A Wireless Robotic Manipulator for Semiconductor Manufacturing Equipment

by

Jevin E. Scrivens

B.S. Mechanical Engineering
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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 to 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.
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.
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 its 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 its 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.

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.
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

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 to 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 its 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 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.
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).
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.
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](image)

**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 line 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.
Straight Line Motion Manipulator System

Figure 5-1
The straight line manipulator concept is significant because of its 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.
5.2 System Design

From the point of concept development, detailed design began 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.
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.
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.
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).
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.
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.
Wireless robot With Two Stations

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 OPERATIONS1. This program stepped through 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 OPERATIONS1 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 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**

**CORE SETS**

Effective core parameters

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<th>SYMBOL</th>
<th>PARAMETER</th>
<th>VALUE</th>
<th>UNIT</th>
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**Core sets for filter applications**

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<th>TYPE NUMBER (WITHOUT NUT)</th>
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<td>=830</td>
<td></td>
<td></td>
<td>P4229-3B7-E400</td>
<td>P4229-3B7-E400</td>
</tr>
<tr>
<td>630 ±3%</td>
<td>=450</td>
<td></td>
<td></td>
<td>P4229-3B7-E630</td>
<td>P4229-3B7-E630</td>
</tr>
<tr>
<td>1000 ±5%</td>
<td>=270</td>
<td></td>
<td></td>
<td>P4229-3B7-A1000</td>
<td>P4229-3B7-A1000</td>
</tr>
<tr>
<td>1600 ±5%</td>
<td>=325</td>
<td></td>
<td></td>
<td>P4229-3B7-A1600</td>
<td>P4229-3B7-A1600</td>
</tr>
<tr>
<td>10300 ±25%</td>
<td>=2090</td>
<td></td>
<td></td>
<td></td>
<td>P4229-3B7</td>
</tr>
</tbody>
</table>

Note:

1. Clamping force 550 ±100 N.
### P cores and accessories

#### Core sets for general purpose transformers and power applications

<table>
<thead>
<tr>
<th>GRADE</th>
<th>$A_{c}^{(1)}$ (nH)</th>
<th>$F_{c}$</th>
<th>AIR GAP (µm)</th>
<th>TYPE NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C81</td>
<td>315 ±3%</td>
<td>65</td>
<td>1100</td>
<td>P42/29-3C81-E315</td>
</tr>
<tr>
<td></td>
<td>400 ±3%</td>
<td>81</td>
<td>800</td>
<td>P42/29-3C81-E400</td>
</tr>
<tr>
<td></td>
<td>620 ±3%</td>
<td>130</td>
<td>500</td>
<td>P42/29-3C81-A630</td>
</tr>
<tr>
<td></td>
<td>1000 ±3%</td>
<td>205</td>
<td>270</td>
<td>P42/29-3C81-A1000</td>
</tr>
<tr>
<td></td>
<td>1600 ±5%</td>
<td>325</td>
<td>150</td>
<td>P42/29-3C81-A1600</td>
</tr>
<tr>
<td></td>
<td>11500 ±5%</td>
<td>2340</td>
<td>0</td>
<td>P42/29-3C81</td>
</tr>
<tr>
<td>3C85</td>
<td>315 ±3%</td>
<td>65</td>
<td>1100</td>
<td>P42/29-3C85-E315</td>
</tr>
<tr>
<td></td>
<td>400 ±3%</td>
<td>81</td>
<td>800</td>
<td>P42/29-3C85-E400</td>
</tr>
<tr>
<td></td>
<td>620 ±3%</td>
<td>130</td>
<td>500</td>
<td>P42/29-3C85-A630</td>
</tr>
<tr>
<td></td>
<td>1000 ±3%</td>
<td>205</td>
<td>270</td>
<td>P42/29-3C85-A1000</td>
</tr>
<tr>
<td></td>
<td>1600 ±5%</td>
<td>325</td>
<td>150</td>
<td>P42/29-3C85-A1600</td>
</tr>
<tr>
<td></td>
<td>8500 ±5%</td>
<td>1250</td>
<td>0</td>
<td>P42/29-3C85</td>
</tr>
<tr>
<td>3F3</td>
<td>315 ±3%</td>
<td>65</td>
<td>1100</td>
<td>P42/29-3F3-E315</td>
</tr>
<tr>
<td></td>
<td>400 ±3%</td>
<td>81</td>
<td>800</td>
<td>P42/29-3F3-E400</td>
</tr>
<tr>
<td></td>
<td>620 ±3%</td>
<td>130</td>
<td>500</td>
<td>P42/29-3F3-A630</td>
</tr>
<tr>
<td></td>
<td>1000 ±3%</td>
<td>205</td>
<td>270</td>
<td>P42/29-3F3-A1000</td>
</tr>
<tr>
<td></td>
<td>1600 ±5%</td>
<td>325</td>
<td>150</td>
<td>P42/29-3F3-A1600</td>
</tr>
<tr>
<td></td>
<td>7700 ±5%</td>
<td>1600</td>
<td>0</td>
<td>P42/29-3F3</td>
</tr>
</tbody>
</table>

**Note**

1. Clamping force 650 ±100 N.

### Properties of core sets under power conditions

<table>
<thead>
<tr>
<th>GRADE</th>
<th>$B$ (mT) at $H = 250$ A/m; $f = 25$ kHz; $T = 100$ ºC</th>
<th>CORE LOSS (W) at $f = 25$ kHz; $T = 100$ ºC</th>
<th>$f = 100$ kHz; $T = 100$ ºC</th>
<th>$f = 400$ kHz; $T = 100$ ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C81</td>
<td>$\geq 315$</td>
<td>$\leq 3.7$</td>
<td>$\leq 2.4$</td>
<td>$\leq 3.5$</td>
</tr>
<tr>
<td>3C85</td>
<td>$\geq 315$</td>
<td>$\leq 2.9$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3F3</td>
<td>$\geq 315$</td>
<td>$\leq 3.7$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Material grade specification

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>μ₀</td>
<td>25 °C; ≤10 kHz; 0.1 mT</td>
<td>2700 ±20%</td>
<td></td>
</tr>
<tr>
<td>μ₀</td>
<td>100 °C; 25 kHz; 200 mT</td>
<td>5500 ±20%</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>25 °C; 10 kHz; 250 A/m</td>
<td>~420</td>
<td>mT</td>
</tr>
<tr>
<td></td>
<td>25 °C; 10 kHz; 250 A/m</td>
<td>~330</td>
<td></td>
</tr>
<tr>
<td>Pᵥ</td>
<td>100 °C; 25 kHz; 200 mT²</td>
<td>≤185</td>
<td>kW/m²</td>
</tr>
<tr>
<td>ρ</td>
<td>DC, 25 °C</td>
<td>~1</td>
<td>Ωm</td>
</tr>
<tr>
<td>T₀</td>
<td>2210</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>density</td>
<td>~4800</td>
<td></td>
<td>kg/m³</td>
</tr>
</tbody>
</table>

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
Material grade specification

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

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

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

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

1995 Aug 25

Figure A-4
The QSE156 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/LSSTL 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/LSSTL interface
- Steel lead frames for improved solder mounting
- Receptacle angle of ±25°
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNITS</th>
<th>TEST CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Supply Voltage</td>
<td>$V_{DD}$</td>
<td>4.5</td>
<td>5.0</td>
<td>16.0</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Pulse Test Current</td>
<td>$I_{PUL}$</td>
<td>0.015</td>
<td>0.25</td>
<td>0.50</td>
<td>mA</td>
<td>$T_r = 25^\circ$C</td>
</tr>
<tr>
<td>Hysteresis Ratio</td>
<td>$E_i$</td>
<td>1.10</td>
<td>1.5</td>
<td>2.00</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Supply Current</td>
<td>$I_{LS}$</td>
<td>12.0</td>
<td>-</td>
<td>50</td>
<td>mA</td>
<td>$E_i = 0 \text{ or } 3 \text{ mW/cm}^2$</td>
</tr>
<tr>
<td>Peak to pulse current which will cause false triggering</td>
<td>-</td>
<td>-</td>
<td>2.00</td>
<td>V</td>
<td>$f = \text{DC to } 50 \text{ MHz}$</td>
<td></td>
</tr>
<tr>
<td>G85106 (BUFFER TOTEM POLE)</td>
<td>$V_{CC}$</td>
<td>2.1</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td>$E_i = 0.3 \text{ mW/cm}^2$, $I_{LS} = 1.0 \text{ mA}$</td>
</tr>
<tr>
<td>Low Level Output Voltage</td>
<td>$V_{OL}$</td>
<td>-</td>
<td>0.40</td>
<td>0.60</td>
<td>V</td>
<td>$E_i = 0.6 \text{ mA}$</td>
</tr>
<tr>
<td>G85107 (INVERTER TOTEM POLE)</td>
<td>$V_{CC}$</td>
<td>2.1</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td>$E_i = 0.3 \text{ mW/cm}^2$, $I_{LS} = 1.0 \text{ mA}$</td>
</tr>
<tr>
<td>Low Level Output Voltage</td>
<td>$V_{OL}$</td>
<td>-</td>
<td>0.40</td>
<td>0.60</td>
<td>V</td>
<td>$E_i = 0.6 \text{ mA}$</td>
</tr>
<tr>
<td>G85109 (BUFFER OPEN COLLECTOR)</td>
<td>$I_{LS}$</td>
<td>100</td>
<td>-</td>
<td>16</td>
<td>mA</td>
<td>$E_i = 0.3 \text{ mW/cm}^2$, $V_{CC} = -30 \text{ V}$</td>
</tr>
<tr>
<td>Low Level Output Voltage</td>
<td>$V_{OL}$</td>
<td>-</td>
<td>0.40</td>
<td>0.60</td>
<td>V</td>
<td>$E_i = 0.3 \text{ mW/cm}^2$, $I_{LS} = 16 \text{ mA}$</td>
</tr>
<tr>
<td>G85110 (INVERTER OPEN COLLECTOR)</td>
<td>$I_{LS}$</td>
<td>100</td>
<td>-</td>
<td>16</td>
<td>mA</td>
<td>$E_i = 0.3 \text{ mW/cm}^2$, $V_{OL} = 30 \text{ V}$</td>
</tr>
<tr>
<td>Low Level Output Voltage</td>
<td>$V_{OL}$</td>
<td>-</td>
<td>0.40</td>
<td>0.60</td>
<td>V</td>
<td>$E_i = 0.3 \text{ mW/cm}^2$, $I_{LS} = 16 \text{ mA}$</td>
</tr>
</tbody>
</table>

Figure A-6
## Logic Detector Specification Sheet 3/4

### Table 1: Parameter Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output rise, fall times</td>
<td>tr, tf</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>ns</td>
<td>E=0 or 3 mA into f=10 kHz DC=50% R=10 TTL Load</td>
</tr>
<tr>
<td>Propagation delay</td>
<td>tpd, tph</td>
<td>6.0</td>
<td></td>
<td></td>
<td>μs</td>
<td>E=0 or 3 mA into f=10 kHz DC=50% R=300 Ω Load</td>
</tr>
</tbody>
</table>

### Switching Test Curves

**Switching Test Curve for Buffer**

**Switching Test Curve for Inverter**

---

1. Derate power dissipation linearly 4.00 mW/ºC above 25ºC.
2. RMA flux is recommended.
3. Methanol or isopropanol solvents are recommended as cleaning agents.
4. Soldering iron tip size (0.8 mm) minimum from housing.
5. As long as leads are not under any stress or spring tension.
6. Intensity measurements are made with an AEGuru LED emitting light at a peak wavelength of 880 nm.

---

Figure A-7
Figure A-8
Flex Motion Controller Specification Sheet 1/6

Figure A-9
Servo Loop Performance

- **Position Accuracy:**
  - Encoder Feedback: ±1 Quadrature Count
  - Analog Feedback: ±1 LSB (0.0049 V ± 10 V Range)
- **Long Term Velocity Accuracy:**
  - Oscillator Based: ±0.02% (±0.0004% / °C)
- **Double Buffered Servo Axis Parameter Ranges:**
  - Velocity Range: 0 to ±16,000,000 counts/sec
  - Acceleration/Deceleration: 312 to 64,217,728 counts/sec
  - Following Error Range: ±32,768 counts

DSP Based Servo Filter Modes:
- PID, IV-FF, Notch, S-Curve, Dual Loop Notch Value
- Filter Q Range, Filter Center Freq: 0.5 - 500 Hz
- S-Curve Value: Per Axis S-Curve Jerk Value (counts/sec)
- Feed Forward Values: Acceleration & Velocity Feed Forward
- Anti-Scroll & Kd Gain: 0 to 65,535
- Integration Limit: 0 to 65,535
- Derivative Sample Period Multiplier: Td: 1 to 255

Servo Command Analog Output:
- Resolution & Range: 16 Bits, ±10 Volts, 0.00005 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: ±0.02% (±0.0004% / °C)
- **Double Buffered Stepper Axis Parameter Ranges:**
  - Velocity Range: 0 to ±1,500,000 steps/sec
  - Acceleration/Deceleration: 1 to ±15,000,000 steps/sec
  - Following Error Range: ±32,768 counts
  - Gear Ratio: 1:32768

Step Pulse Output:
- Maximum Pulse Rate: 1.5 MHz (Full, Half & Microstep), 30% Duty
- Step Pulse Width: 30 nsec to 1.5 MHz, 0.5 nsec to 1 Hz
- Step Output Signals: Step & Direction or CW/CCW

General Purpose Analog & Digital I/O

- **Digital I/O:**
  - 24 Bits of Non-Dedicated Digital I/O
  - 50 Pin D-type 22 1/2 box connector
  - Output: Eight Uncommitted Outputs /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, 10µsec Convert, 210 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

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: Capture on Input Signal
  - Programmable Timer Compare Registers
  - Output Transition on Timer Match
  - Counter Functions:
    - Counter Input Poles & Accumulate Count
    - User Programmable PWM Outputs
  - Clock Source:
    - Internal or External Timer Clock Source

Multi-Axis Functionality & Performance

- **Axiom Operation Modes:**
  - Single Axis Point-To-Point Positioning
  - S-Curve Mechanical Jerk Control
  - Feedrate (Velocity) Control
  - Torque Limb Control
  - Coordinated Multi-Axis Motion
  - Linear & Circular Interpolation
  - 2/3 Axis Vector w/ Coordinate N° Axis
  - Blended Multiple Move Sequences
  - Continuous Motion Contouring
  - Electronic Gear, Clamping & Following
  - Multi-Axis Cubic Spline Interpolation
- **Multi-Axis Performance:**
  - Synced DSP Clock, <1 P/D Period
### Per Axis Outputs

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakpoint Output: <strong>Y</strong></td>
<td>Programmable Output Polarity</td>
</tr>
<tr>
<td>Amplifier Enable/Inhibit:</td>
<td>User Programmable Output Polarity</td>
</tr>
</tbody>
</table>

### Power Requirement & General Configuration

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Input Requirements:</td>
<td>ISA Bus or External Power Connector</td>
</tr>
</tbody>
</table>

### Bus Interface, Expansion & Cabling

<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watchdog Timer Function:</td>
<td>Processor based Watchdog Timer Reset</td>
</tr>
<tr>
<td>Communications Interface:</td>
<td>16 Bit ISA Bus Standard, PC/AT Config, On-Board RS-232 Port</td>
</tr>
<tr>
<td>Motion I/O Interconnect:</td>
<td>Industry Std. 100 Pin Dual Ribbon Cable</td>
</tr>
<tr>
<td>Expansion Modules:</td>
<td>Servo, Stepper, Encoder, I/O, Sensor</td>
</tr>
<tr>
<td>Cable Assembly Included:</td>
<td>100 Pin &gt; Dual 50 Pin Ribbon Cables</td>
</tr>
</tbody>
</table>

| Optocoupled Signals: **Y**                                                 | All Signals with this Marking, **Y** are Optically Isolated, Optocoupled signal line with 2.2 kΩ in series to +ISO Voltage for Inputs and 2.2 kΩ Pullup to +ISO Voltage for Outputs. With ISO Return(Gnd) |
Flex Motion Controller Specification Sheet 4/6

**Flex Motion Commands**

<table>
<thead>
<tr>
<th>Setup &amp; Configuration</th>
<th>Serve Loop PID &amp; FF Filter Control</th>
<th>Stepper Motor Control</th>
<th>Motion I/O Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force Power Up Reset</td>
<td>Set Filter Kp Value</td>
<td>Set Step Output Mode</td>
<td>Set Limit Switch Polarity</td>
</tr>
<tr>
<td>Force Reset Using Watchdog Timeout</td>
<td>Set Filter Ki Value</td>
<td>Set Steps Per Revolution</td>
<td>Enable Limit Inputs</td>
</tr>
<tr>
<td>Run On-Board Self Test</td>
<td>Set Filter Kd Value</td>
<td>Set Base Velocity Value</td>
<td>Read Limit Input Status</td>
</tr>
<tr>
<td>Set High-Impedance Interface</td>
<td>Set Filter Td Value</td>
<td>Set Acceleration Factor</td>
<td>Enable Home Inputs</td>
</tr>
<tr>
<td>Set Interrupt Condition Mask</td>
<td>Set Notch Filter Value</td>
<td>Read Home Input Status</td>
<td>Read Home Input Status</td>
</tr>
<tr>
<td>Set Axis Operation Mode</td>
<td>Set All PID &amp; FF Values</td>
<td>Enable Software Limits</td>
<td>Set Software Limit Values</td>
</tr>
<tr>
<td>Define Vector Space</td>
<td>Set Acceleration Feed Forward Value</td>
<td>Enable High Speed Position Capture</td>
<td></td>
</tr>
<tr>
<td>Define Axis Resources</td>
<td>Set Velocity Feed Forward Value</td>
<td>Enable High Speed Position Capture</td>
<td>Read High Speed Capture Status</td>
</tr>
<tr>
<td>Enable Encoder Channels</td>
<td>Start Motion Control</td>
<td>Set Position Breakpoint Values</td>
<td>Set Position Breakpoint Value</td>
</tr>
<tr>
<td>Enable Axis Operation</td>
<td>Start Axis/Axis/Vectors</td>
<td>Enable Position Breakpoint</td>
<td>Read Position Breakpoint Status</td>
</tr>
<tr>
<td>Read Return Data Buffer</td>
<td>Decel Stop Axis/Axis/Vectors</td>
<td>Read Velocity Breakpoint Value</td>
<td>Read Velocity Breakpoint Status</td>
</tr>
<tr>
<td>Save Current Parameters as Defaults</td>
<td>Hall Stop Axis/Axis/Vectors</td>
<td>Set Anticipation Time B.P. Value</td>
<td>Read Anticipation Time B.P. Value</td>
</tr>
<tr>
<td>Motion Trajectory Control</td>
<td>End Stop Axis/Axis/Vectors</td>
<td>Set Breakpoint Outputs</td>
<td>Set Breakpoint Outputs</td>
</tr>
<tr>
<td>Set Position Mode</td>
<td>End Array Table Storage</td>
<td>Configure Amp. Enable/Inhibit Outputs</td>
<td>Config. Amp. Enable/Inhibit Outputs</td>
</tr>
<tr>
<td>Set Trajectory Mode</td>
<td>Enable Gearing</td>
<td>Set Amp. Enable/Inhibit Outputs</td>
<td></td>
</tr>
<tr>
<td>Set Blending Factor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read Position Counter (zero/value)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Target Position</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Velocity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Rotary Count Modulus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Counts Per Revolution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Acceleration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Accel. Jerk Factor (S-Curve)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Deceleration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Decel. Jerk Factor (S-Curve)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Velocity Filter TC/RS Threshold</td>
<td></td>
<td></td>
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<td>Follow Error Trip Value</td>
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<td>Read Velocity (Filtered)</td>
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<td>Motion Axis Initialization</td>
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<td>Find Home Input</td>
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<tr>
<td>Find Index Input</td>
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<td></td>
</tr>
<tr>
<td>Read Index Found Status</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Figure A-12**
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 additional axes of servos 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 naDrive Amplifier units. An alternate 100 pin ribbon cable assembly maintains all signals in 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 Signal 5V

100 Pin Motion Interface Connector Pinout

1  Power (5V)  X-Forward Limit  2
3  A1 Input 2  X-Reverse Limit  4
5  A1 Input 1  X-Enable Output  6
7  A1 Input 0  Y-Forward Limit  8
9  A1 Input -1 Y-Reverse Limit  10
11 4-Wire Feedback Y-Enable Output 12
13 4-Wire Feedback Y-Enable Limit 14
15 4-Wire Feedback Y-Enable Limit 16
17 4-Wire Feedback Y-Enable Limit 18
19 4-Wire Feedback Y-Enable Limit 20
21 4-Wire Feedback Y-Enable Limit 22
23 4-Wire Feedback Y-Enable Limit 24
25 4-Wire Feedback Y-Enable Limit 26
27 4-Wire Feedback Y-Enable Limit 28
29 4-Wire Feedback Y-Enable Limit 30
31 4-Wire Feedback Y-Enable Limit 32
33 4-Wire Feedback Y-Enable Limit 34
35 4-Wire Feedback Y-Enable Limit 36
37 4-Wire Feedback Y-Enable Limit 38
39 4-Wire Feedback Y-Enable Limit 40
41 4-Wire Feedback Y-Enable Limit 42
43 4-Wire Feedback Y-Enable Limit 44
45 4-Wire Feedback Y-Enable Limit 46
47 4-Wire Feedback Y-Enable Limit 48
49 4-Wire Feedback Y-Enable Limit 50
51 4-Wire Feedback Y-Enable Limit 52
53 4-Wire Feedback Y-Enable Limit 54
55 4-Wire Feedback Y-Enable Limit 56
57 4-Wire Feedback Y-Enable Limit 58
59 4-Wire Feedback Y-Enable Limit 60
61 4-Wire Feedback Y-Enable Limit 62
63 4-Wire Feedback Y-Enable Limit 64
65 4-Wire Feedback Y-Enable Limit 66
67 4-Wire Feedback Y-Enable Limit 68
69 4-Wire Feedback Y-Enable Limit 70
71 4-Wire Feedback Y-Enable Limit 72
73 4-Wire Feedback Y-Enable Limit 74
75 4-Wire Feedback Y-Enable Limit 76
77 4-Wire Feedback Y-Enable Limit 78
79 4-Wire Feedback Y-Enable Limit 80
81 4-Wire Feedback Y-Enable Limit 82
83 4-Wire Feedback Y-Enable Limit 84
85 4-Wire Feedback Y-Enable Limit 86
87 4-Wire Feedback Y-Enable Limit 88
89 4-Wire Feedback Y-Enable Limit 90
91 4-Wire Feedback Y-Enable Limit 92
93 4-Wire Feedback Y-Enable Limit 94
95 4-Wire Feedback Y-Enable Limit 96
97 4-Wire Feedback Y-Enable Limit 98
99 4-Wire Feedback Y-Enable Limit 100

Figure A-13

Call us today, toll free: 1-888-444-FLEX
Motion System Components

UMI™
Universal Motion Interface
Interconnect Module

- Direct ribbon cable FlexMotion connection
- Pluggable screw terminal connectors
- Easily connect to other system components
- Simplifies motion system setup & wiring
- All signals available for connection
- Filtering for all input signals
- PC bus SV shutdown/interlock monitor
- DIN rail or panel mount configurations

Figure A-14
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
- TIL-CMOS Compatible Inputs
- No RFI or EMI Problems

GENERAL DESCRIPTION
The ANAHEIM AUTOMATION TM3000 is a low cost, bislevel 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.

BIPLEVEL 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.

Bislevel 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.

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" (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 T12 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 TRANSFORMER
TM3000-71 | DRIVER w/ TRACK and 100VA TRANSFORMER
TM3000-72 | 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

Figure A-15
Inputs may be used (see Table 2 and Figure 1).

**MOTOR CONNECTIONS**
Figure 2 is a hook-up 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.

For example: For a motor rated at 2.6 amps per phase, the POT should be set between 50 and 60.

**POWER REQUIREMENTS**
The TM5000 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.

**TM5000-1**
The TM5000 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 TM5000-1. Dimensions are shown in figure 3.

<table>
<thead>
<tr>
<th>POT</th>
<th>RATED MOTOR CURRENT</th>
<th>ACTUAL STANDSTILL CURRENT</th>
<th>KICK CURRENT</th>
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<tr>
<td>6</td>
<td>0.21</td>
<td>0.15</td>
<td>0.3</td>
</tr>
<tr>
<td>10</td>
<td>0.55</td>
<td>0.385</td>
<td>0.77</td>
</tr>
<tr>
<td>20</td>
<td>0.89</td>
<td>0.62</td>
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<tr>
<td>30</td>
<td>1.22</td>
<td>0.835</td>
<td>1.71</td>
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<tr>
<td>40</td>
<td>1.56</td>
<td>1.09</td>
<td>2.15</td>
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<tr>
<td>50</td>
<td>1.89</td>
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<td>100</td>
<td>3.57</td>
<td>2.5</td>
<td>5</td>
</tr>
</tbody>
</table>

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' = 3.3 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°C to 60°C

FUSE: 5 Amp Fast Blow, 5mm

Figure A-17
Figure A-18
Stepper Motor Specification Sheet 1/4

Figure A-19
Figure A-20
## SPECIFICATIONS 40 HYBRID, 1.8° ± 5% STEP ANGLE

<table>
<thead>
<tr>
<th>Model Numbers</th>
<th>Step Angle (deg)</th>
<th>Voltage per Phase (V)</th>
<th>Current per Phase (mA)</th>
<th>Resistance per Phase (Ohm)</th>
<th>Inductance per Phase (mH)</th>
<th>Torque to Stall (oz in)</th>
<th>Torque to Stall (Nm)</th>
<th>Normal Max. Torque (oz in)</th>
<th>Normal Max. Torque (Nm)</th>
<th>Stall Current (mA)</th>
<th>Max. Length (in)</th>
<th>Weight (oz)</th>
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<td>5.1</td>
<td>1.0</td>
<td>5.10</td>
<td>10.0</td>
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<td>53</td>
<td>35</td>
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<td>33.1</td>
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<td>1.50</td>
<td>2.50</td>
<td>5.0</td>
<td>53</td>
<td>35</td>
<td>1.5</td>
<td>33.1</td>
<td>250</td>
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</tr>
<tr>
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<td>3.9</td>
<td>0.33</td>
<td>0.63</td>
<td>5.0</td>
<td>53</td>
<td>35</td>
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<td>250</td>
<td>2.00</td>
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<td>1.8</td>
<td>2.60</td>
<td>5.70</td>
<td>8.0</td>
<td>100</td>
<td>65</td>
<td>3.0</td>
<td>33.3</td>
<td>250</td>
<td>3.25</td>
</tr>
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<td>4.7</td>
<td>0.37</td>
<td>0.80</td>
<td>8.0</td>
<td>100</td>
<td>65</td>
<td>3.0</td>
<td>33.3</td>
<td>250</td>
<td>3.25</td>
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<td>1.16</td>
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<td>150</td>
<td>100</td>
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<td>4.6</td>
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<td>0.95</td>
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<td>150</td>
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<td>200</td>
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<td>2.70</td>
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<td>200</td>
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<td>15.4</td>
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<td>10.0</td>
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<td>15.8</td>
<td>375</td>
<td>5.3</td>
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<td>425</td>
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<td>625</td>
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<td>110.5</td>
<td>10.2</td>
<td>625</td>
<td>6.99</td>
</tr>
</tbody>
</table>

*Add suffixes S or DS to single ended shaft D or DDS to double ended shaft.

| Operation below rated current will reduce torque and may degrade step accuracy.

| Conduct box, keyway, and encoder ready options are available on request.

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

| 62 |

**ANAHEIM AUTOMATION**

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

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Figure A-21
WIRING INSTRUCTIONS

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

**MOTOR CHECK**
Set ohmmeter to highest scale available. Do a resistance check between each motor lead (8 total) and the motors face plate. The resistance in each case should be infinite. Do this before connecting the motor to the drives. Slowly rotate motor one complete revolution, and make sure readings are infinite, if any of the leads appear to be grounded to the case, DO NOT use the motor to the driver. If the motor passes this check, wire the motor to the drives as follows:

**BLD/BLEN-3/BLEN/DPS/DDP Series**
- RED: TERMINAL 1 (R1)
- BLACK: TERMINAL 3 (COM 01 & 3)
- WHITE: TERMINAL 11 (COM 02 & 4)
- GREEN/WHITE: TERMINAL 13 (G4)

**SPT Series**
- RED: TERMINAL 1 (R1)
- RED/WHITE: TERMINAL 2 (G2)
- BLACK: TERMINAL 3 (COM 01 & 3)
- WHITE: TERMINAL 4 (COM 02 & 4)
- GREEN: TERMINAL 5 (G5)
- GREEN/WHITE: TERMINAL 6 (G6)

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

**IMPORTANT NOTE:** Before wiring from the motor to the drive, consult the factory for proper safety guidelines. Wiring connected to inputs must be isolated from motor control and any other possible sources of interference, i.e., 110VAC power lines or other motor/induction loads.

**MOTOR/DRIVE CHECK**
Once the motor is wired to the drive, RE-CHECK TO MAKE SURE EACH WIRE IS CONNECTED TO THE PROPER TERMINAL. Set ohmmeter 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/BLEN-3 & BLEN) 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/BLEN-3 & BLEN) 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 DRIVE, DO NOT APPLY POWER TO DRIVER PACK. CONTACT ANAHEIM AUTOMATION (714) 952-6699 OR YOUR LOCAL REPRESENTATIVE/DISTRIBUTOR FOR FURTHER ASSISTANCE.

If all readings are correct, you will need to set the Kick Current potentiometer for the required setting for each motor used in the system. DPM, DTP, DPO, CPW 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 provisions violates safety standards of design, manufacture, and intended use of products. Anaheim Automation assumes no liability for the customer’s 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.
Appendix B

Part Drawings
SCALE : 0.500  TYPE : PART NAME : RECEPTION BLOCK SIZE : A
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, 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 PLATE 1
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
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   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 PLATE 1
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