05, Retn Vect = FF, 0, 62
rem     ROTATE BACK TO 0
Board ID = 1, load_target_pos, dev = 05, Retn Vect = FF, 0, 0
Board ID = 1, start, dev = 00, Retn Vect = FF, 20
Board ID = 1, wait, dev = 0, Retn Vect = 0, 1C, 2000, 200
Board ID = 1, load_delay, dev = 0, Retn Vect = 0, 0, 7D0
Board ID = 1, end_store, dev = 98, Retn Vect = FF
```