AUTOMATION OF SEMICONDUCTOR

PROCESSING EQUIPMENT

by

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A THESIS

IN

ELECTRICAL ENGINEERING

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

MASTER OF SCIENCE

IN

ELECTRICAL ENGINEERING

Approved

August, 1999

ACKNOWLEDGEMENTS

I am deeply indebted to my advisor, Dr. Micheal Parten, for his most valuable guidance and colossal support during my education at the Texas Tech University. Thank you for being patient and understanding. I thank Dr. David Mehrl and Dr. Sunanda Mitra, thesis committee members, for their excellent cooperation and interest in this project. A special thanks to the Department of Electrical Engineering for giving me this valuable opportunity to study at Texas Tech University.

I wish to extend my deepest gratitude to my grandparents, Mr.Nageshwara Sharma and Mrs. Padmavati, my parents Mr. Venkat Rathnam and Mrs. Meena Kumari, for their love, encouragement and blessings throughout my entire life. I thank my little sister, Sirisha, for her affection and well wishes.

I would like to thank my uncle Dr. Naga S.Bushan and my aunt Mrs. Jyothi Bushan for their guidance and encouragement during my stay at Lubbock.

I am extremely thankful to Mr. Amit Deshpande, and Mr.Vishal Agrawal for their timely help. A special thanks to Mr.Tasnim Murad Hossain for his help and cooperation.

Finally, I thank all my friends for their support, encouragement, and well wishes. Thanks for the memorable moments and friendship.

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ABSTRACT

This thesis describes a methodology to Automate Semiconductor Fabrication Equipment. The current processing Industry makes use of stand-alone equipment with built-in Microcontrollers, which are hardcoded or programmed using EPROMs to accomplish that particular process. The cost of building such systems is expensive. Automation of these systems is time consuming and difficult. These systems require a lot of user intervention during processing.

This thesis presents a comprehensive insight into a generic approach of Automation of a process. A methodology has been discussed to automate a machine using DAQ (Data Acquisition Boards) and External Interface Boards controlled by LabVIEW, a graphical programming language tool. This approach of automation is implemented and verified on two processing systems, namely a Plasma Etcher and a Plasma Deposition System.

The project explains the specifications of the hardware needed and describes a modular approach to design the LabVIEW control program. It explains how this approach can achieve improved process performance by efficient monitoring and controlling of the process parameters for increased yield and productivity. The advantages of this methodology of automation are discussed along with applications.

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CHAPTER I

INTRODUCTION

Growing technological requirements and the widespread acceptance of sophisticated electronic devices have created an unprecedented demand for large-scale, complex, integrated circuits. Meeting these demands has required technological advances in materials and processing equipment, and an increased emphasis on effectively utilizing the computer to aid the process of manufacturing integrated circuits.

The IC manufacturing process involves many physical and chemical processing steps such as; oxidation, photolithography, epitaxy, ion implantation, chemical vapor deposition, etching and diffusion. To create an IC, these processes have to be repeated many times [1]. IC fabrication requires the use of electromechanical, optical and electronic equipment and materials capable of precisely maintaining close tolerances and small geometries.

VLSI processing requires that the process parameters, like gas flow rates, pressure and RF power be tightly monitored and controlled. In any typical fabrication equipment with minimal automation, the process parameter settings have to be controlled manually. Any changes in process parameters leads to variation in the results that are unacceptable for sub micron device geometries. Manual control of process parameters and equipment may induce errors that are cost prohibitive in todays wafer labs.

As wafer size increases and the critical dimensions decrease, stringent requirements are imposed on processing. It is desirable to process every wafer under identical conditions. Process yield has increased with the evolution of single wafer processing systems that are fast replacing batch reactors where several wafers are processed together. Due to the nature of single slice processing, machine dynamics may change from second to second and from wafer to wafer. It becomes necessary to monitor all the run time data such as pressure changes, flow rate changes, RF power, and other parameters.

With changing technology, newer recipes for processing are developed at increasing frequency for smaller device sizes and to increase the yield. The fabrication systems must be able to implement the new recipes without many changes in the system setup. Hence for a successful, high yield process, automation and control of semiconductor fabrication equipment is necessary. With the evolution of single wafer processing systems and using microprocessor-based hardware and software, real time monitoring and control systems have been developed to ensure that wafers are processed properly at every step. An automated wafer fab increases productivity and cycle time through manufacturing by as much as 50% and reduces the cost of manufacturing and labor.

The current processing industry makes use of automated equipment for each process. The processes use stand-alone equipment with built-in microprocessors or application specific microcontrollers, which are hardcoded or programmed to accomplish that particular process. If equipment for an other process has to be automated then again a process of designing an entire stand-alone system takes place. The disadvantages of using such systems are: they are expensive to manufacture; it consumes a lot of time to program the devices for such systems; and the user has little control of the internal system. In todays rapidly changing environment, manufacturers want to be able to improve the processes continually. This can require being able to alter the monitoring and control of the individual process. To accomplish these changes, a generic approach for monitoring and control of processes and equipment is desired. The main emphasis of this work is to develop a methodology for automatic monitoring and control of fabrication equipment using readily available hardware and software while still providing tight control over the process parameters for increased yield and productivity.

The challenge is to achieve improved processing performance by monitoring and controlling parameters using readily available and modifiable systems. This can be done by using a data acquisition (DAQ) and control system with LabVIEW, a graphical programming language (GUI) tool. Data acquisition is the process of bringing a real world signal, such as voltage, into the computer for processing, analysis, storage or other manipulation. Each process is characterized by certain parameters like gas flow rate, pressure inside the chamber, temperature and RF power. Using a PC- based DAQ and control system run by LabVIEW, it is possible to control the equipment with a hardware and software system that can be easily understood and modified.

LabVIEW can command DAQ boards in the computer to read analog input signals (A/D conversion), generate analog output signals (D/A conversion), read and write digital signals. So using a data acquisition system and generic LabVIEW code, that can be easy modified, automation of equipment for any process can be implemented instead of using embedded devices and stand alone automation.

The advantages of such a generic approach are that system monitoring and control are easier to understand and modify because of LabVIEW's flexibility and ease of programming. Excellent control can still be maintained, over process parameters because of the real-time feedback control system. This system can be implemented without losing the integrity and the safety parameters of the equipment.

This generic approach, i.e., using LabVIEW controlled DAQ system for automation, has been realized and implemented on two semiconductor processing pieces of equipment, namely, a Plasma Etcher and a Plasma Deposition system. The methodology, results and applications are discussed in the ongoing Chapters.

Chapter II explains the approach for Automation. It discusses the requirements of DAQ Boards and External Interface Boards, along with the tools that have to be used in automation.

Chapter III explains the implementation of the Generic approach on a Plasma Etcher and Chapter IV explains the implementation of the approach on a Plasma Deposition System. Both the chapters explain the DAQ Boards Used, their specifications, and the design of external interface boards. The LabVIEW code used for automation is also explained in both the chapters. Chapter V discusses the Measurements taken. Chapter VI discusses the merits of such an automation approach and its applications.

CHAPTER II

APPROACH FOR AUTOMATION

2.1 Introduction

This chapter discusses an approach to automate, i.e. to enhance the monitoring and control of a process and its parameters using an IBM-PC and a LabVIEW control program. A block diagram of a general processing system is shown in Figure 2.1.

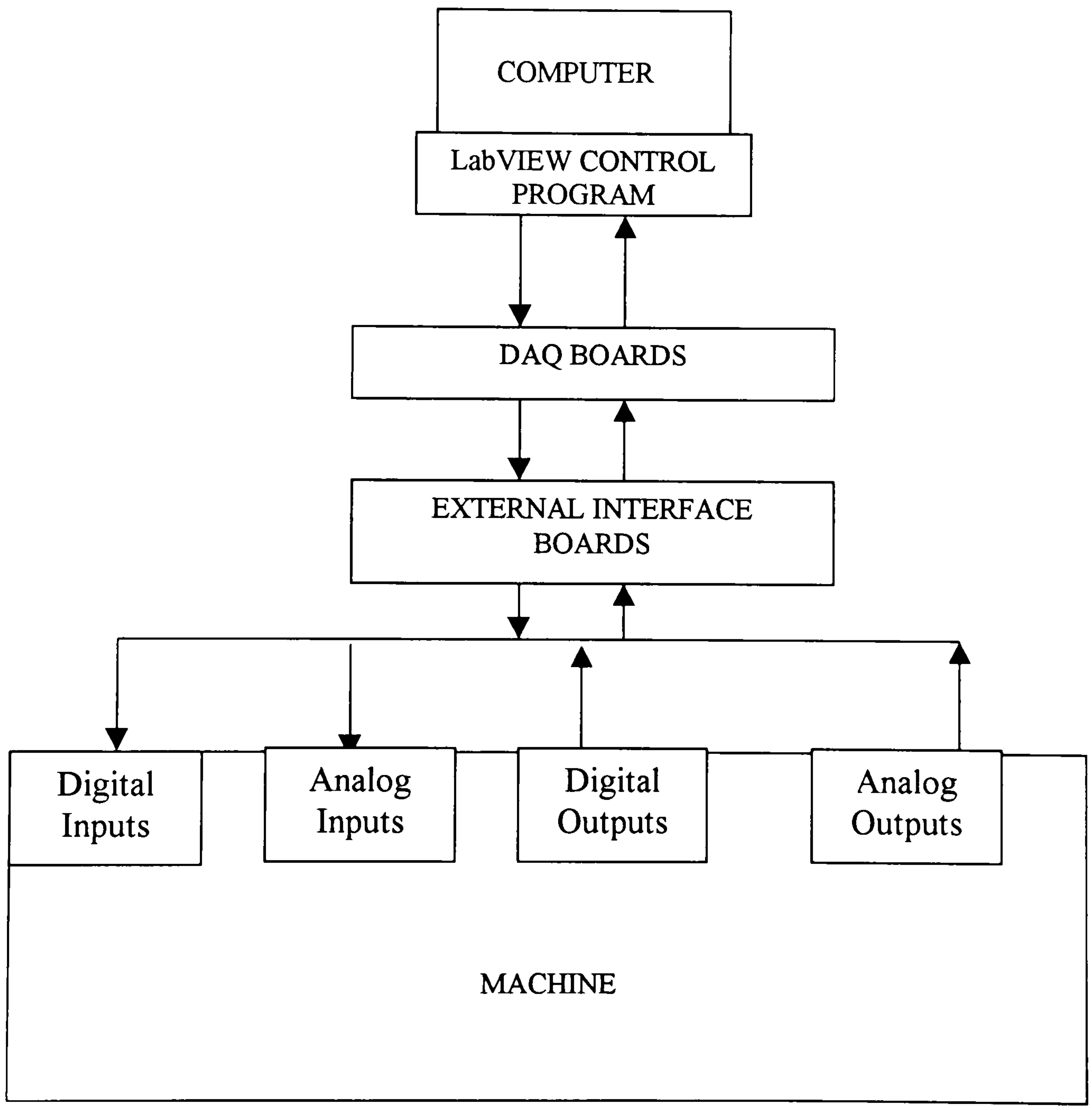


Figure 2.1 Block diagram of an automated system.

A processing machine may require digital input signals or analog input signals from the computer and it can send out digital signals or analog signals or both, back to the computer. Digital signals are used to control the energizing of components like solenoids and relays on the machine. Analog inputs to the machine may be setpoint voltages to throttle valve controllers, or mass flow controllers (MFCs). Analog outputs from the machine can be feed back signals like gas flow rates from MFCs or signals from other transducers. An example of digital input signal to the computer is a set point from a temperature sensor.

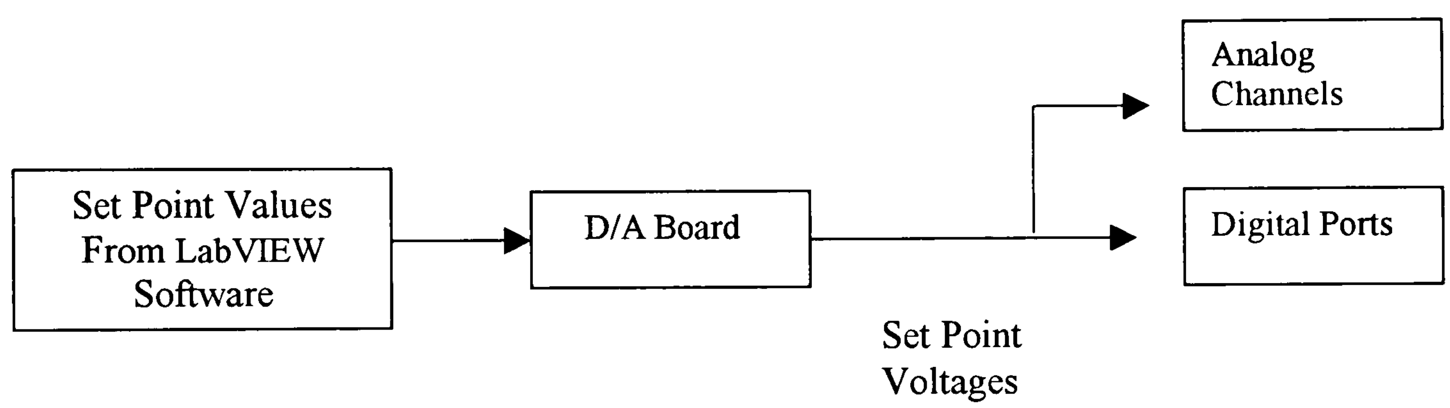
2.2 Approach and Requirements

To properly control the process, an interface is needed to allow the computer and machine to communicate with each other efficiently without making many modifications to the machine. LabVIEW is an excellent GUI software tool that can be used as a control program. The first step in developing a controller is to determine the parameters that need to be controlled. The corresponding components on the machine, must be identified along with their voltage and current specifications, like MFCs for gas flow rate, throttle valve controllers to control pressure in the chamber of a processing equipment, solenoids and their voltage ratings, etc.

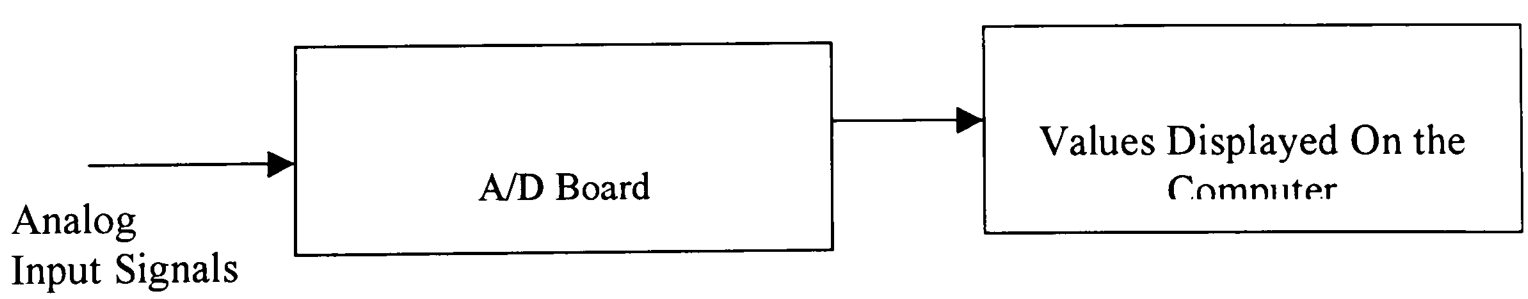
The signals sent out by the computer are digital but the machine may accept analog and/or signals. At the same time, the machine sends analog and/or signals as inputs to the computer. Therefore, DAQ (data acquisition) boards that have the capability to do D/A (Digital to Analog) conversion and A/D (Analog to Digital) conversion are needed.

2.2.1 DAQ (Data Acquisition) Boards

The D/A DAQ board must accommodate the right number of D/A channels with a good bit resolution, sampling rate and extra lines of digital input/output. The D/A channels are used to control the analog inputs to the system. The extra lines of digital outputs are used to control the energizing of components like solenoids and relays. Figure 2.2 (a) shows the diagram of operation of a D/A board. The A/D DAQ board is used to read in the analog input signals into the computer. It should have the right number of A/D channels to accommodate all the parameters that affect the process. Figure 2.2 (b) shows the diagram of operation of an A/D board.



(a)



(b)

Figure 2.2 DAQ Boards (a) D/A DAQ Board (b) A/D DAQ board

The DAQ boards should have an option for the user to select the voltage ranges of incoming and outgoing signals to some degree.

2.2.2 External Interface Boards

In most cases, the signals sent out by the computer are 5 volts or maximum of 10 volts. But a machine may use components like solenoids and relays, which operate at a DC or AC voltage that is far greater than TTL voltages and currents provided by DAQ boards. Hence, to energize these switches and high voltage rated components on the machine, and to buffer the DAQ card signals, an external interface board, is needed. The driver circuits for the interface should be designed taking the specifications of the components on the machine into consideration. Figure 2.3 shows the data flow.

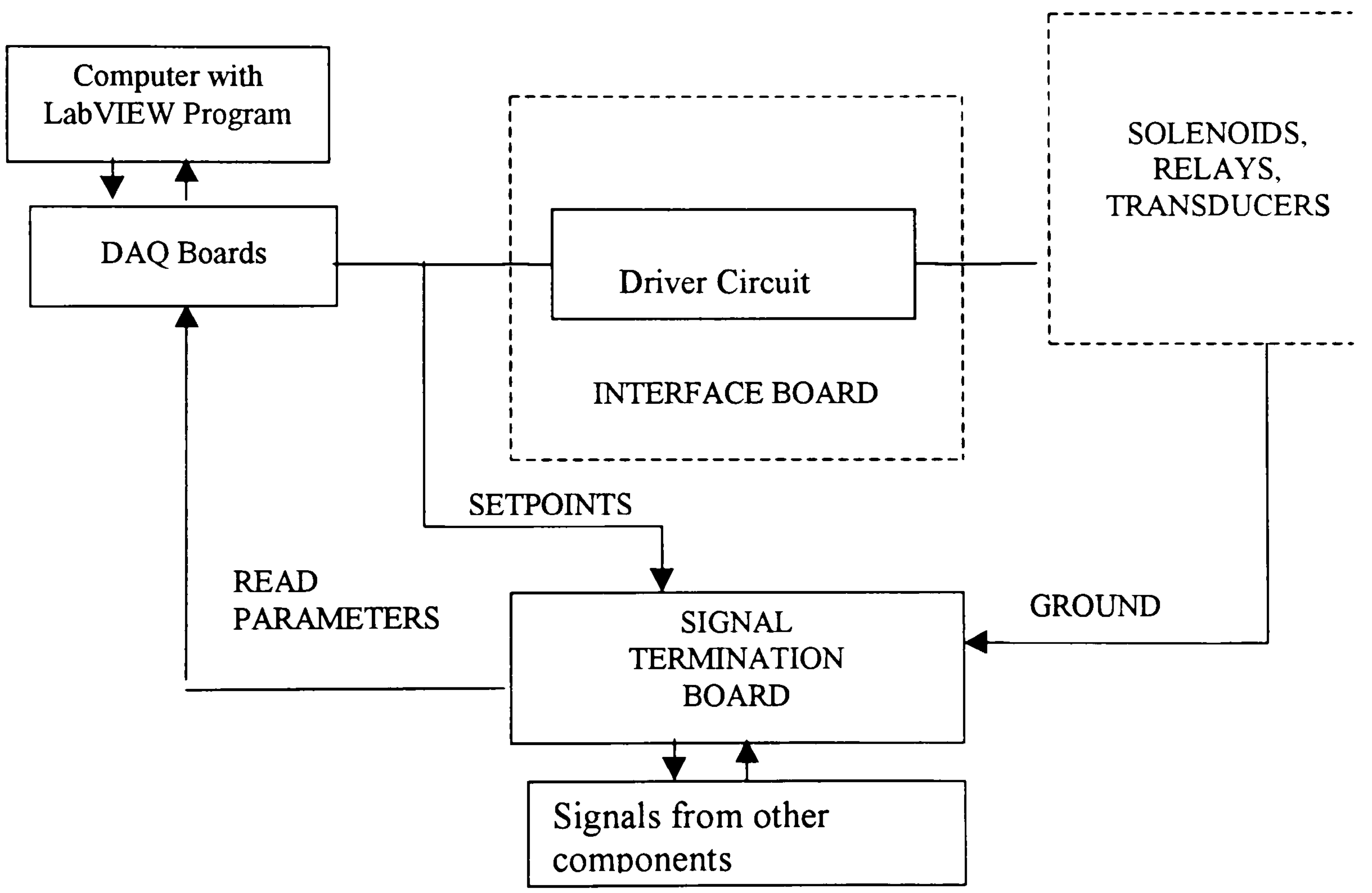


Figure 2.3 External Interface Board

All the signals should be routed through a signal termination board to avoid the complexity of wiring. For example, the computer can send a setpoint voltage to a Mass Flow controller through a signal termination board and also read the flow rate value from that MFC through the same board.

With this kind of hardware setup, the communication between the computer and the machine can be established very efficiently and the user will have tight control over the process. With the interface found and DAQ boards selected, the next step is to develop the software to control the process.

2.2.3 LabVIEW Control Program

The control program is written in LabVIEW. It controls the parameters that effect the process. LabVIEW is short for Laboratory Virtual Engineering Workbench. LabVIEW is a program development application, much like commercially available C or BASIC development systems. The only difference between LabVIEW and other programming languages is that LabVIEW is graphical in nature, while the other languages are text based. LabVIEW uses a graphical programming language, G, to create programs in a flow chart like form, eliminating a lot of syntactical details [4].

LabVIEW is a powerful and very flexible instrumentation and analysis software system that runs on PCs, Apple Macintoshes, Sun SPARC stations and HP 9000/700 series workstations running HP-UX. LabVIEW programs are called Virtual Instruments (VIs), because their appearance and operation imitate actual instruments. It has two main parts:

a. The front panel is an interactive user interface of a VI, because it simulates the panel of a physical system. The front panel can contain Switches, knobs, graphs and all kinds of numeric, Boolean or string controls (user input) and indicators (result of program).

b. The block diagram is the VI's source code, which is designed using LabVIEW's graphical tools. A VI can have a number of sub VIs which are like Functions in a C Program. The graphic tools have all the control loops like "for" and "while" loops, all the arithmetic and logical tools and some in-built VIs for data acquisition and statistical analysis.

The user sets all the parameters using a LabVIEW control program and the DAQ boards send the set point voltages to the machine and feed the run time data from the machine into the computer and the control program displays the data on the screen. Once the process time finishes, the system shut downs automatically. The program has to be written in such a way, that the entire system can have a sequential control or closed loop control depending on the application.

2.3 An Approach to Control Program

The software is divided into three stages. They are:

1. Setup Stage,
2. Monitor Stage,
3. Shut Down Stage.

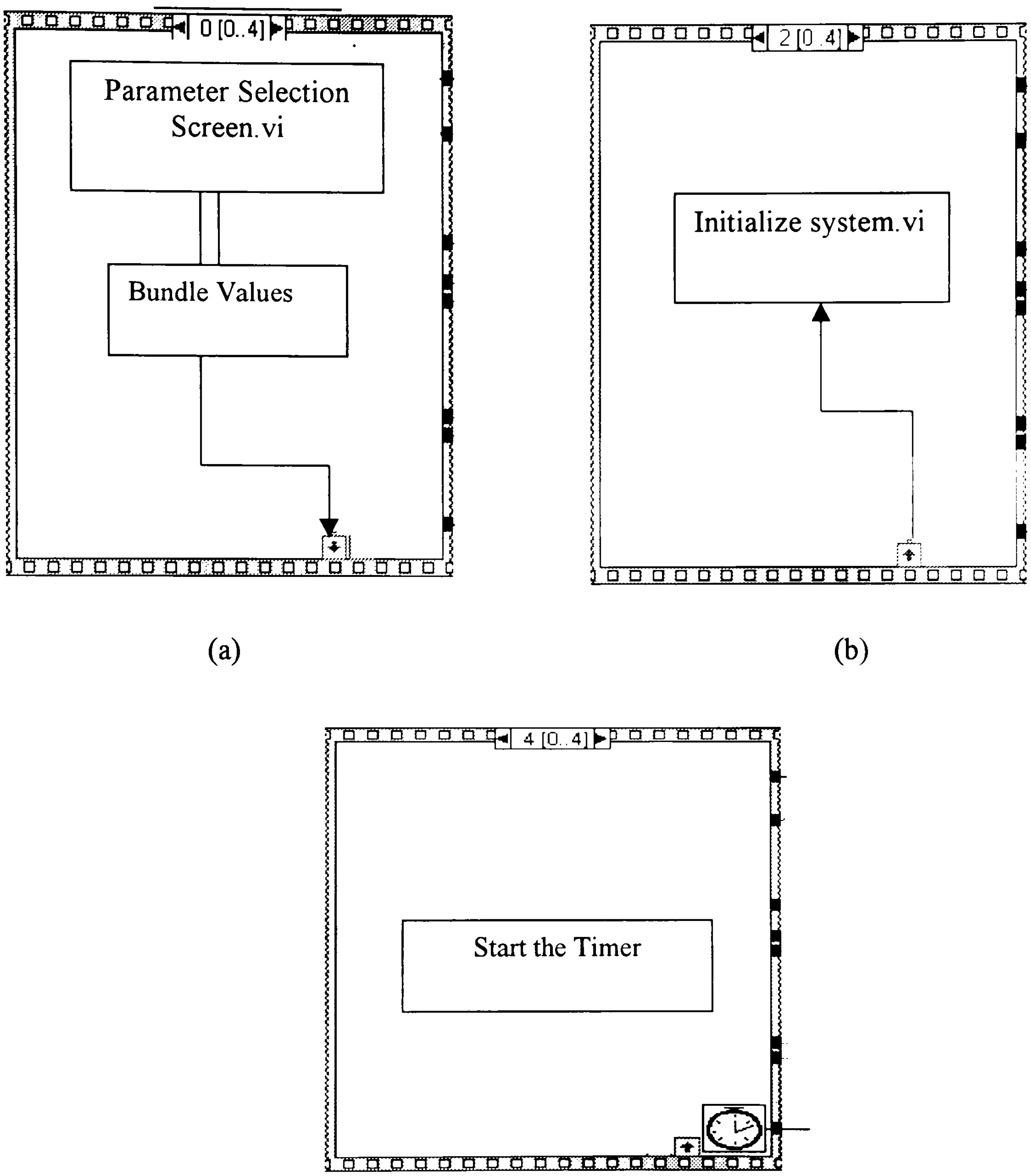
The DAQ boards are used to output the setpoints to the Machine and to get the fedback signals into the computer. The next section discusses how each stage should be designed and also explains the LabVIEW tools to be used for reading analog and digital Signals into the computer and sending out the same to the machine. Before designing the control program, the user has to configure all the boards using driver software, so that the system can recognize the boards and their addresses.

2.3.1 Setup stage

This stage takes different input values from the user. LabVIEW allows the user to create a VI and to call it in an other VI. It is called a subVI. It has inbuilt control loops like WHILE loop, FOR loop, CASE structure, and SEQUENCE structure. LabVIEW allows the user to use one loop inside an other loop. This feature is an advantage in designing the control program. The setup stage is divided into three more substages. In the first substage the user selects the parameters and sets the values along with the process time. These values are bundled and passed onto the next stage, where the DAQ boards are initialized and the values are written to the output Ports (substage 2). In the third substage, the timer is started. The Timer stage is optional. This is shown in Figure 2.4

As mentioned earlier, LabVIEW allows use of one loop in another loop. This is shown in Figure 2.5. Here a CASE structure is used in a SEQUENCE structure. This is an example, which shows how multiple CASE structures can be used to send out values to the next stage. A parameter selection sub VI is shown in Figure 2.5 where the user selects a parameter, out of four, along with its value. The "wires" which go to the CASE structure are parameter values and the wires which go to the function 'Build Array' are

Boolean values, which indicate the parameter selected by a binary '1' and the one not selected, by a binary'0'.



(c)

Figure 2.4 Different Stages of Setup Stage (a) Substage1 (b) Substage2 (c) Substage3

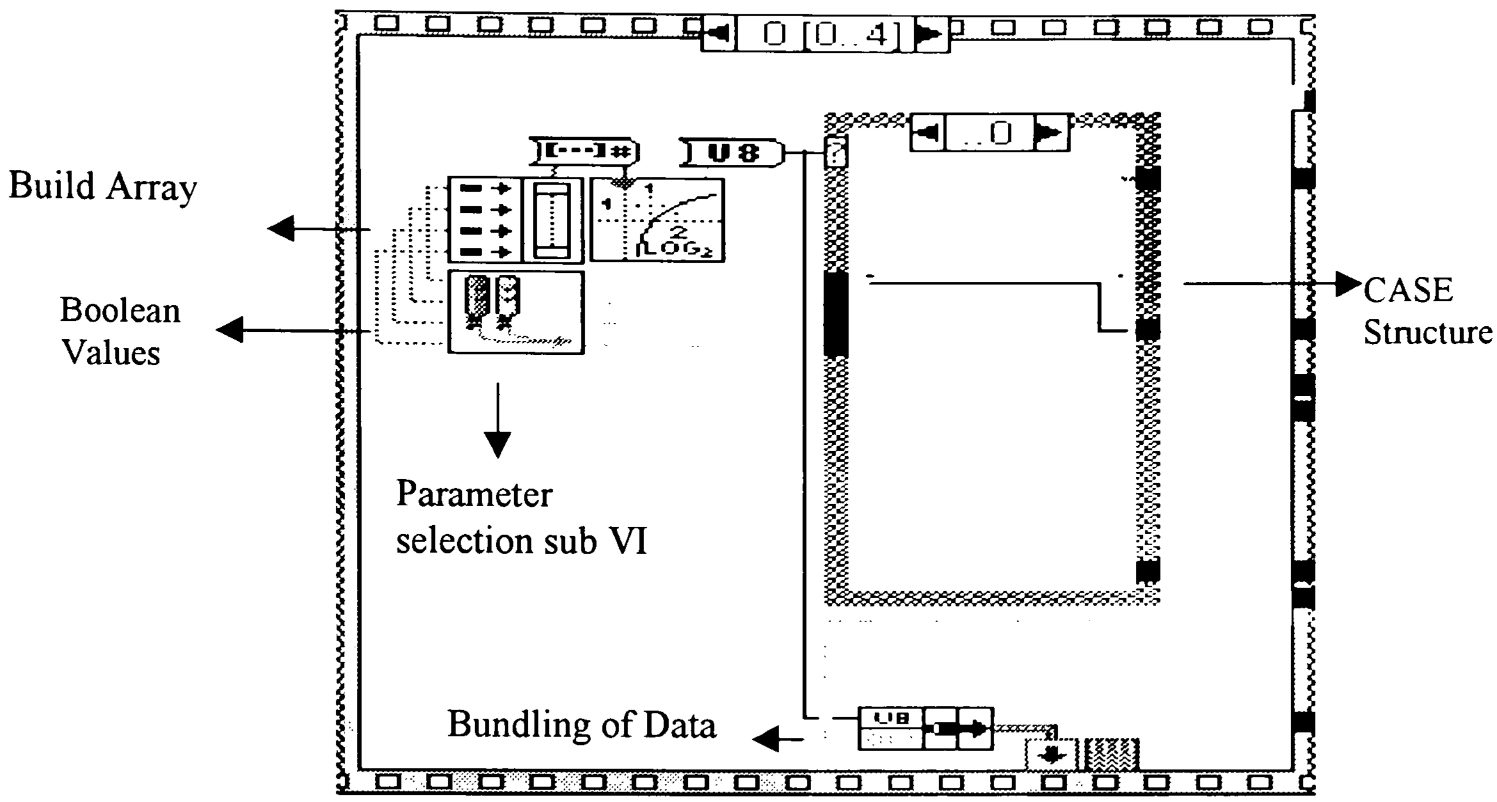


Figure 2.5 Example to show bundling and CASE selection

Then, these Boolean values which are either 1or 0 are given to a function in LabVIEW, called 'Build Array'. The build array function appends any number of array or element inputs in top to bottom, to create an array with appended elements. This array is then given to function called 'Boolean Array to number', which converts this Boolean array to long integer by interpreting it as 2's complement representation of an integer with 0 th element as least significant bit.

This number is then given to a 'Logarithm Base 2' function tool, which computes the log of the number to the base 2. This final number is given to the CASE structure. Depending on the value of the number, that particular CASE will be evaluated. The number of CASE structures will depend on, number of parameters used. Then the parameter number (CASE number) and value are bundled together and advanced into next Sequence frame. There are other ways of selecting a CASE, but this way of selection is efficient and useful when an operation in a CASE has to be evaluated depending on the input selection in another VI.

In SubStage 2 of Figure 2.4, the DAQ Boards are initialized. The values set by the user in the previous stage are used to write to the ports. But before writing to the port, the value must be converted to an equivalent value in volts. This is done using a function called 'Formula Node'. This is shown in Figure 2.6. The left side of the node has the incoming value (P) and the right side of the node has outgoing value in volts or millivolts (PS). The floor function truncates the value to a decimal value.

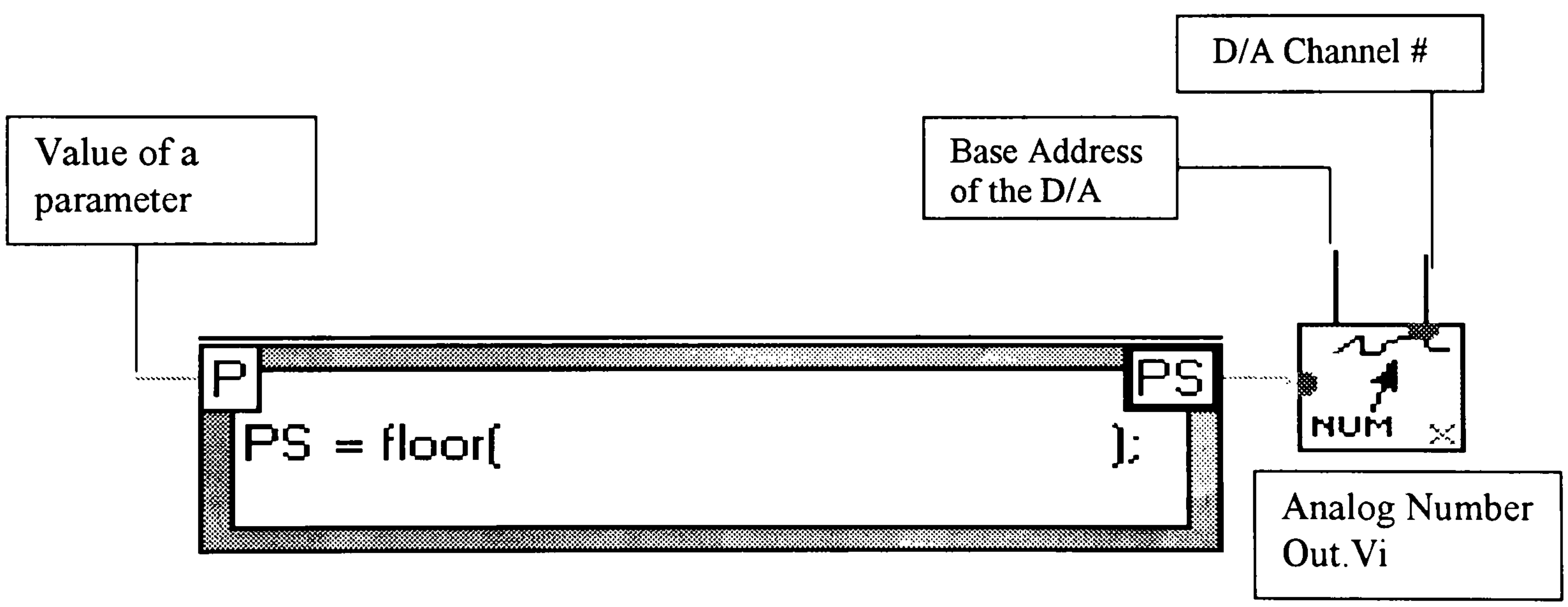


Figure 2.6 Writing a value to an output port.

A sub VI called 'Analog Number Out.vi' is used to write the value to a port. Figure 2.7 describes the operation of this VI with a Base address of H330. The absolute address of the D/A channel is calculated by multiplying the D/A channel number by 2 and adding it to the base address, which in this case is 330H. All addresses are sixteen bit. So for a D/A #4 the absolute address is

0330H + [(4*2) =008H] = 0338H or 0000 0011 0011 1000 b.

This VI makes use of a 'call library function', that calls standard libraries and DLL function libraries. The 16-bit value is written at the sixteen-bit address by calling a shared library function. For some boards, for which specifying base address is not necessary, an inbuilt VI in LabVIEW, called 'Analog Output Update channel.vi' is used. Figure 2.8 shows the necessary inputs to this VI.

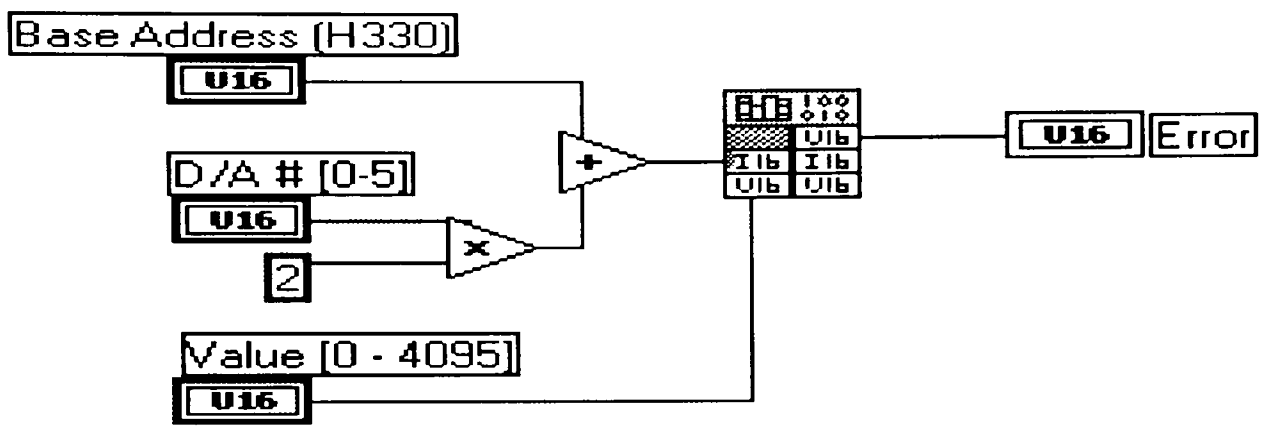


Figure 2.7 Analog Number Out.vi

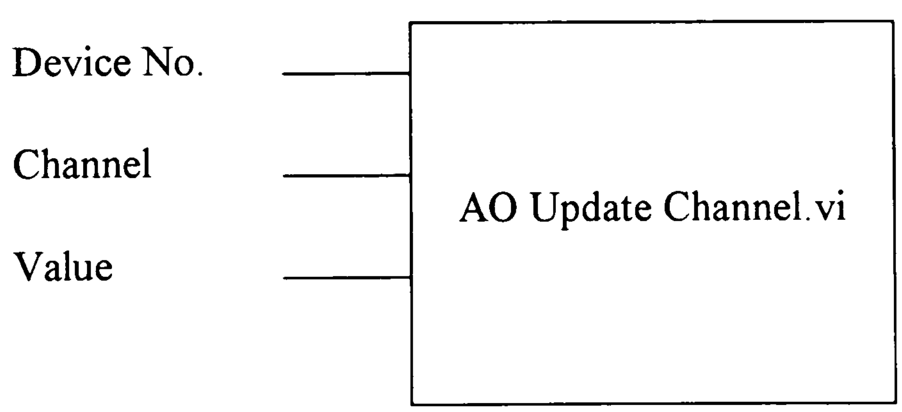


Figure 2.8 Analog Output Update channel.vi

To send out a digital signal, a VI called ' Digital Out.vi' is used. This VI is shown in Figure 2.9. This sub VI is used to write to a digital port. It is basically the same as an Analog Out.Vi with a difference that instead of D/A channel number, integer 0-N is

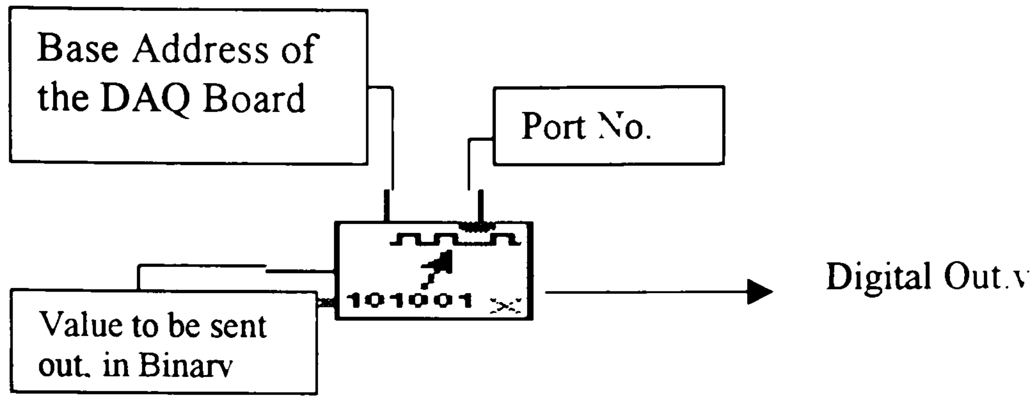


Figure 2.9 Writing a value to a Digital Port

assigned to each PORT. A binary value is written to a port. An example, where base address is H330 is shown in Figure 2.10. In cases where it is not necessary to specify the base address, another VI called ' write to digital port .vi' is used. The function diagram is shown in Figure 2.11

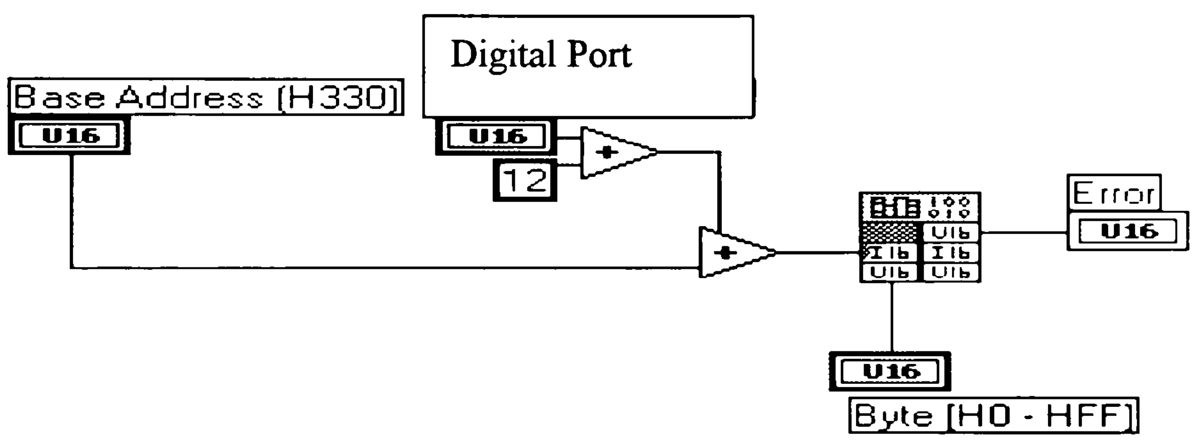


Figure2.10 Digital Out.vi

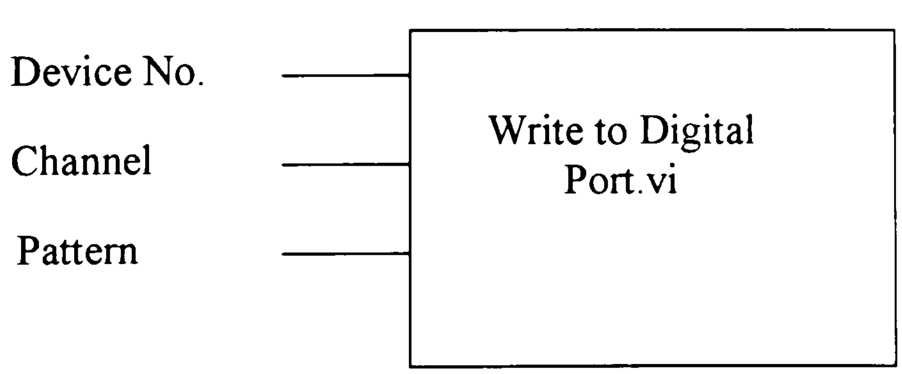


Figure 2.11 write to digital port .vi

Once the Boards are initialized and values are written to output ports, the Timer turns on, in the substage 3 (If time is necessary in the process) and the control goes to the next stage of the program, 'Monitor Stage'.

2.3.2 Monitor Stage

This stage takes the run time data from the machine and processes it for displaying on the computer. In this stage the values of different parameters are obtained using DAQ boards (A/D) and checked for Tolerance. If either the tolerance is exceeded or if the process time finishes, the control goes to the next stage, the 'shutdown stage'. To read in the data an inbuilt VI called 'Analog Input Sample Channel.vi', is used. This VI is explained in Figure 2.12. If it is a digital input, a VI called 'Read from Digital Port.vi' is used. This is shown in Figure 2.13

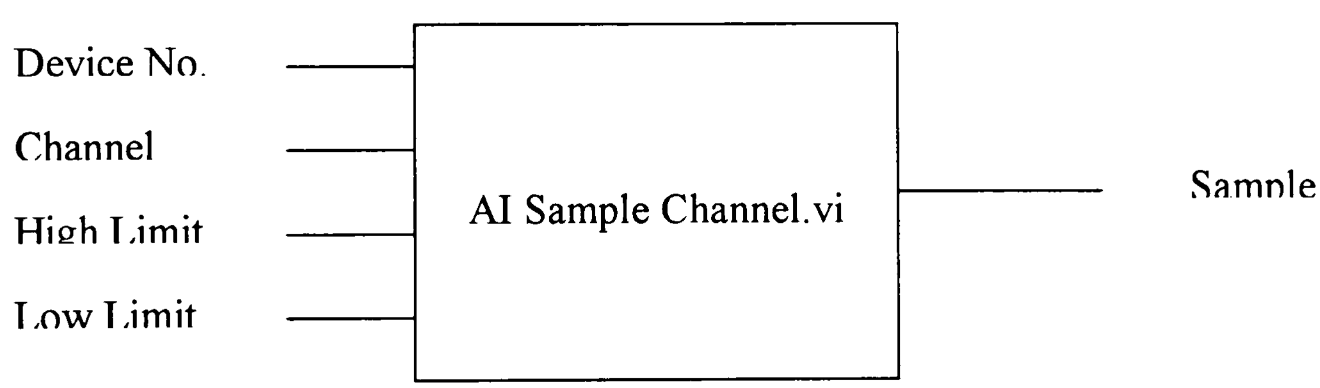


Figure 2.12 VI used to read in an Analog Input.

The terminals for this VI are:

1. Device No.: the number assigned to the DAQ device during configuration.
2. Channel: The analog channel, which will be used for data acquisition. This is a string type variable.
3. High Limit: The expected level of the signals.

4. Low Limit: The lowest expected signal level.
5. Sample: The measured signal.

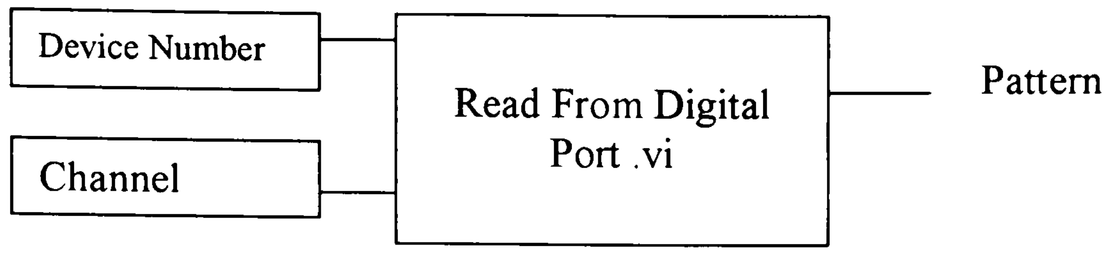


Figure 2.13 VI used to read Digital Input

2.3.3 Shutdown Stage

This stage de-energizes all the controls on the machine and writes '0's to all the output ports and the system will be ready for the user to repeat the process.

2.4 Flow of Data

A flow chart is shown in Figure 2.14 to depict the flow of data and to explain the entire process control using the hardware described and the LabVIEW control program. First the user selects the parameters needed for the process and their setpoint values, using the control program. These setpoint values are converted to equivalent volts or millivolts and are given to their corresponding controllers on the machine through the DAQ boards (D/A). The user sets the timer and the process is started. The controllers on the machine adjust the parameters of the process by comparing their current value, to the value set by the user. The values of the process parameters are read into the computer using the DAQ boards (A/D) and the control program displays them on the monitor. The program also checks values for their tolerance. If either the parameters exceed their tolerance value or if the process time finishes, the system is shut down by making the setpoint values going to the machine, zero. The system will be ready for the user to make an other run.

A LabVIEW program designed using this modular approach will be efficient in monitoring and controlling a process. With these kind of tools and VIs to send out signals from the computer and to read in signals into the computer, using DAQ boards and interface boards, automation of an equipment can be done efficiently. This generic approach to automation was implemented and verified on two semiconductor-processing systems, namely a Plasma etcher and a Plasma Deposition System. The next chapters discuss how the two systems were automated using this methodology of automation.

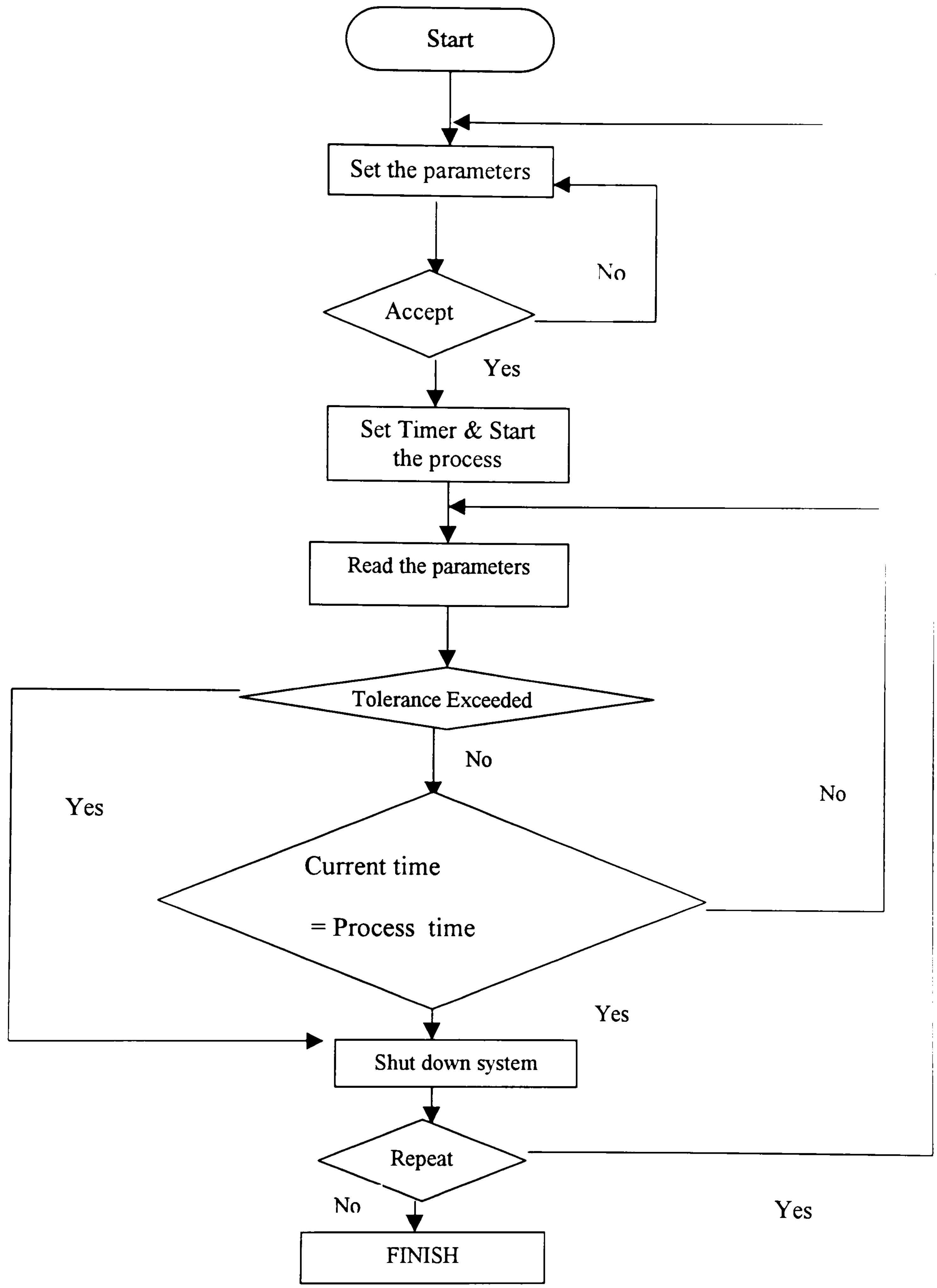


Figure 2.14 Flow Chart of Process Control

CHAPTER III

IMPLEMENTATION OF AUTOMATION APPROACH ON A PLASMA ETCHER

3.1 Introduction to the Plasma Etcher

An Autoload Single Slice plasma reactor (ASPR) [2], Plasma Etcher, was originally manufactured by Texas Instruments, Inc. It has the capability of processing a single slice at one time. It has a non-symmetric parallel plate capacitively coupled planar reactor, where the power is applied to the top electrode and the bottom electrode is grounded. The discharge is created between these two plates. The ASPR consists of a RF generator cabinet, Process Chamber, remote vacuum pump and a computer controlled automation system as illustrated in Figure 3.1. The original monitoring and control system has been replaced with a PC-based system.

The process chamber provides a controlled process environment for plasma etching. The chamber consists of an enclosure, powered electrode plate and substrate plate. The process gases flow from top to bottom through the chamber. The electrical system of the power supplies, RF tuning assembly, remote RF console, the DAQ system. The plumbing system provides for the various gases, an exhaust system and chamber vacuum control. The gases are controlled by Solenoid valves and the amount of gas flow

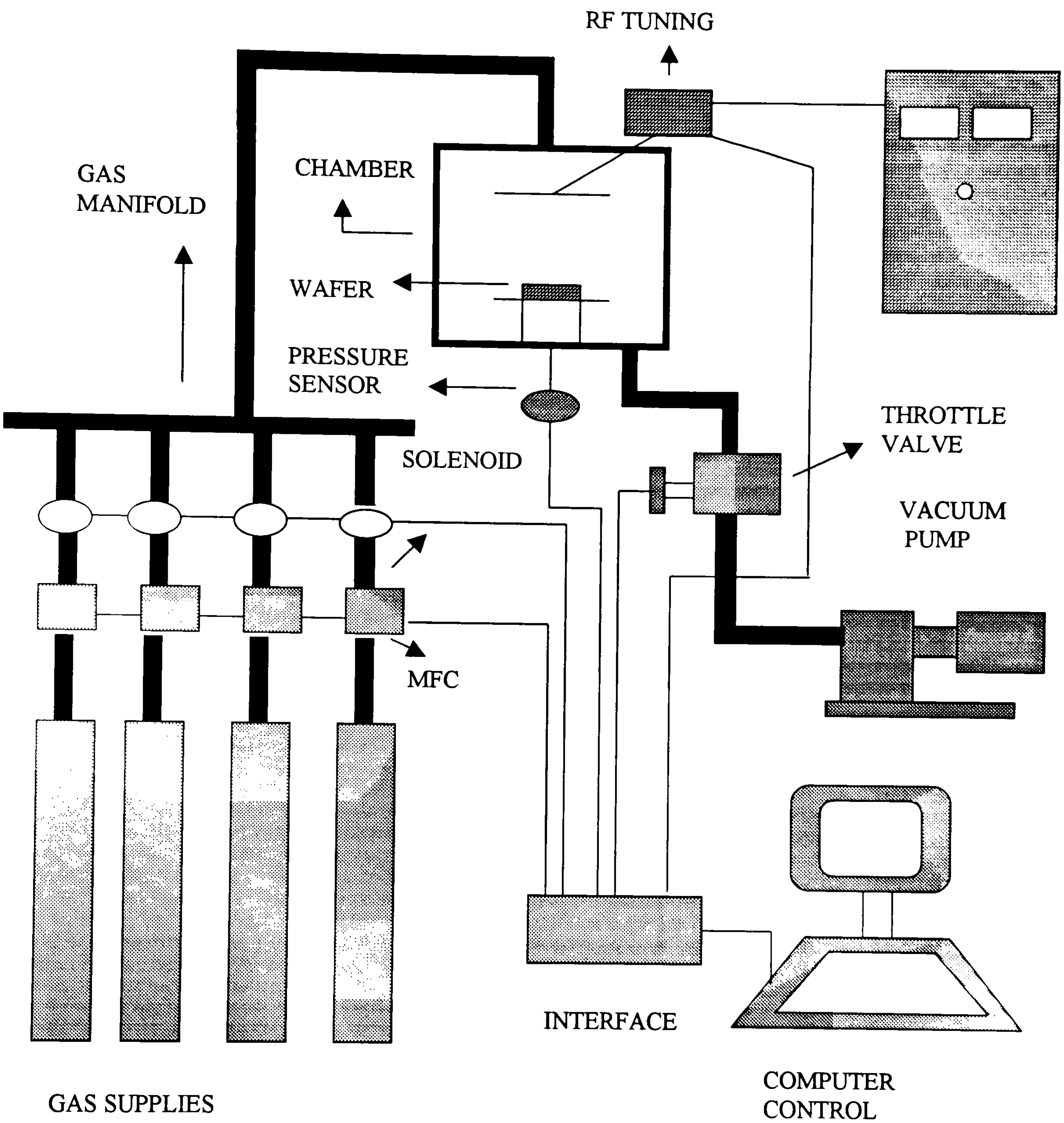


Figure 3.1 The automated Plasma Etcher System

is controlled using mass flow controllers. The by-products during etching are removed by the exhaust system. The pressure is controlled by software actuation of a throttle valve.

The ASPR was originally designed to be controlled by an ASD/99A on-board computer and a manual data terminal. The control software was stored in EPROMs. Thus the modifications to the control program were time consuming and inconvenient. Hence, it is interfaced with a PC and DAQ boards which proved to be efficient. Before discussing the DAQ Boards and interface boards, a brief explanation of the system is given.

3.1.1 Process Chamber

The process chamber assembly consists of the upper electrode assembly, the chamber housing and the substrate plate. The process chamber electrode assembly consists of a parallel plate electrode design with the radial gas flow from the top to bottom of the chamber. The ion and electron production between the electrodes in the chamber housing and the gas flow determine the etch characteristics. The upper electrode is powered by the RF generator, it provides the electrical field between the electrodes that ionizes the gases to produce the ions and electrons. The cross section view of process chamber is shown in Figure 3.2

3.1.2 Chamber Housing

The chamber housing consists of the bottom plate, which is the lower enclosing surface of the process chamber, an optical window, and a window for end point detection.

The bottom plate has ports for various accesses to the chamber. Th exhaust gases are removed through the exhaust port. The pressure is monitored by the sensor assembly mounted below the bottom plate. Chamber housing has an inlet to let the air inside the

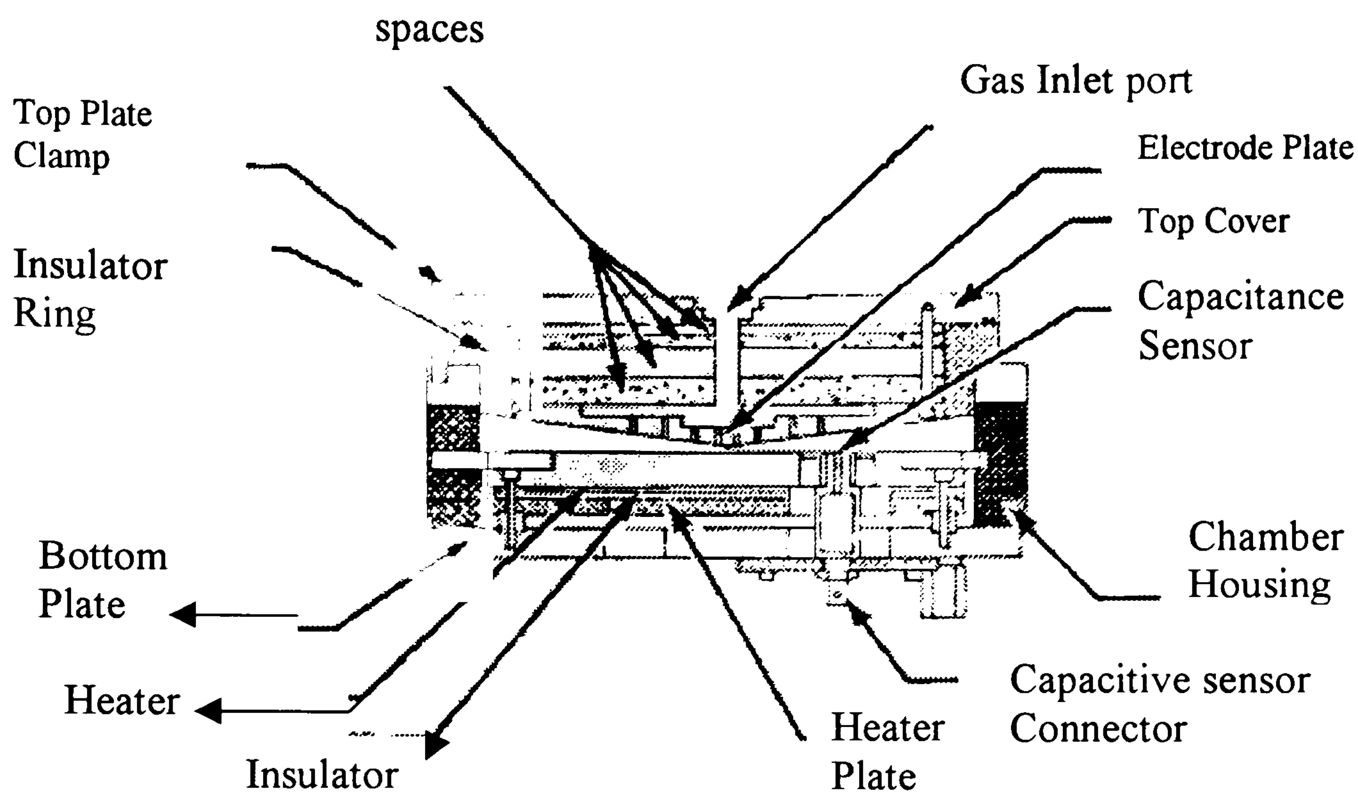


Figure 3.2 Cross Section of Process Chamber

pressure housing which prevents the RF generator from being turned on until the chamber is evacuated to a low pressure. An additional aluminum spacer is added between the bottom plate and the chamber housing to facilitate the addition of an external heater in the chamber.

3.1.3 Upper Electrode

The feature that separates the ASPR from the conventional parallel plate plasma reactors is the use of porous, non-flat upper electrode. The multiple process gas enters through the upper electrode. The upper electrode assembly consists of a number of spacers fastened together. It is insulated from the rest of the chamber using dielectric rings. The spacers help in changing the plate to electrode distance.

The process gases enter the chamber through the gas filter block. The gases flow through the central passage between the spacers and the upper electrode. The upper side of the electrode has a gas plenum chamber to equalize the flow from multiple orifices. The gas orifices are radially distributed with greater density towards the center. The upper electrode is connected to a RF generator through the ASPR tuning network for the maximum power transfer of power.

3.1.4 Substrate Plate

The substrate plate holds the wafer during the process. A heater can be placed below the substrate plate to increase the temperature of the wafer.

3.1.5 RF generator

The HFS-1500D RF generator is manufactured by RF Power Products, it has a maximum output of 1500 Watts at a frequency of 13.56 MHz [2]. The RF generator is composed of power supplies, an oscillator, a buffer amplifier, a power amplifier and a tuning network. The oscillator of this generator is a crystal controlled oscillator that drives a buffer amplifier. The buffer stage reduces the effect of loading and also provides some intermediate amplification. The buffer amplifier drives the power amplifier for more amplification in the output stage. The RF power is coupled to the reaction chamber through an automatic RF matching network. The purpose of this network is to provide compensation for the RF chamber impedance in an attempt to match the chamber load to the 50 Ω impedance of the transmission line. A directional coupler is provided at the end of the PA stage to sense both the incident and reflected power. The front panel of the RF generator is shown in Figure 3.3.

3.1.6 Plumbing System

The plumbing system provides for the gas system, which supplies the process gases to the chamber, a vacuum system and the chamber pressure monitoring assembly. Figure 3.4 shows the plumbing system. The flow rate for the process gases are monitored by the MFCs. The setpoint is an analog signal (0 to 5 VDC) from the D/A board. The MFC produces an analog signal (0 to 5 VDC) proportional to gas flow, which is read into the computer through the A/D board. The DAQ boards are explained in later sections. The process gas is piped in through the floor of the etcher directly to the mass flow panel. If the solenoid valve is open, the gas flows into the MFC to an air operated bellow valve. If the bellow valve is enabled, the gas flows through the process gas manifold to another air-operated valve located on the top of the process chamber. This allows the gas to enter the chamber. Chamber gases are exhausted through a vacuum pump. The actual flow in SCCM (standard cubic centimeters per minute) can be read on the computer using LabVIEW control program.

3.1.7 Gas System

The gas system provides for four gases Ar, CF_4, H_2, O_2, which can be used alone or in a mixture for the etching process. The gases pass through electrically operated solenoid valves, a mass flow controller (MFC), a normally closed pneumatic bellow valve, a process gas manifold, and a normally open pneumatic bellow valve on the top of the chamber. The flow rates of gases are controlled by the MFCs. On entering the MFC, the gas stream is divided into two parallel paths, one path is directed through the thermal sensor tube and the other passes through a bypass. The two are rejoined to pass through the control valve. The bypass forces a proportional flow through the thermal sensor tube. The thermal sensor converts the gas flow into a voltage.

As shown in the Figure 3.5, the valve, the thermal sensor and the valve controller form a closed-loop control system. The input signal from the computer varies from 0 to 5 volts, which controls the valve from a fully open to fully closed position. The difference between the voltage from the thermal sensor and the input signal is used to adjust the valve position and, thus, the flow rate of the gas.

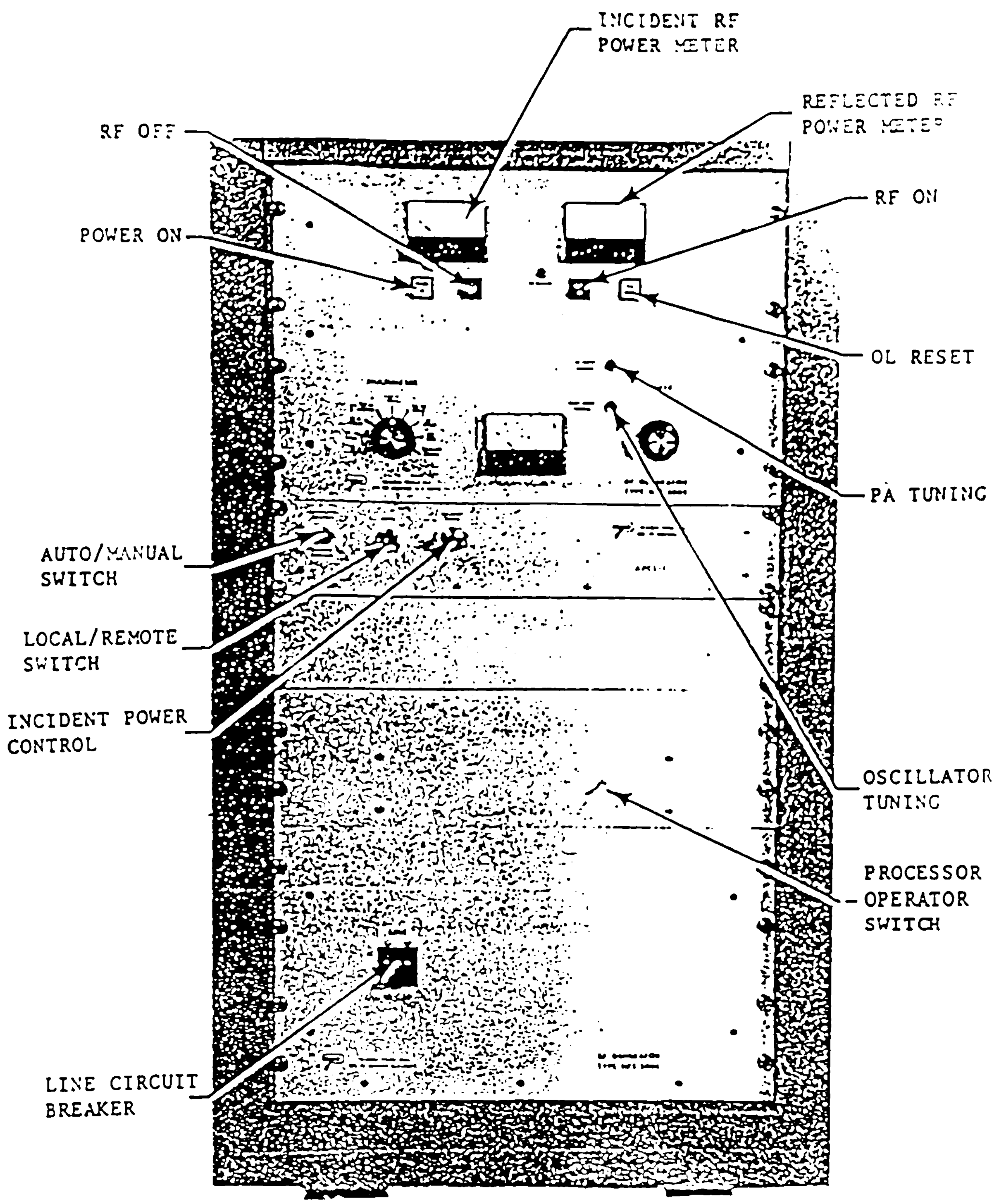


Figure 3.3 RF Generator

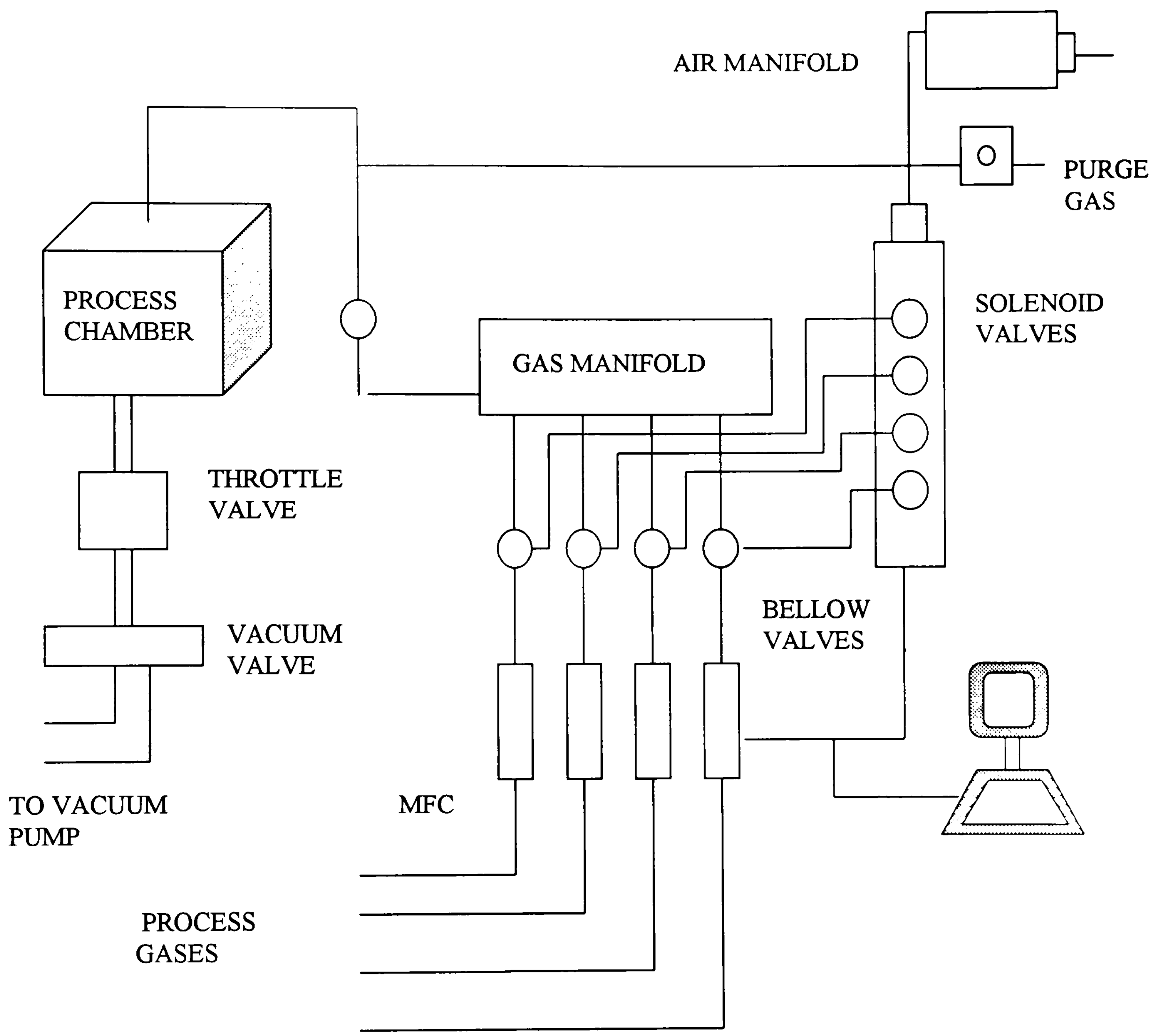


Figure 3.4 Plumbing System

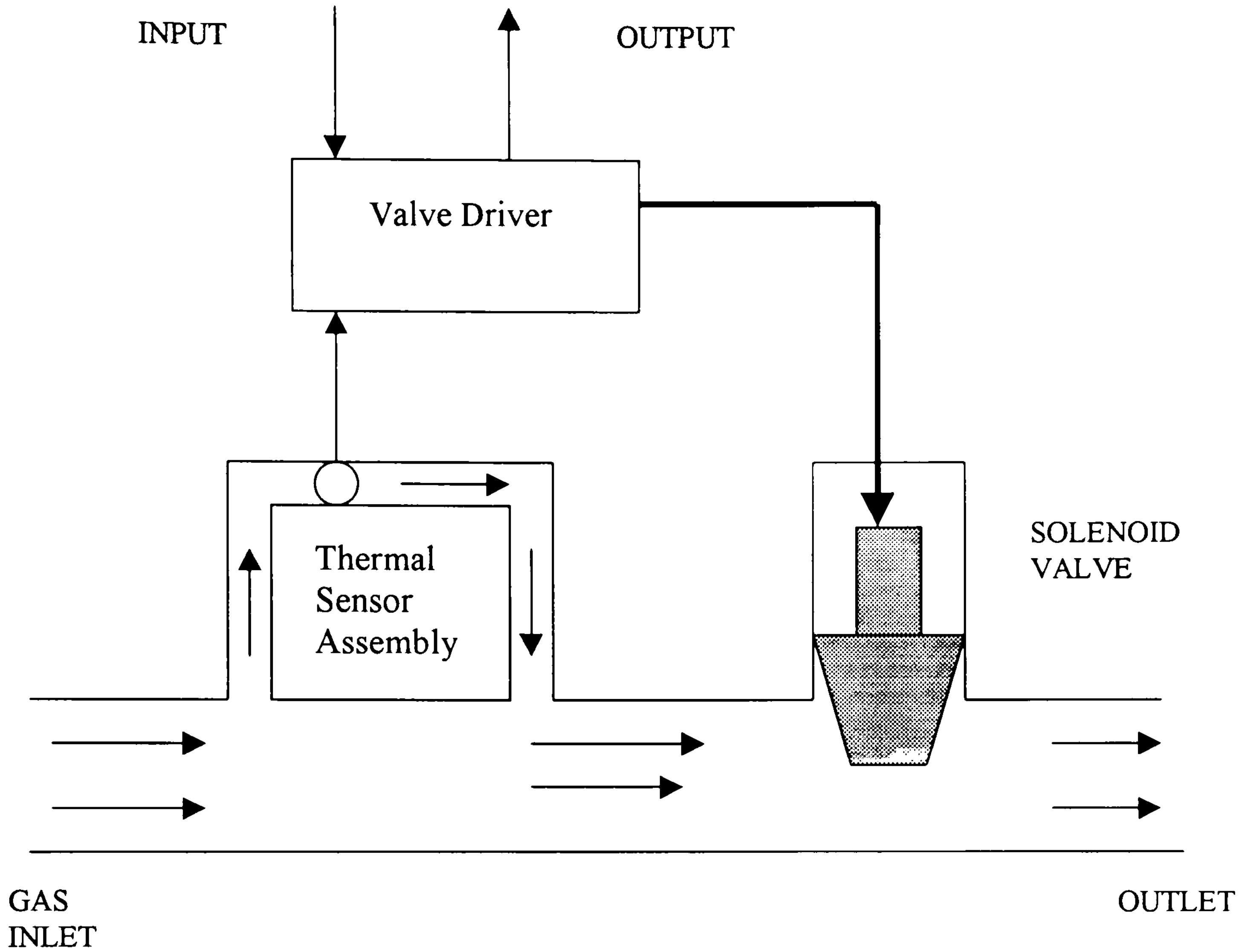


Figure 3.5 Mass Flow Assembly

3.1.8 Vacuum System

The vacuum system consists of a remote vacuum pump and a throttle valve controller. The vacuum system first pumps down the chamber to remove any contaminants, then it is used to remove the process gases during the etching process. Variation in the pumping speed is achieved with the help of the exhaust valve controller that controls the throttle valve.

3.1.9 Pressure Monitoring System

Constant monitoring of the chamber pressure is necessary for the etching process. This is done by a MKS manometer, which is a pressure transducer and an exhaust valve controller. The MKS manometer converts the pressure inside the chamber into voltage. This is then compared with setpoint in the exhaust valve controller, depending on the difference the exhaust valve opens or closes. A vacuum switch allows the MKS manometer to be exposed to the chamber when the chamber is under vacuum. The sensitive manometer cannot be exposed to atmospheric pressure, because the diaphragm may get spoiled, thus making the vacuum switch necessary.

3.1.10 Power Supplies

The electric circuits in the plasma etcher are powered by three power supplies. A 24 VDC supply is used for the solenoid and the relays, 5 VDC power supply is used to power the MFCs and a regulated +15VDc and −15VDC is used for the tuning network controlling card in the matching network [2].

3.1.11 Optical Setup

The optical setup is used for analyzing the light emissions from the plasma reactor system. The major components of the optical setup are a spectrometer EG&G PARC model 1229, detector interface model 1452A, fiber optic bundle and a host computer (see Figure 3.6) The light is collected and sent to the spectrometer that separates the different wavelengths of light. The detector determines the intensity of different wavelengths of light, which are sent to the computer via a GPIB board. The resolution of the spectrometer depends on the spectral response and calibration of the system. There is a grating inside the spectrometer that defracts the light into its component wavelengths and directs them to a focusing mirror. The mirror reflects the light out of the assembly. The light detector, which is mounted on the exit of the assembly, has an array of 512 photo diodes that sense the light coming from the spectrometer. With the help of an external

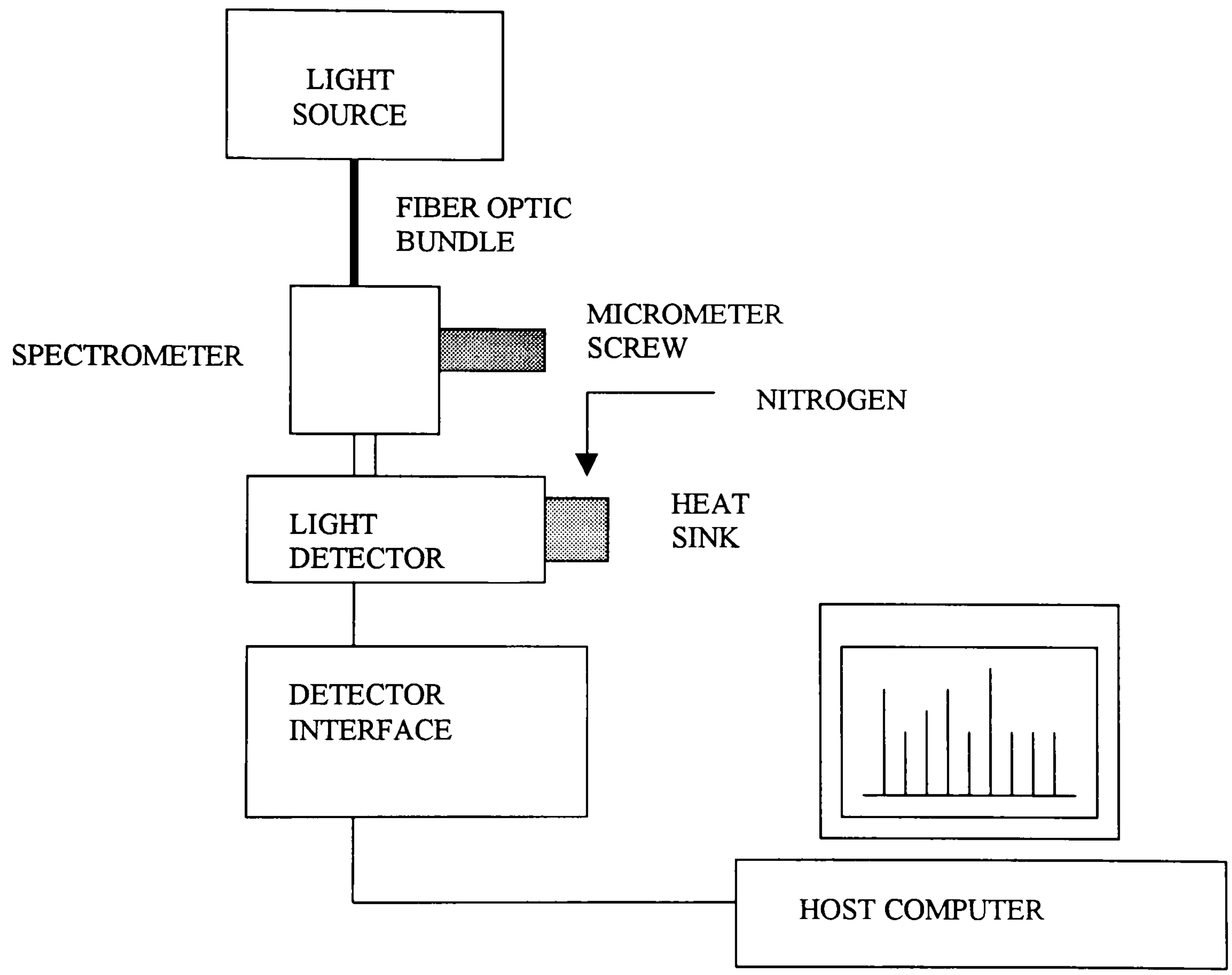


Figure 3.6 Optical Setup

Micrometer screw, the spectrometer can be tuned to different ranges so that wavelengths from 200nm to 1100nm can be measured. This type of setup makes it very easy for the user to decide on the endpoint detection by looking at the optical emission lines and their wavelengths. Table 3.1shows the optical emission lines used for endpoint detection. It shows the Etchant gas to be used for a particular type of material, the emitted species and its corresponding wavelength.

Table 3.1 Optical Emission Lines Used for endpoint Detection

Material	Etchant Gas	Emitting Species	Wavelength (nm)
Silicon	CF4 /O2	F (Etchant) SiF4 (Product)	704 440, 777
SiO2	CHF3	CO (Product)	484
Si3N4	CF4/O2	N2 (Product) CN (Product) N(Product) F(Etchant)	337 387 674 704
Resist	O2	CO (Product) OH (Product) H (Product) O (Etchant)	484 309 656 777,843

The next topics discuss about the hardware and software required to automate the plasma etcher.

3.2 DAQ Boards Used For Plasma Etcher

The ASPR was originally controlled by an ASD/99 on-board computer and a manual data terminal, and the software was stored in EPROMs. Any modification in the software was a difficult and time-consuming process. Two DAQ boards were used to automate the plasma etcher. A DDA-06, D/A board, was used to send analog signals to the etcher and a PC-LPM-16, A/D board, was used to read in the analog signals from the machine. The boards were selected depending on the number of parameters that had to be controlled and monitored, as mentioned in the generic approach in the previous chapter. The DAQ boards used, met the specifications mentioned in the automation approach.

3.2.1 Metrabyte DDA-06 Analog Output Board

The metrabyte DDA-06 board is an analog output board, which provides six channels of analog output with 12-bit resolution and 24 lines of digital input/ output. Each output channel occupies its own I/O address location. The output channels are switch selectable to 0V to 10V, 0V to -5V, -2.5V to 2.5V, -5V to 5V, -10V to 10V and 4-20mA current. All output channels are set to 0V to 5V range in this application. The digital I/O consists of three ports (ports A, B and C). They are 8-bit ports. Each of the ports can be configured as an input or output port. Analog output channels 0 through 3 are used to control the set points for the flow rates of four process gases. Analog output channel 4 is used to control the set point for the chamber pressure and the channel 5 is used for RF power set point. Bits 1,2,5,6,7 of port B are used to control the process and purge gas solenoids. Bits 4 and 5 are used to turn the RF generator on and off respectively. Figure 3.7 summarizes the operation of this board. Table 3.2 shows the pin connections and the functions for the DDA-06.

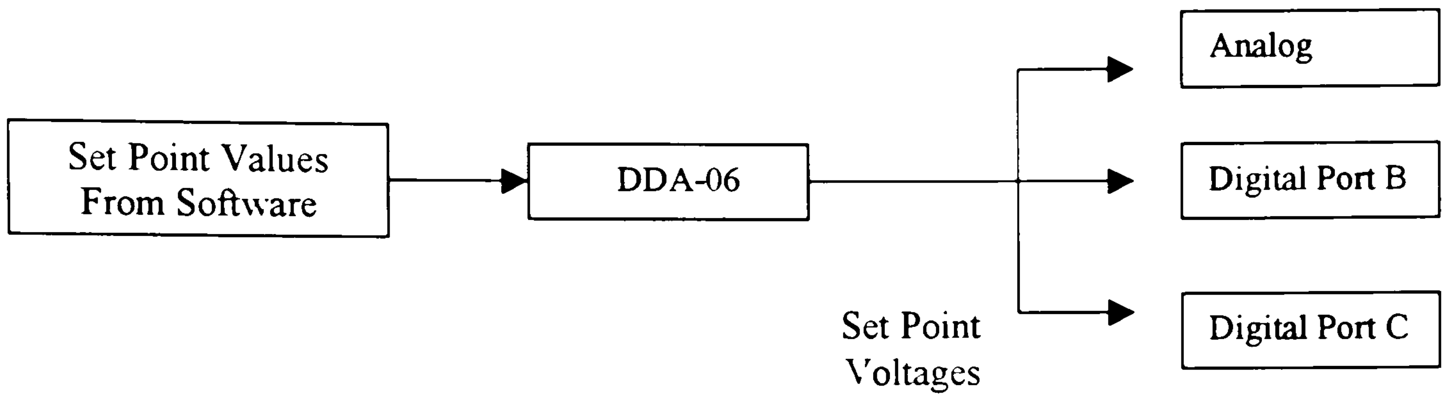


Figure 3.7 Diagram of operation of DDA-06

3.2.2 National Instruments PC-LPM-16 Analog Input Board

The PC-LPM-16 [6] Analog input board has 16 single-ended input channels with 12-bit plus sign bit resolution. Each input channel is jumper selectable to accept inputs of $\pm$2.5V, +5V, 0V to 5V, 0V to 10V. All input channels have been set to 0V to 5V for this application. A maximum sampling rate of 50KHz can be achieved. The board also has one 8 bit digital input port; one 8 bit digital output port, and 16-bit counter/timers. Figure 3.8 summarize the operation of this card. Table 3.3 shows the pin assignments and the pin functions for the PC-LPM-16 card.

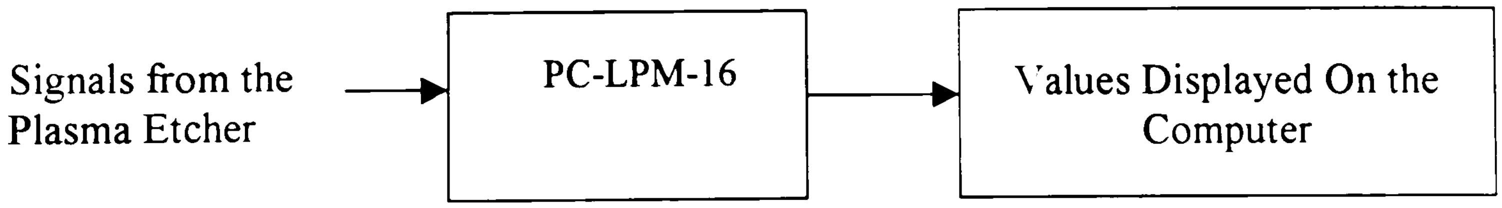


Figure 3.8 Diagram of operation of PC-LPM-16

Table 3.2 Pin configuration of the DDA-06 Analog Output Board

Pin Number	Pin Function	Pin Assignment
1	D/A # 5	RF Power Set Point
2	D/A # 4	Pressure Set Point
3	PB7	Gas Solenoid (H_2)
4	PB6	Gas Solenoid (O_2)
5	PB5	Gas Solenoid (Ar)
8	PB2	Gas Solenoid (CF_4)
9	PB1	Gas Solenoid (N_2)
11	Digital com	Digital Ground
12	D/A # 3	O_2 Flow Rate Set Point
14	D/A # 2	H_2 Flow Rate Set Point
16	D/A # 1	CF_4 Flow Rate Set Point
17	GND	Analog Ground
18	D/A # 0	Ar Flow rate set Point
24	PC5	RF Power Off
25	PC4	RF Power On

The mass flow rates of the gases are inputs to channels 0 through 3, the RF power is input to channel 4, the pressure is input to channel 5, and the RF impedance is input to channels 8 and 9. Neither the digital I/O ports nor the counters are currently used for this project.

Table 3.3 Pin Configuration of PC-LPM-16 Analog Input Board

Pin Number	Pin Function	Pin Assignment
1	AIGND	Analog Ground
2	ACH0	Ar Flow rate
5	ACH1	CF_4 Flow Rate
7	ACH2	H_2 Flow rate
9	ACH3	O_2 Flow Rate
11	ACH4	RF power
13	ACH5	Chamber Pressure
15	ACH8	RF Impedance
17	ACH9	RF Impedance

By using these A/D and D/A interface boards 6 analog parameters are set and 8 analog parameters are monitored. The boards have to be configured before using them. The LabVIEW code generates the set point voltages and they are assigned to corresponding channels.

3.3 External Interface Board

The external interface board was designed as mentioned in the generic approach Digital signals from the DDA-06 are used to control the solenoid switches. These solenoids operate at 24 VDC and 250mA, which is far greater than the TTL voltages and currents provided by the DDA-06. The interface board has three ECG 2013 Darlington transistor array drivers and two 74LS245-line drivers. The ECG 2013 drivers can handle more than 24 VDC and 600 mA on the output.

All the digital and analog signals for the plasma etcher go through the board. There are two 37 pin D- subconnectors: one for the DDA-06 and the other for the PC-LPM-16 board, to connect them to the interface board, one 50 pin stick header connector, and one 40 pin edge connector. The 50-pin connector goes to the signal termination board, from where the connections are given to the MFCs, RF generator, pressure transducer, and other parts of the etcher. The 40-pin connector goes to the solenoid board. Figure 3.9 shows the logical connection of the two chips, along with the schematic layout of the interface board and termination board.

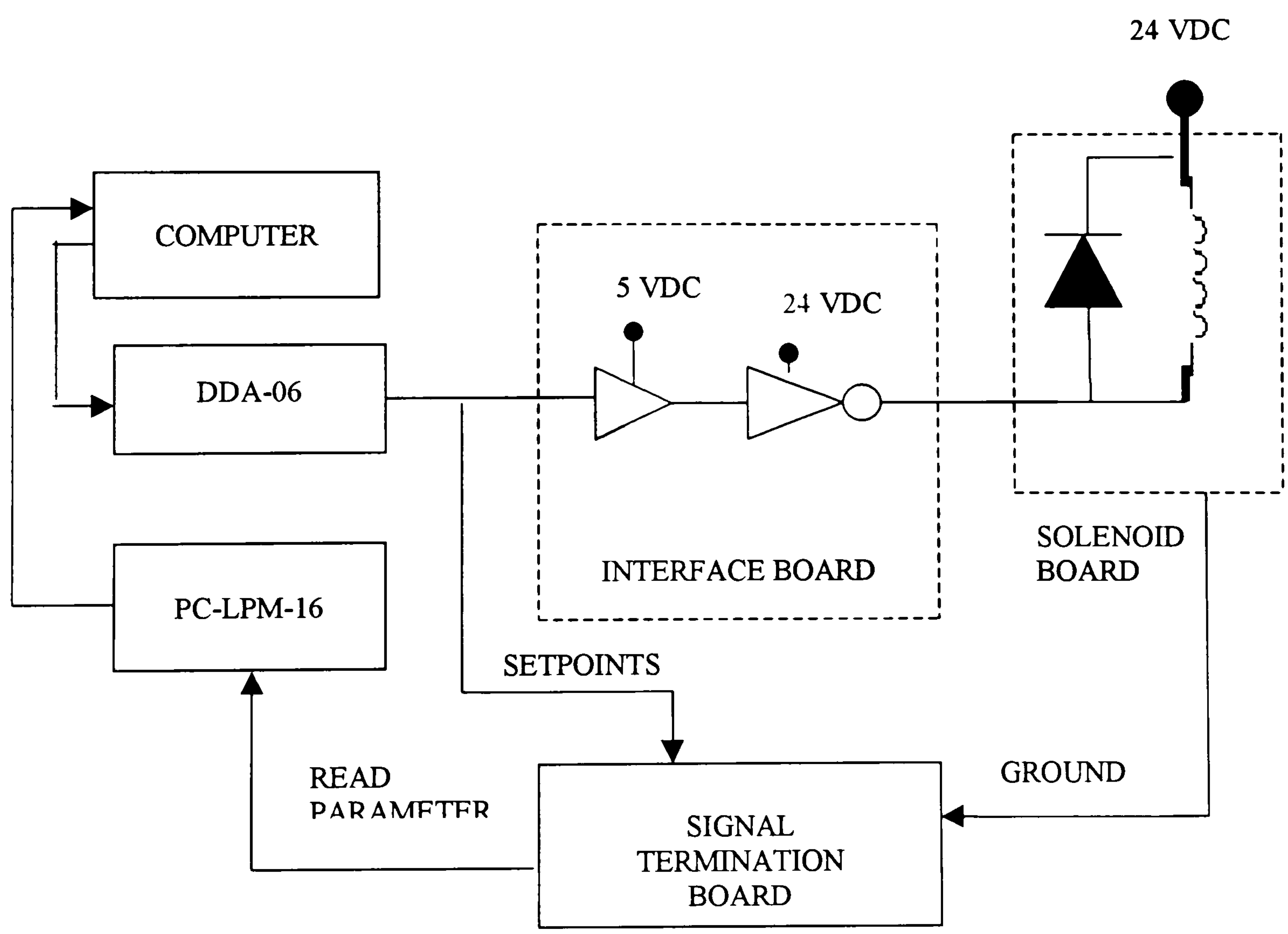


Figure 3.9 External Interface Boards

3.4 RF Tuning Network

To minimize the reflections in the RF power due to the impedance mismatch between the ASPR's capacitive impedance and the RF generator's output impedance, a tuning network is necessary. The tuning network is designed to transform wide range of resistive and reactive impedances to the 50 ohms desired by the RF generator. The tuning network employd here is an L configuration, which includes two capacitors and an inductor as shown in Figure 3.10. The tuning network has a shunt capacitor Cp to handle the loading, a fixed inductor and a series capacitor Cs for tuning. The capacitors are servo motor driven simultaneously to allow the instant tuning. To accomplish the automatic tuning of the system, a phase detector and a magnitude detector are used. The signal from the phase detector controls the servo motor of the series tunign capacitor, and the signal from the magnitude detector controls the servo motor driving the shunt capacitor. Both the detectors operate simulataneously to transform the impedance of the load to 50 ohms.

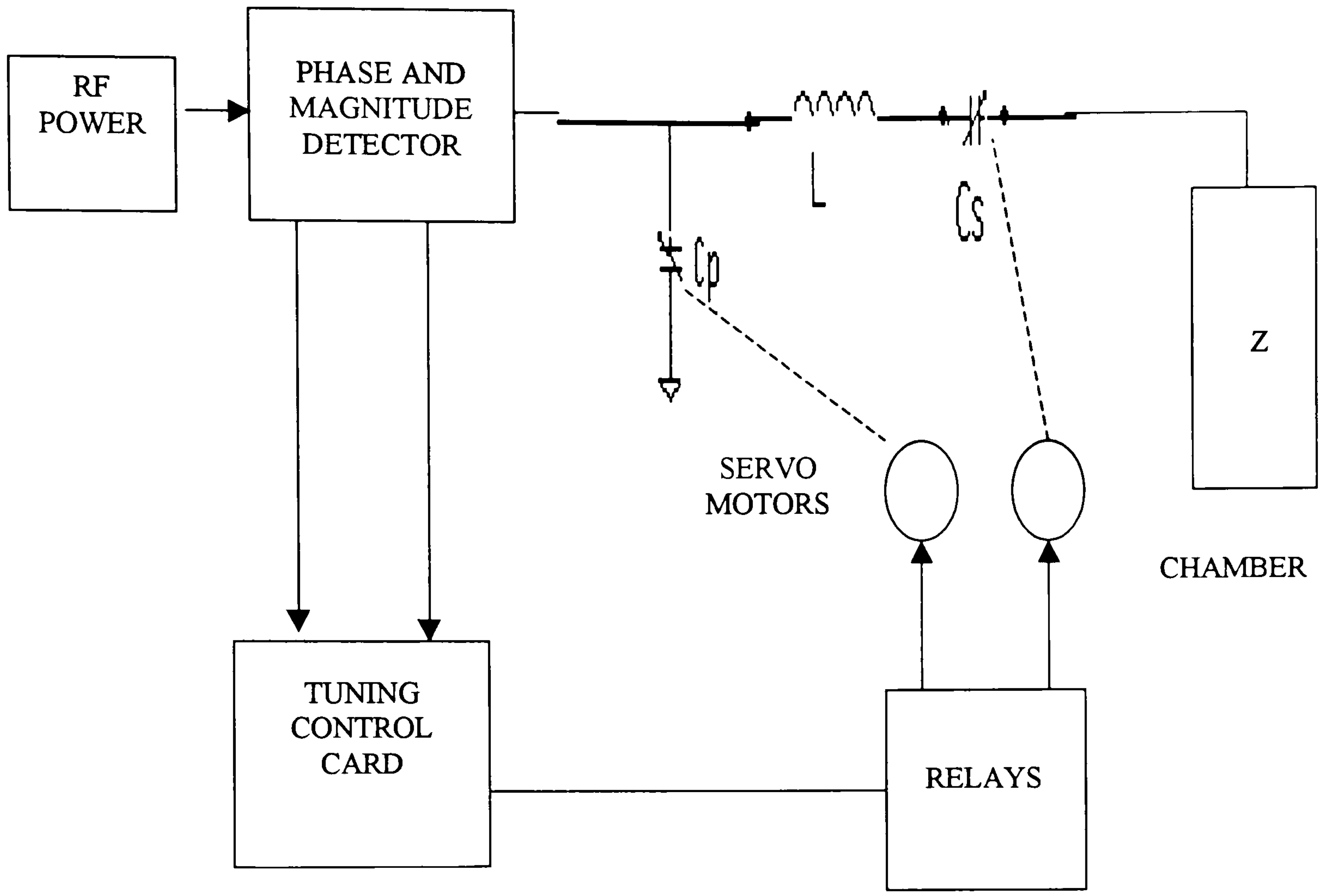


Figure 3.10 Tuning Network

3.5 LabVIEW Control Program for the Plasma Etcher

The software should be in such a way that it is flexible and modifiable. The input parameters that the user has to select are the following:

- Selection of a gas Ar, CF_4, H_2, O_2.
- Set the gas flow rate.
- Set the pressure.
- Set the RF power
- Set the total time for the process.

The user has to monitor the following parameters in a plasma chamber.

- Pressure.
- Power.
- Flow rate.
- Impedance.
- Process time left.

Figure 3.11 shows the flow chart for the automation Program for the etcher. The program is designed according to the algorithm mentioned in the generic approach. The user sets all the parameters and the D/A DAQ board sets the set point voltages to the machine and the A/D DAQ board feeds the run time data from the machine into the computer

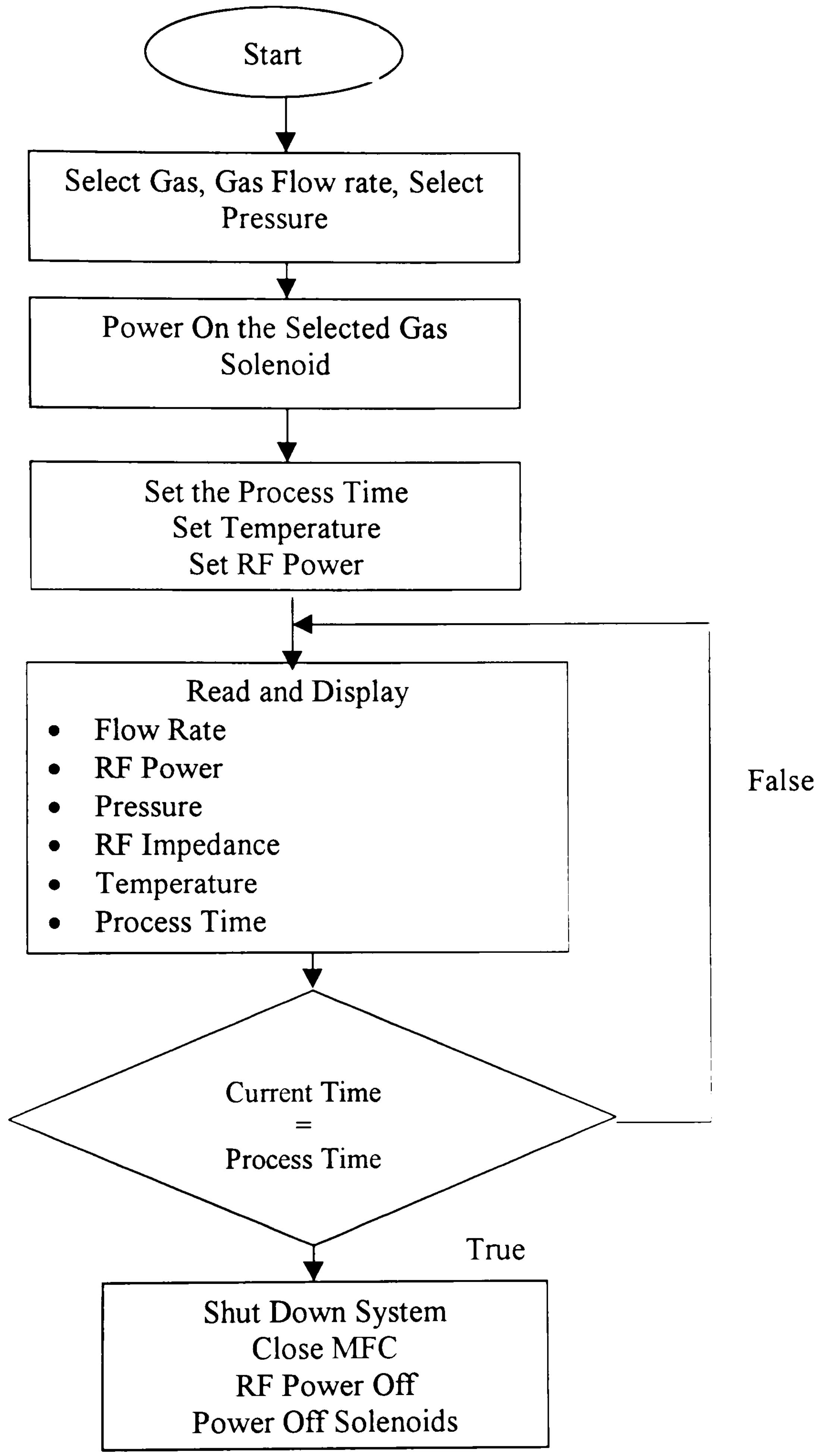


Figure 3.11 Control Program Flow Chart

and the software displays the data on the screen. The program controls the machine until the process time completes and then the system shut downs automatically.

The Etcher software is divided into three stages as mentioned previously. They are

1. Setup Stage,
2. Monitor Stage,
3. Shut Down Stage.

The DDA-06 (D/A DAQ board) is used to output the setpoints to the Machine and the PC-LPM-16 (A/D DAQ board) is used to get the feedback signals into the computer. The pin configuration and the functioning of these boards are already. The front panel of the Plasma Etcher program is shown in Figure 3.12. The source code is shown at the end of this chapter. The individual blocks in the code are explained first and finally the integration is showed.

3.5.1 Setup Stage

This stage takes the different input values from the user. The main sub VIs for this stage are the following:

1. Gas Setup Screen. Vi
2. Power, Pressure and Time Setup Screen. Vi
3. Initialize system. Vi

   The tools, method to select CASE structures, and bundling of data that were discussed in the generic approach were used.

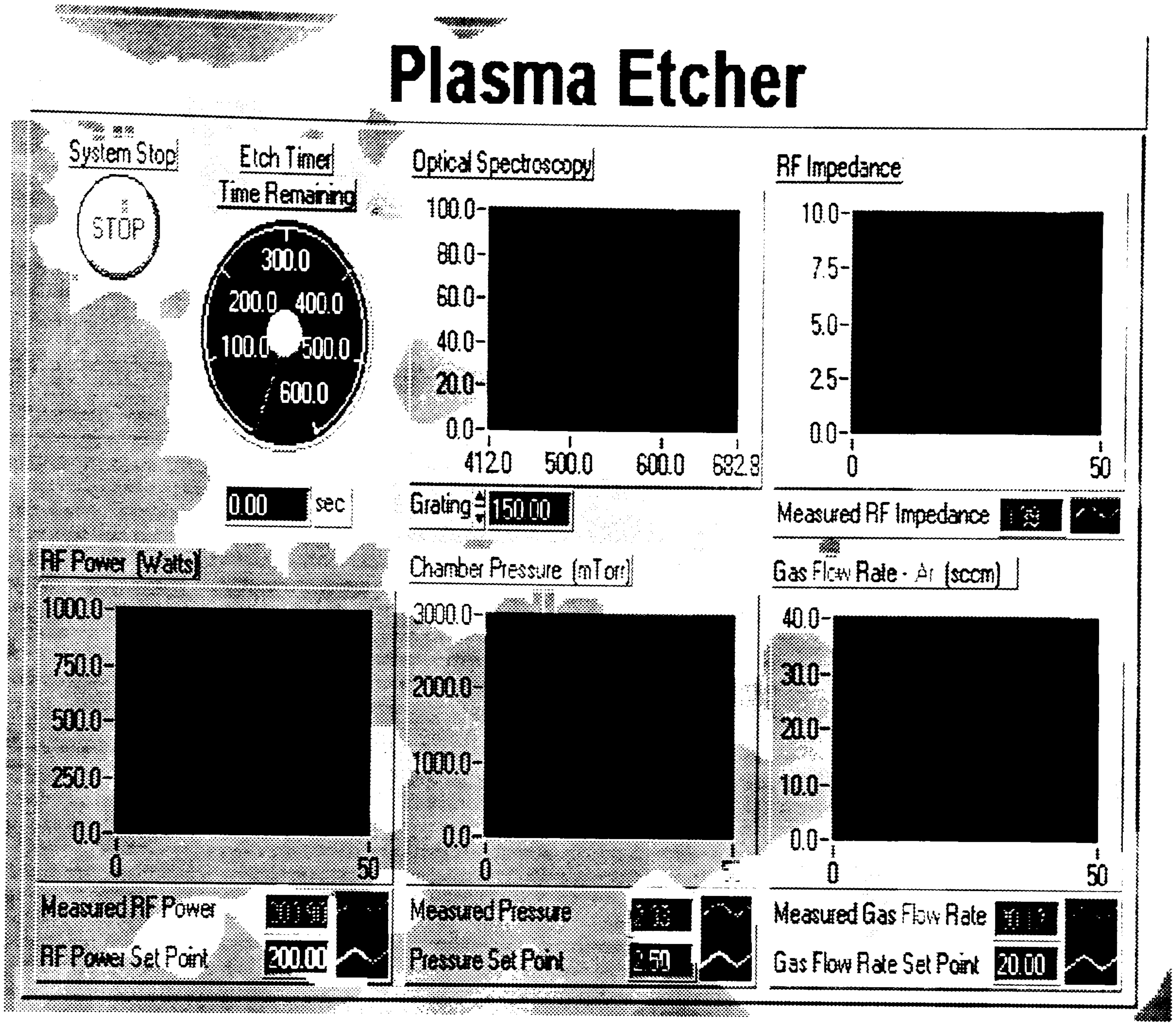


Figure 3.12 Front Panel of Plasma Etcher Program

The setup stage has 5 sub-frames. Figure 3.13 shows different frames (0 through 3) of the Setup Stage. Figure 3.14 shows the frame 4. The substage1, which is frame "0" uses a Gas Setup Screen VI, to read the selected gas number and the flow rate setpoint. The user will get a screen as shown in Figure 3.15 (a) to select the gas and the flow rate. The block diagram (source code) of the gas selection screen.vi is shown in Figure 3.15 (b).

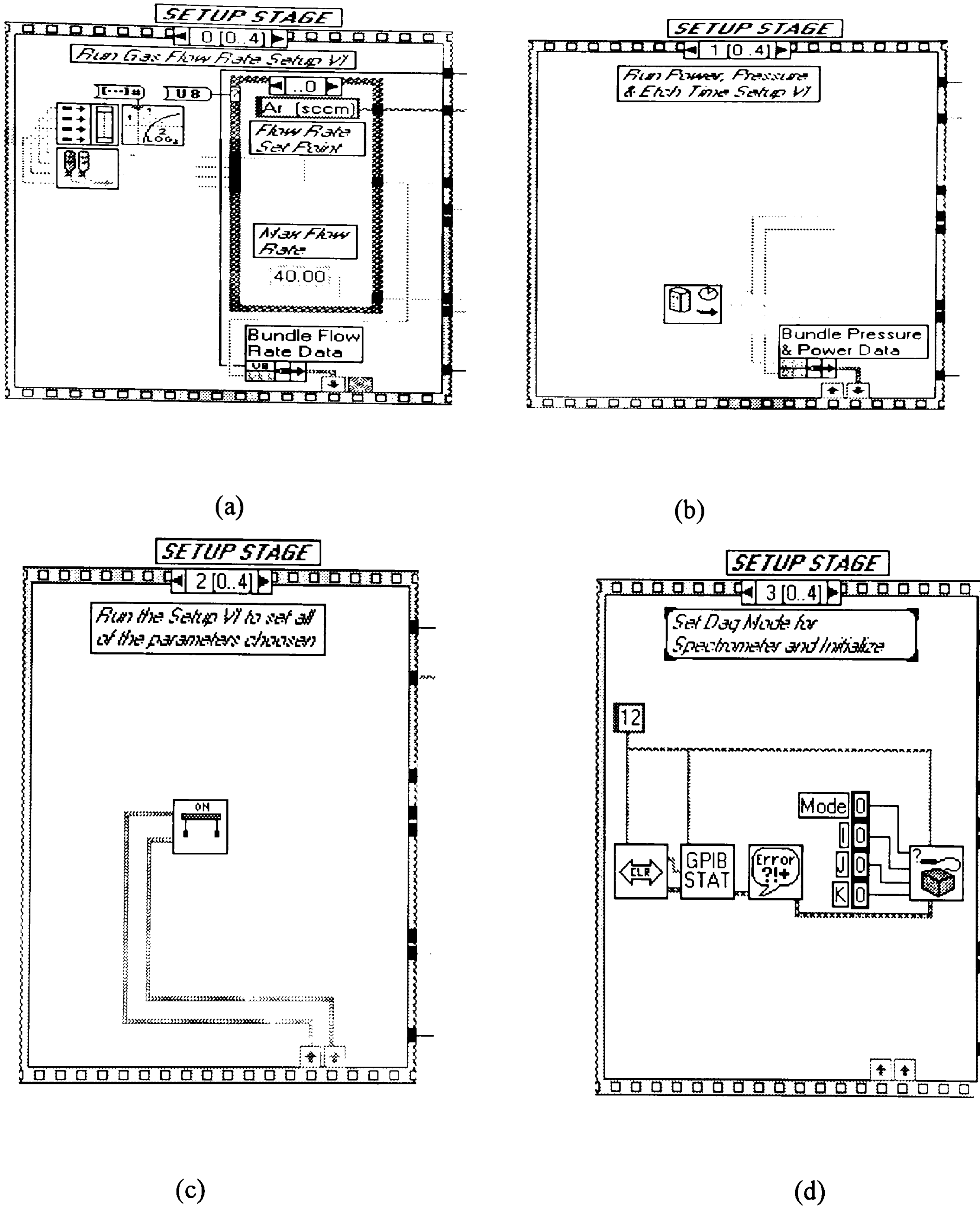


Figure 3.13 Different Frames of the Setup stage (a) Frame No. 0 (b) Frame No. 1 (c) Frame No. 2 (d) Frame No. 3

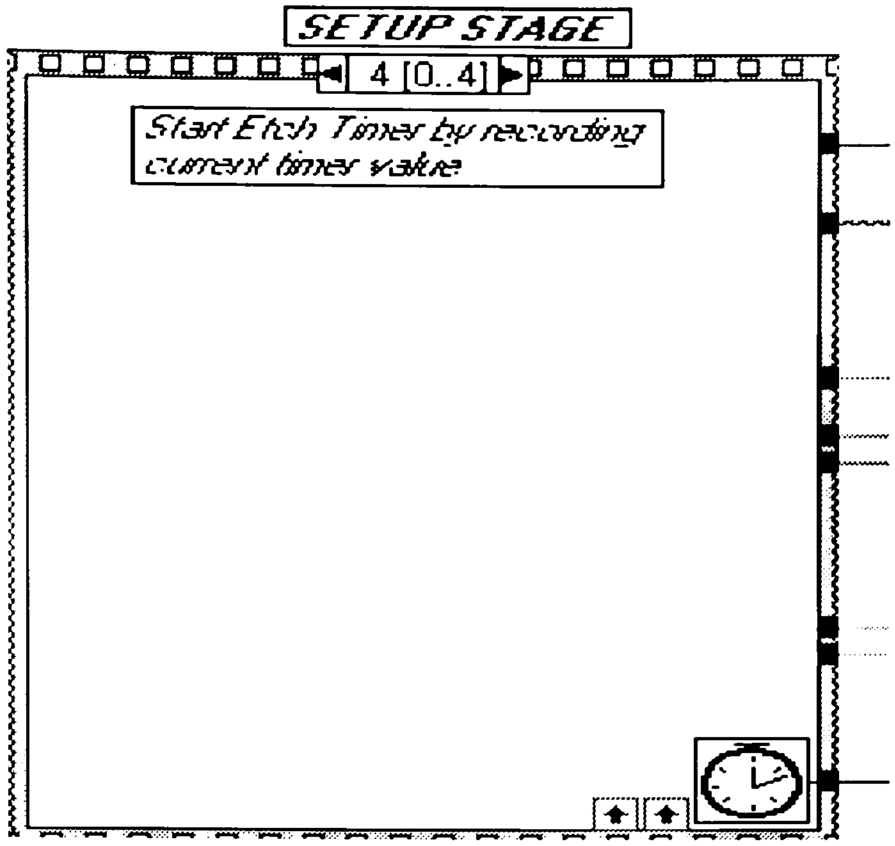
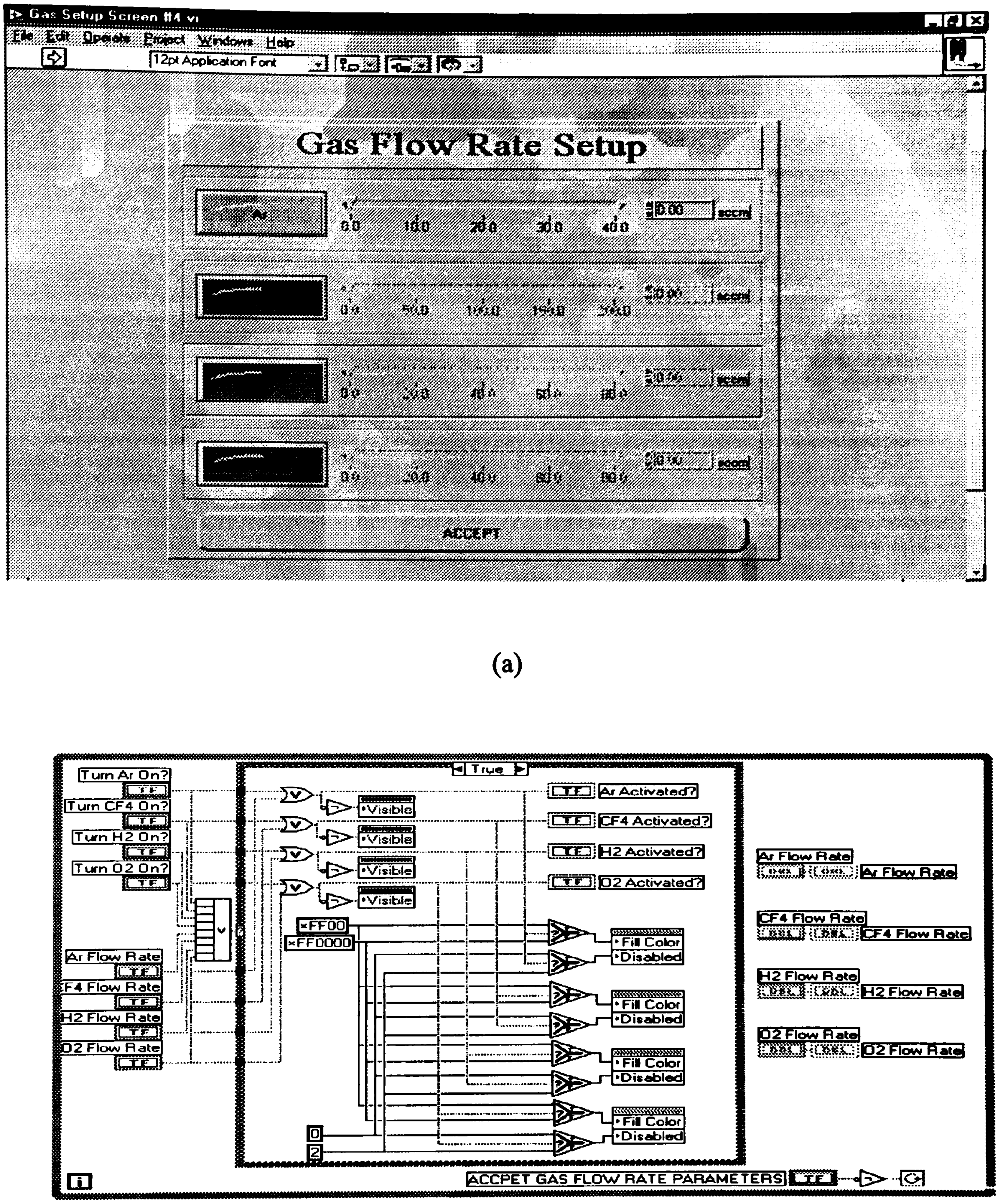


Figure 3.14 Frame for the Timer

The gas number and the flow rate are bundled together in frame 1 and advanced into frame 2. In frame no.1, the power, pressure and the etch time are specified by the user. The Power and Pressure data are also bundled and advanced into frame no.2. The screen for selection is shown in Figure 3.16.

Frame No.2 receives Gas Number, gas flow rate, power and pressure and these are passed to an another VI called, Initialize system.vi. As the name implies, this VI initializes the system and plugs in the setpoint values. Figure 3.17 shows frame number '0' of the diagram for the initialize system.vi. The total number of frames in this VI are four. Frame '0' sets digital Port A, Port B, Port C as output ports. Different pins of these ports are used to activate the gas solenoids. The base address for the DDA-06 card is 330H.



(a)

(b)

Figure 3.15 Gas Selection VI (a) Front Panel (b) Block Diagram

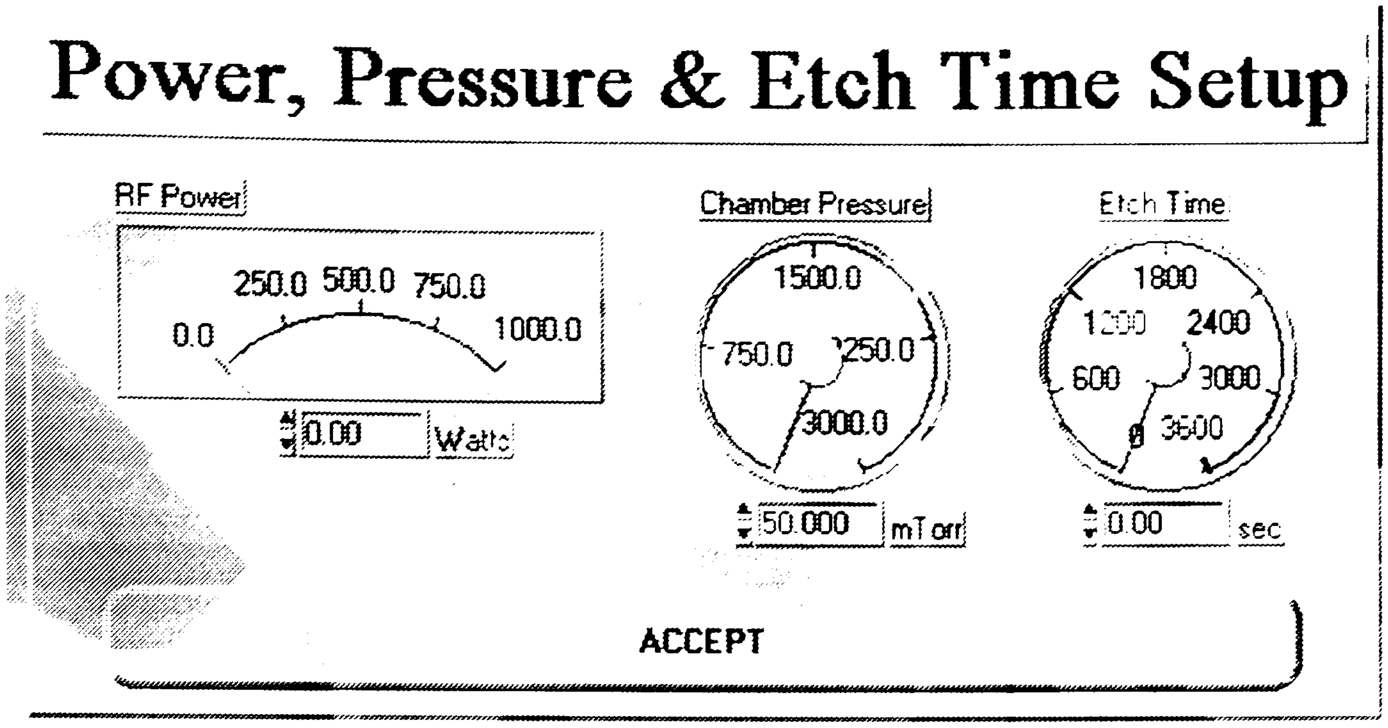


Figure 3.16 Pressure and Time selection screen

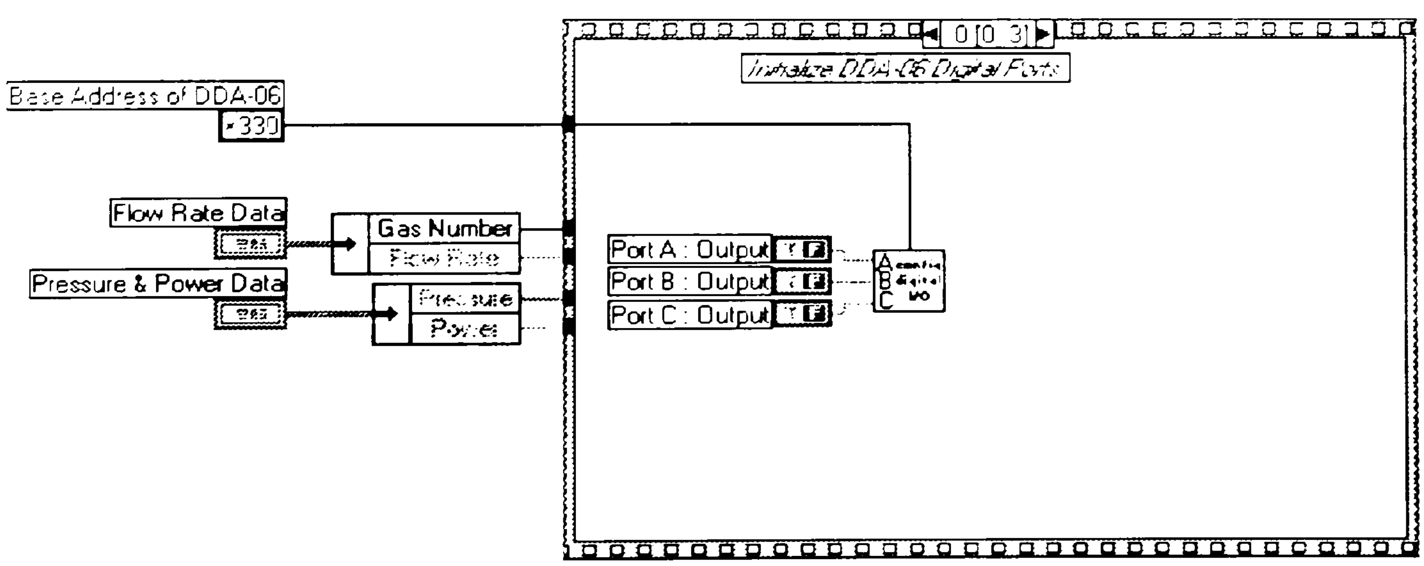


Figure 3.17 Frame No.'0' of the Initialize System.vi

Figure 3.18 shows the frame number '1' for the same VI. This frame sets the chamber pressure. The governing equation is PS= floor (P/1.22466663).

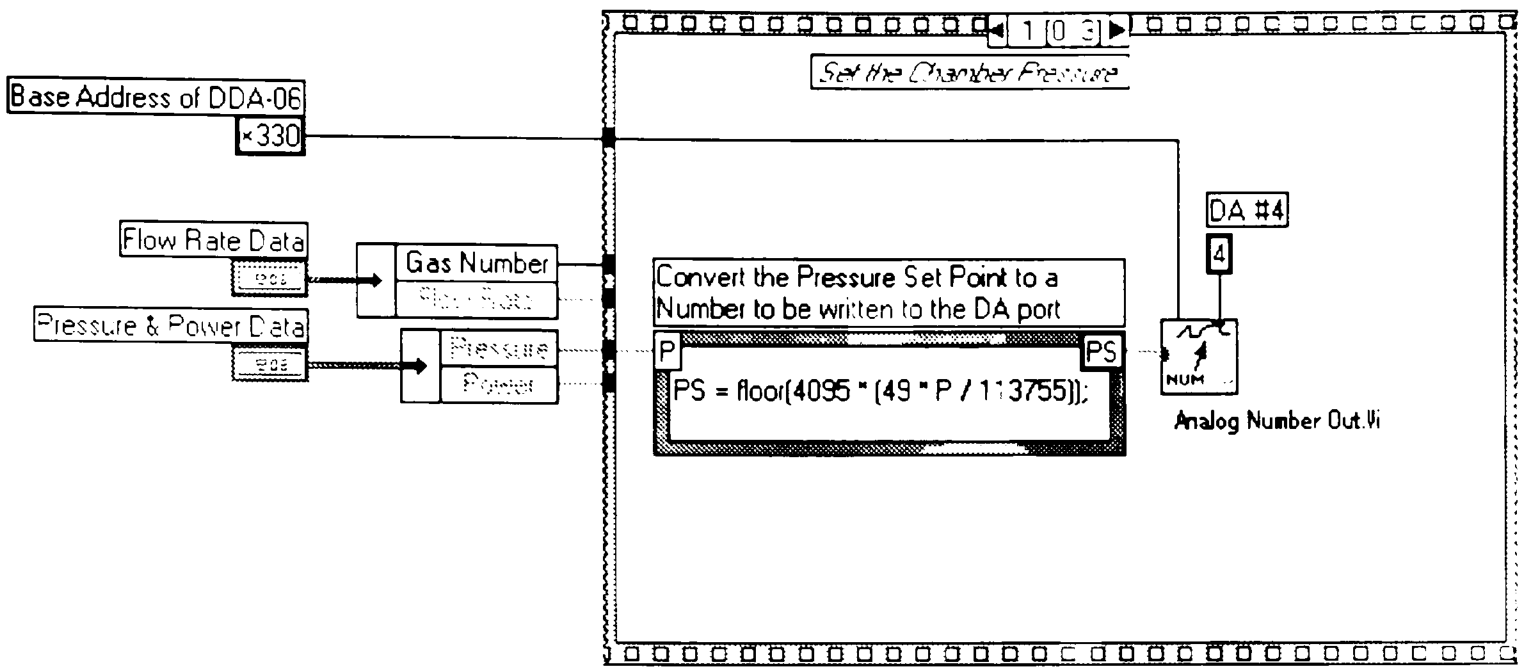


Figure 3.18 Frame Number '1' of the Initialize system.vi

Here P is the setpoint value of the pressure in milli torrs. The pressure and power are 'unbundled' to get the pressure alone. The 'floor' function truncates any value after the decimal point and makes PS a whole integer. The pin assignment for DDA-06 is shown in Table 3.2. The analog number out.vi commands DDA-06 card to convert the value of PS into milli volts and make it available between D/A #4 (Pin2) and analog ground GND (Pin 17). For a setpoint of 100 milli torrs, the value of PS will be 94 and 94mV will be available between Pin 2 and Pin 17 of DDA-06.

The 16-bit value is written at the 16-bit address by calling a shared library function DlPortWritePortUlong. This function resides in DLPORTIO. DLL, a Dynamic Link Library file, written in other language. LabVIEW allows the programmer to call this DLL file to communicate with the DDA-06.

Figure 3.19 shows the frame number '2' of the Initialize system.vi. The gas number and flow rates are unbundled here. This frame has four sequence structures, which get selected according to the gas number. Table 3.4 shows the number allotted to each gas. When a particular gas is chosen, it activates the corresponding sequence. That sequence has a governing equation for the flow rate of that particular gas and also a binary value to activate the solenoid for that gas. In Figure 3.19, the sequence structure for Argon is shown.

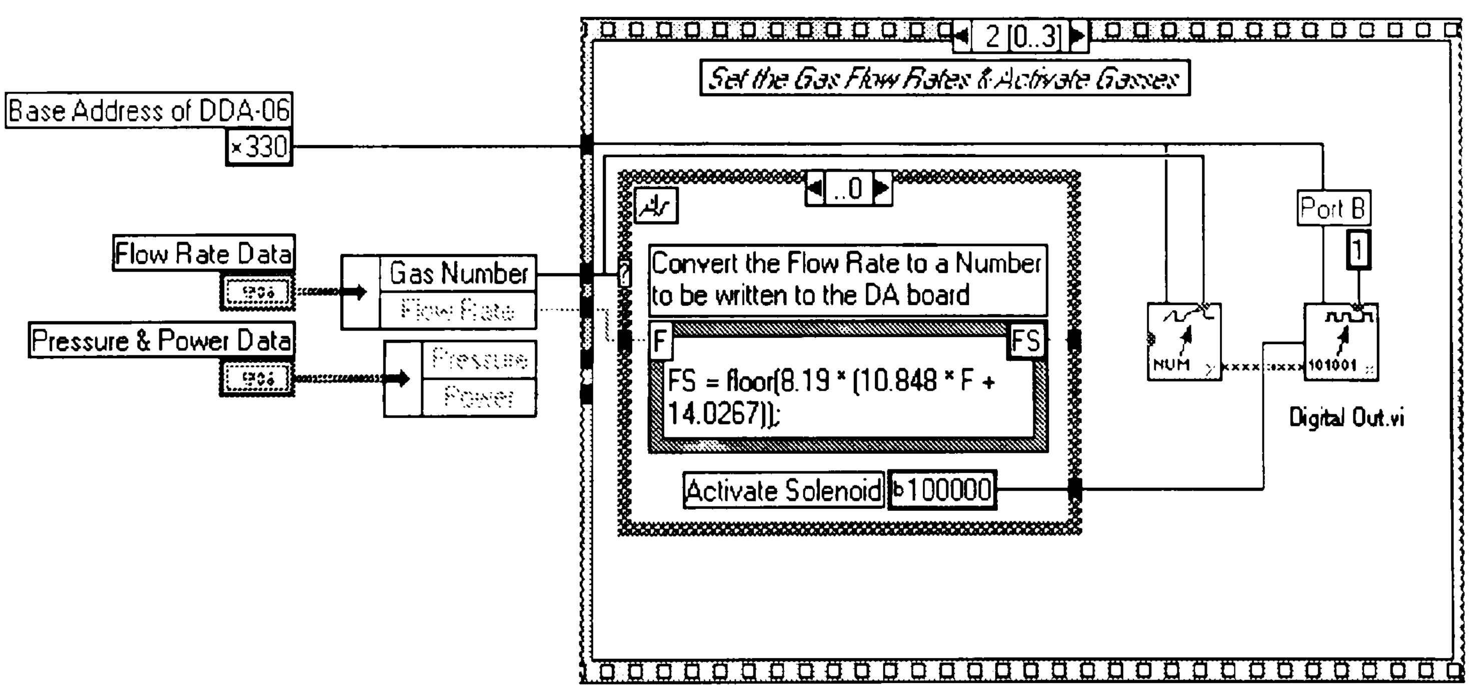


Figure 3.19 Setting of Gas Flow Rates and Activation of Solenoids

If Argon is chosen, sequence number '0' of frame '2' is selected. The flow rate equation for Argon is FS = floor (8.19* (10.848 * F + 14.0267)).

Table 3.4 Gas Number Assignment

Name of the Gas	Number Assigned
Argon	0
CF4	1
Hydrogen	2
Oxygen	3

The coefficients for this equation were experimentally determined. Here F is the set point value of the flow rate in SCCM (Standard Cubic Centimeters per Minute). The mV equivalent of FS is made available between DA # (Gas Number) and GND (ground) by Analog Number Out.vi. For setting the flow rate of Argon, DA # 0 (Pin 18) is selected since the gas number for Argon is '0'.

The binary value for activating the Ar Gas solenoid is 100000b. From Table 3.2, the bit 5 of 8-bit digital Port B has to be set to binary '1' to activate the Ar Solenoid, while all the other bits should remain '0'. Figure 3.20 lists all binary values for activation of different gas solenoids.

Argon Gas

0	0	1	0	0	0	0	0
PB7	PB6	PB5	PB4	PB3	PB2	PB1	PB0

CF_4 Gas

0	0	0	0	0	1	0	0
PB7	PB6	PB5	PB4	PB3	PB2	PB1	PB0

Hydrogen Gas

1	0	0	0	0	0	0	0
PB7	PB6	PB5	PB4	PB3	PB2	PB1	PB0

Oxygen Gas

0	1	0	0	0	0	0	0
PB7	PB6	PB5	PB4	PB3	PB2	PB1	PB0

Figure 3.20 Binary Values for Gas Solenoids

The sub VI, Digital Out .vi', is used to write to a digital port. The other sequence structures for other gases in Frame '2' are similar except for the governing equation for the flow rates. Each sequence has an equation and its binary value for activating its solenoid. The equations for other gases are given below.

For CF_4:

FS= floor (8.19 * (2.15 * F + 55.2));

For Hydrogen:

FS= floor (8.19 * (8.55 * F –100.8));

For Oxygen:

FS= floor (8.19 * (5.8387 * F +15.954));

These FS values are converted to mV by the DDA-06 card and applied to the Mass Flow Controllers.

Figure 3.21 shows the frame number '3' of the diagram of Initialize system.vi. This frame sets and turns the RF power on. This value of PS is written by 'Analog Number Out.vi.'

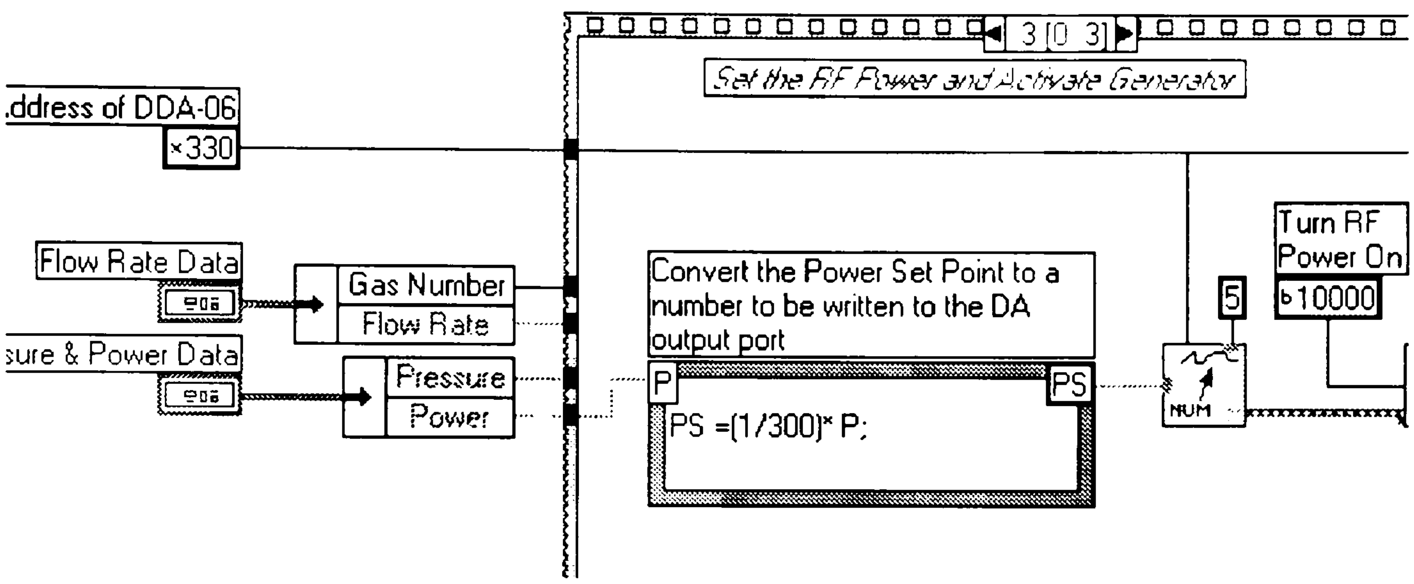


Figure 3.21 Frame Number '3'

The next frame, frame no.3, in the setup stage (See Figure 3.13), sets the DAQ mode for the spectrometer for the end point detection and initializes the AT-GPIB/TNT board. The GPIB initialization is shown in Figure 3.13. The base address for the GPIB board is H2C0, the DMA channel is 5 and the Interrupt line is 11. Once the program runs, the user gets a prompt if there is any error, like error connecting to driver, GPIB bus errors, and error if board is not present or if address specified is not correct. This is done by the 'General Error handler.vi '. The GPIB is configured using the NI-488.2 driver software. The DDA-06 and the PC-LPM-16 are configured using the NI-DAQ configuration utility software, which checks for the cards and allows the user to specify the Interrupts, DMA channels and the base address. Finally the user makes use of the device numbers specified by the driver software in the LabVIEW source code. for it to communicate with the peripherals. The output of the spectrometer is connected directly to the port of the GPIB. The GPIB consists of a bi-directional bus that has the capability of sending and receiving signals from a device. The wavelengths of light emitted by different species in the plasma chamber are displayed on the display, which enables the end point detection.

The next frame, frame number '4' (Figure 3.14), starts the timer, which is compared in the next stage to the process time and if they are equal, the program halts.

3.5.2 Monitor Stage

This stage takes the run time data from the machine and processes it for displaying. Figure 3.22 shows the Monitor Stage. The sub VIs for this stage are:

1. Acquire Run Time Data.vi
2. Validate Data.vi

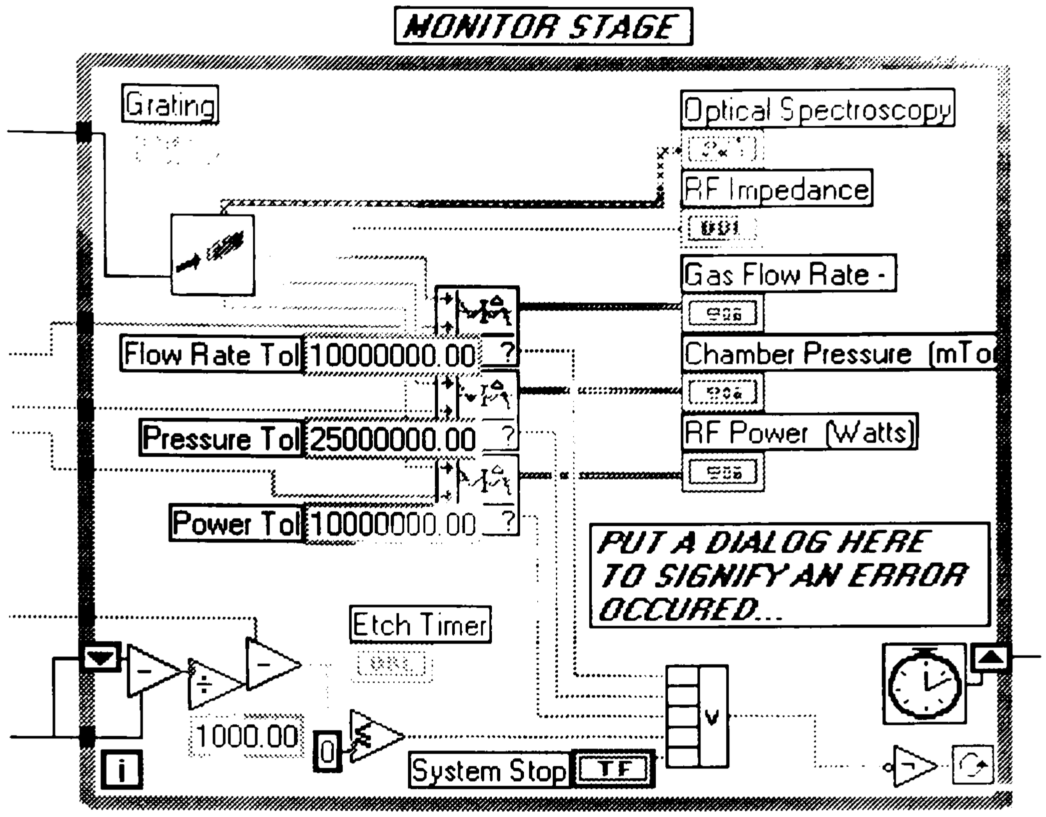


Figure 3.22 Monitor Stage

A shift register is used to count down the time. The time from the previous stage is subtracted from the current time and it is compared with the process time specified by the user and if they are equal the program stops. Since the 'tick count' function counts time in milli seconds, it is necessary to convert the time to seconds by dividing with 1000.

The Acquire run time data.vi is the data acquisition VI for the etcher software. The PC-LPM-16 card is used to read in the data. This VI uses the sub VI 'AI Sample Channel.vi', to acquire data from the plasma etcher.

Figure 3.23 shows the diagram of acquire runtime data.vi. The device number assigned to the PC-LPM-16 card is 1. The channel numbers for different input

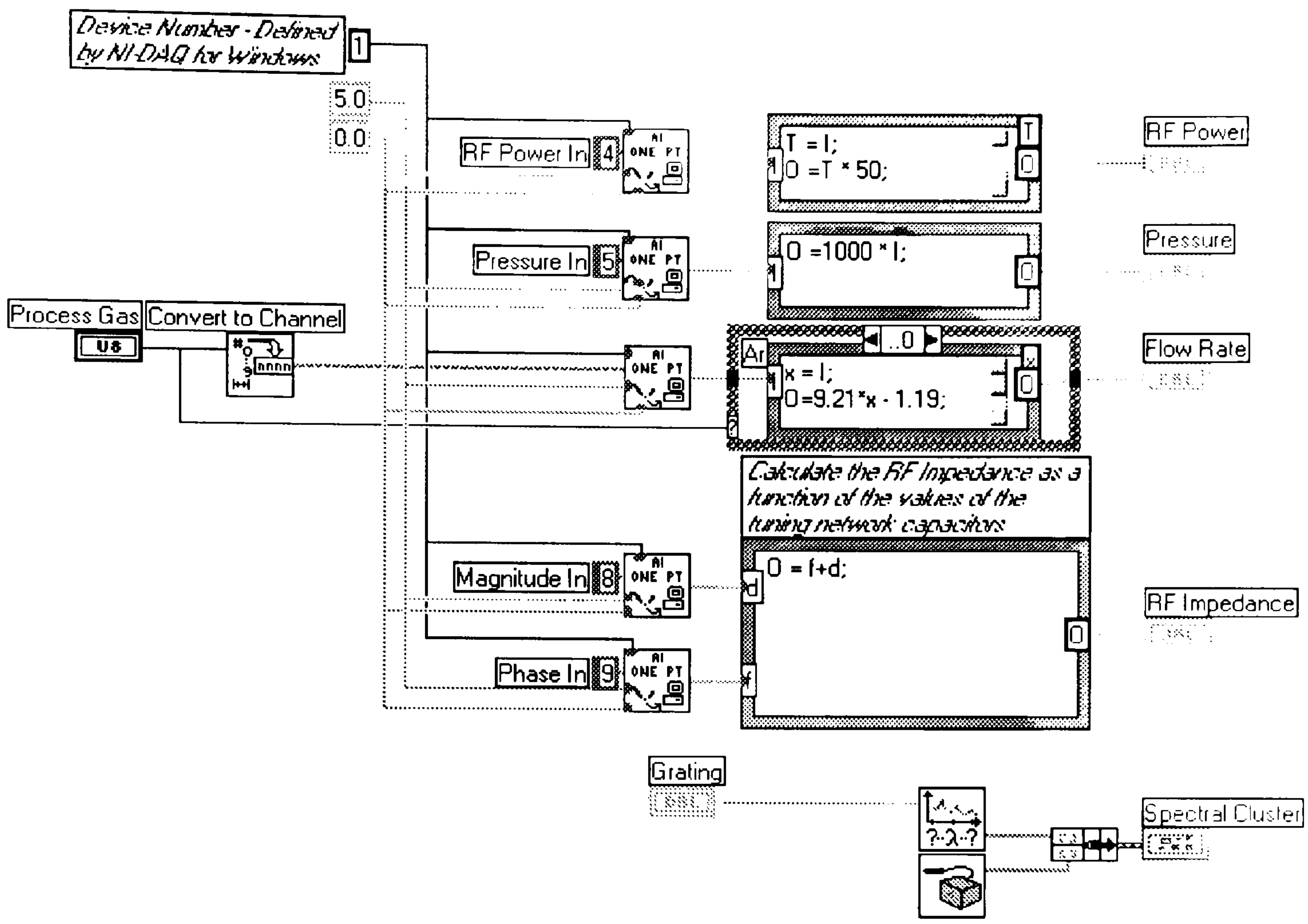


Figure 3.23 Acquire Runtime Data.vi

parameters are shown in Table 3.3. The high limit is set to 5.0 volts and the Low limit is set to 0volts. A formula node is used for each input parameter. Formula nodes for the gas flow rates are grouped together inside a CASE structure. The gas number selects the sequence with the formula node for that particular gas. The 'convert to channel.vi', is used to convert the gas numbers to a string. The coefficients for the equations in the formula nodes are experimentally determined. The flow rate equations for different gases are listed in Table 3.5.

Table 3.5 Equations for the gases

Gas	Flow Rate Equation
Ar	X = I; O= 9.21*X-1.19 ;
CF_4	T= (I* (10/4096)-5)*100; O=T* 0.5-27.75;
H_2	T= (I* (10/4096)-5)*100; O=T* 0.11+ 12;
O_2	T= (I* (10/4096)-5)*100; O=T* 00171292-2.7328;
Pressure	O=(0.961001/1000000) *I + 0.000539;

These parameters are then passed into Validate Data.vi, where they are checked to determine if they have exceeded the specified tolerance level or not. The diagram for this VI is shown in Figure 3.24. The Boolean variables (True or False) from the validate data.vi are given to the 'compound Arithmetic' function. The remaining time

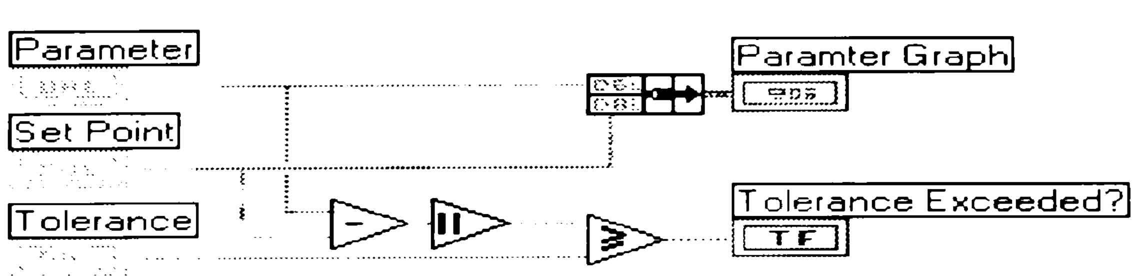


Figure 3.24 Diagram of Validate Data.vi

of the timer is also given to this function. This 'compound Arithmetic' function performs logical OR on these Boolean variables. If any of the parameters exceed the tolerance or if the etcher system times out, then the WHILE loop terminates causing the shutdown of the system.

3.5.3 Shutdown System

The shutdown System de-energizes the solenoids and switches off the Mass Flow Controllers and the sends 0 Volts to the pressure controller. Figure 3.25 shows the

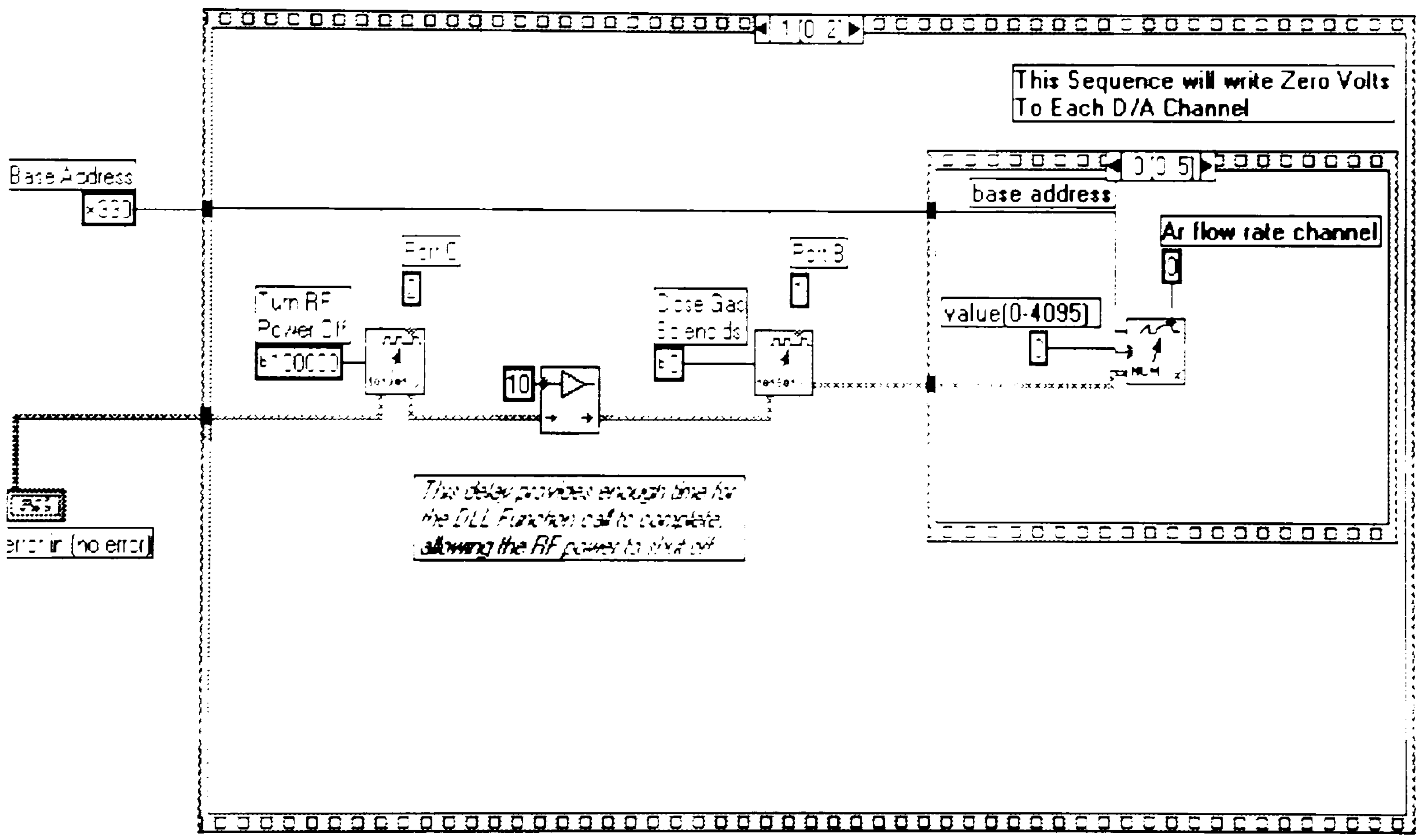


Figure3.25 Shutdown System.vi

Shut down System.vi. Frame '0' initializes the DDA-06 card as before. In frame '1', b00000000 is written at Port B to power off all the gas solenoids. There are 5 frames in this Frame itself, in which the D/A channels are reset. Once the system is shut down, the user gets an option to purge the system. A snapshot of the program when purging was being done is shown in Figure 3.26.

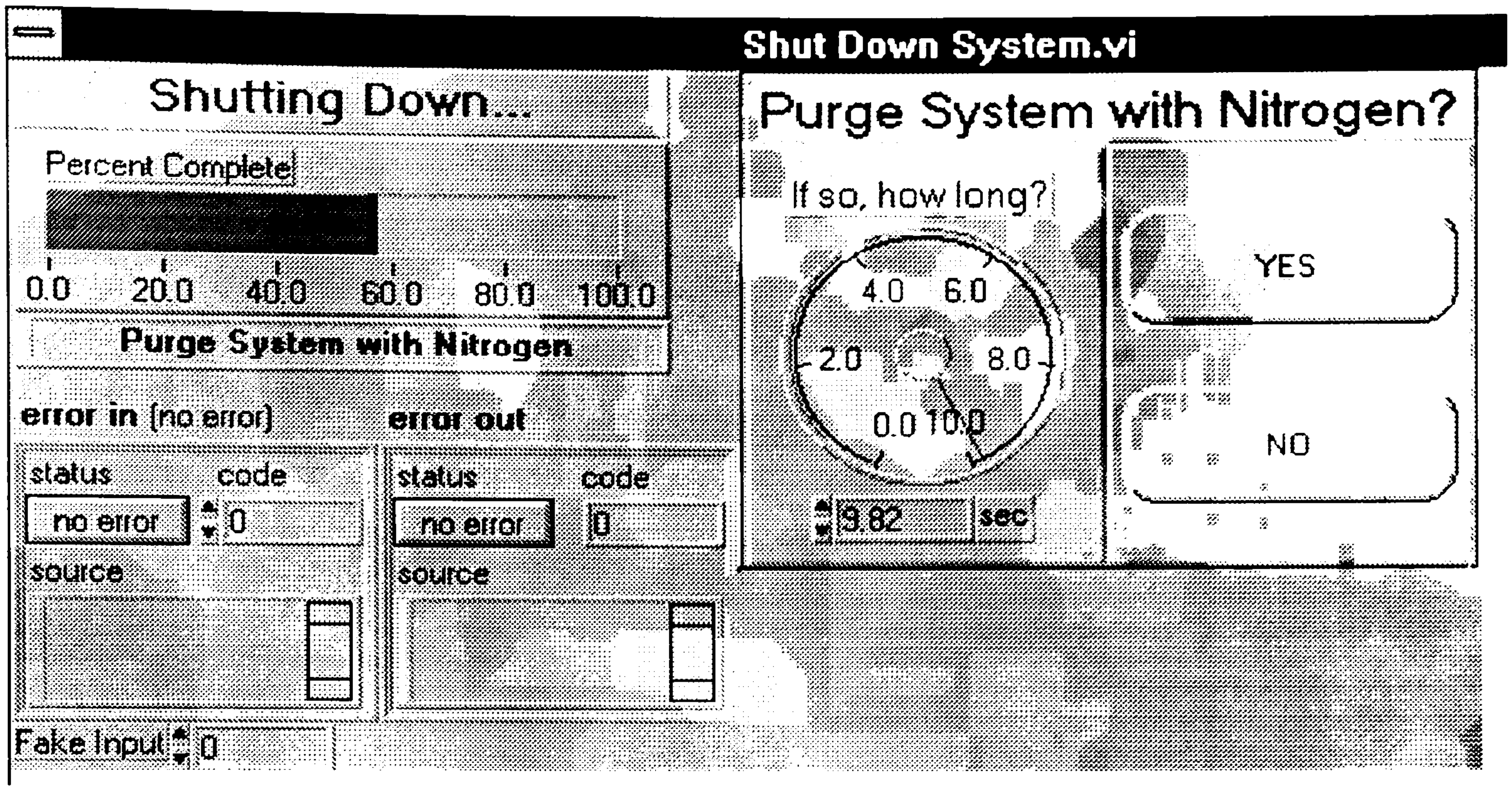


Figure 3.26 Purging with Nitrogen

Now that all the modules in the diagram are explained, the entire etcher source code is shown in Figure 3.27. So, once the user sets the parameters in the setup stage, the program initializes all the cards, starts the system, sends the appropriate voltages to different peripherals and sends the control to the next stage, monitor stage, which receives signals from the machine, processes them and makes it compatible for the display and once the process time is finished, the system shuts down.

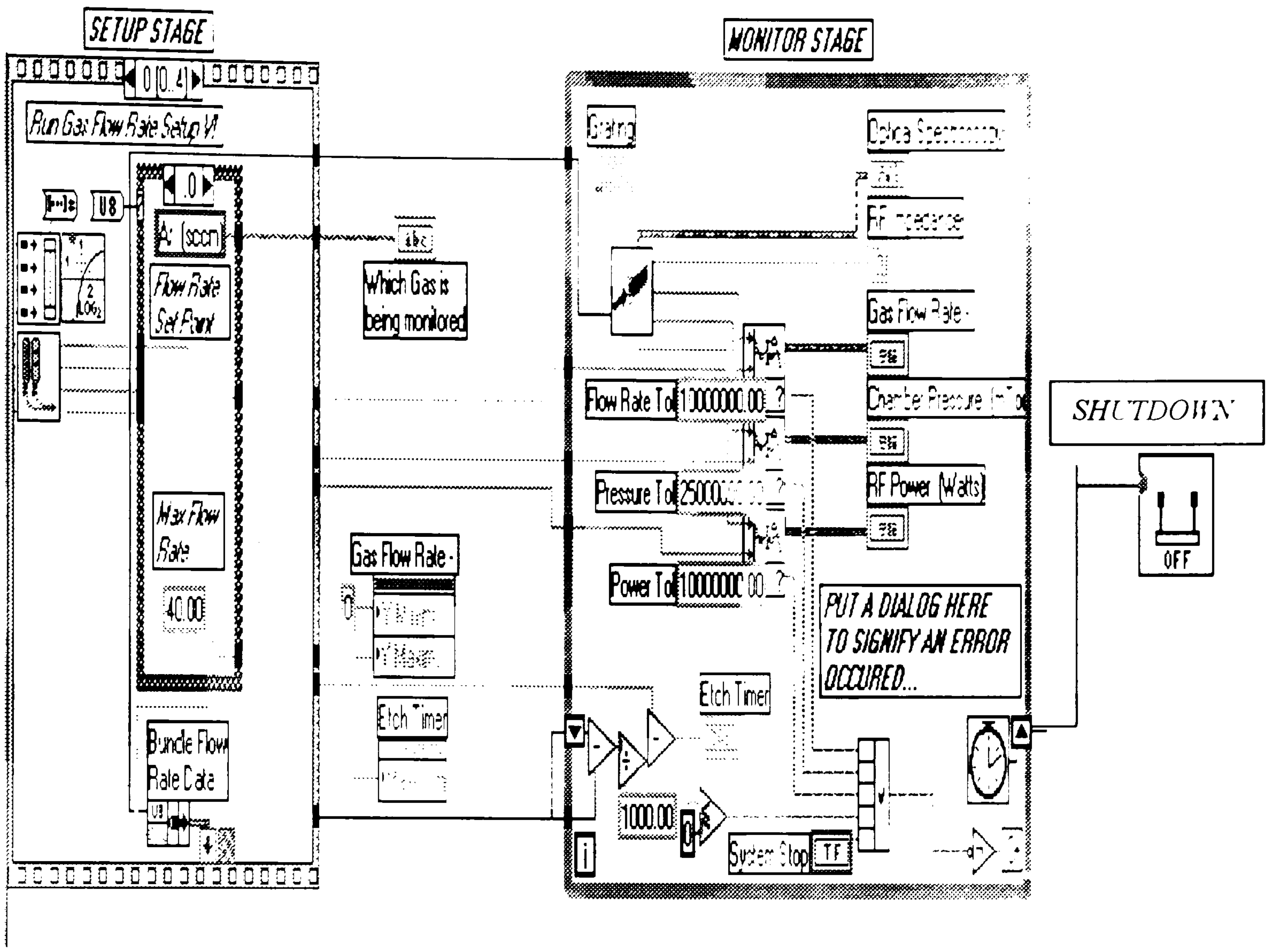


Figure 3.27 Control Program

Thus, the Control program was designed using the generic approach discussed in Chapter II. This modular approach of designing the program is easy and changes to the code can be made easily. This methodology of automation was successfully implemented on the Plasma Etcher. The next chapter, Chapter IV, discusses the implementation of the automation approach on an other system called Plasma deposition system.

CHAPTER IV

IMPLEMENTATION OF AUTOMATION APPROACH ON PLASMA DEPOSITION SYSTEM

4.1 Introduction to the Plasma Deposition System

The generic approach explained in Chapter II was also used to automate an other equipment, a Plasma Deposition system [3]. This plasma reactor system is designed to deposit a variety of types of films at high speeds onto large numbers of semiconductor slices. The block diagram of the system is shown in Figure 4.1. The signals to select the gases, certain controls like selecting the vacuum valves, raising the chamber cover, these signals come from a sequencer box which will be explained further. Even though it is called a deposition system, it can also etch and ash wafers. Ashing is a process of removing photoresist on wafers. There are two modes of operation on the system. One is manual mode and the other is automatic mode. In manual mode, all the controls (toggle switches) are on the electrical cabinet. In the automatic mode the system is controlled by signals from the computer. Before discussing the DAQ Boards, External Interface boards a brief explanation of the system setup is given.

The reactor system is comprised of three major assemblies, the plasma depositioner assembly, the electronic cabinet and the vacuum pump. The reactor system is comprised of subsystems that function to perform deposition, etching or ashing processes. The subsystems are Gas and compressed air system, vacuum system, RF power generator system, the reactor, sequencer, and pressure control system. Heating and cooling systems are optional. The optical spectroscopy is not used in the automation. The other systems of the depositioner assembly are explained in the ongoing topics. The Plasma depositioner assembly and the electrical cabinet are shown in Figure 4.2 and Figure 4.3, respectively.

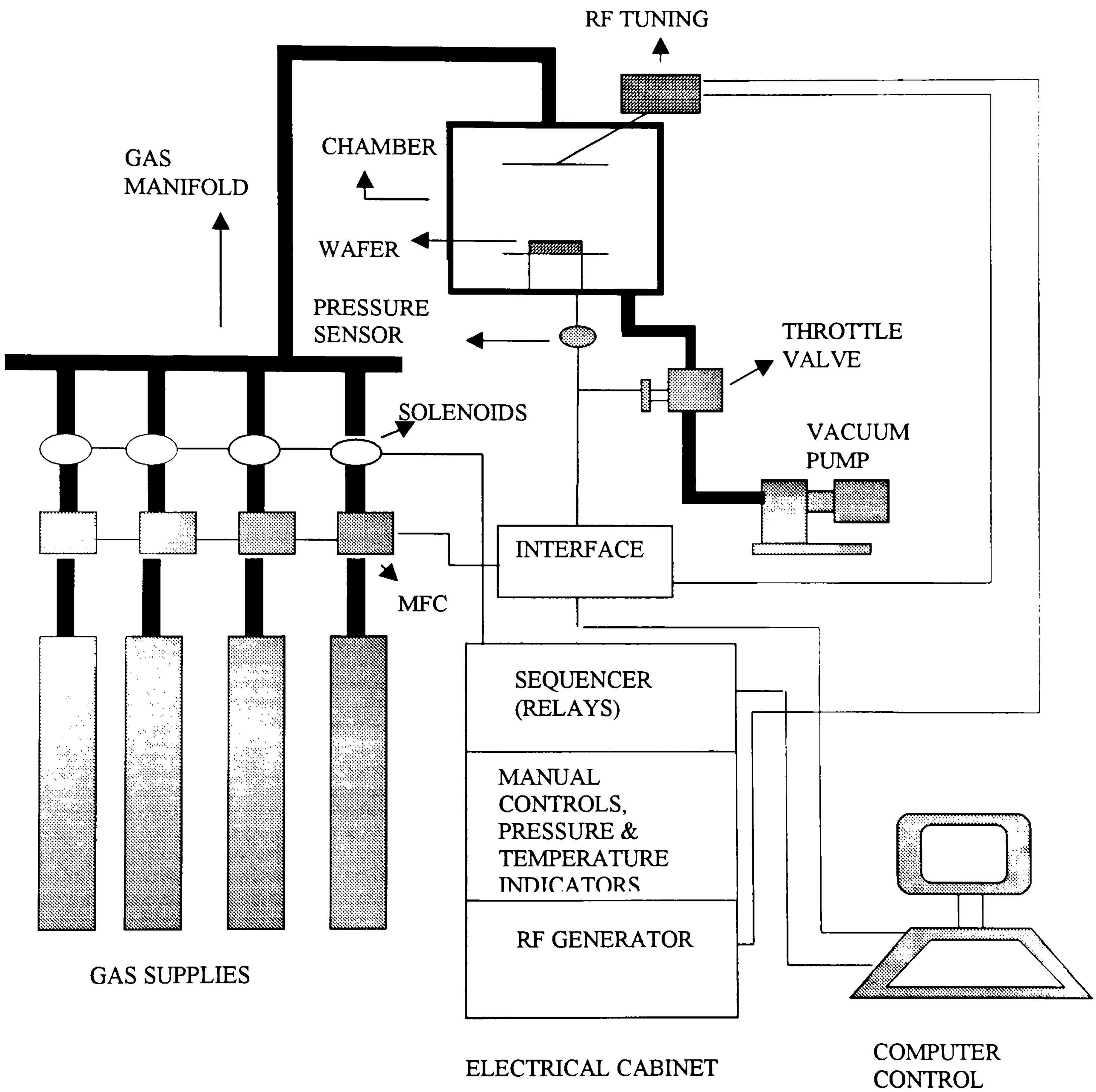


Figure 4.1 Deposition System

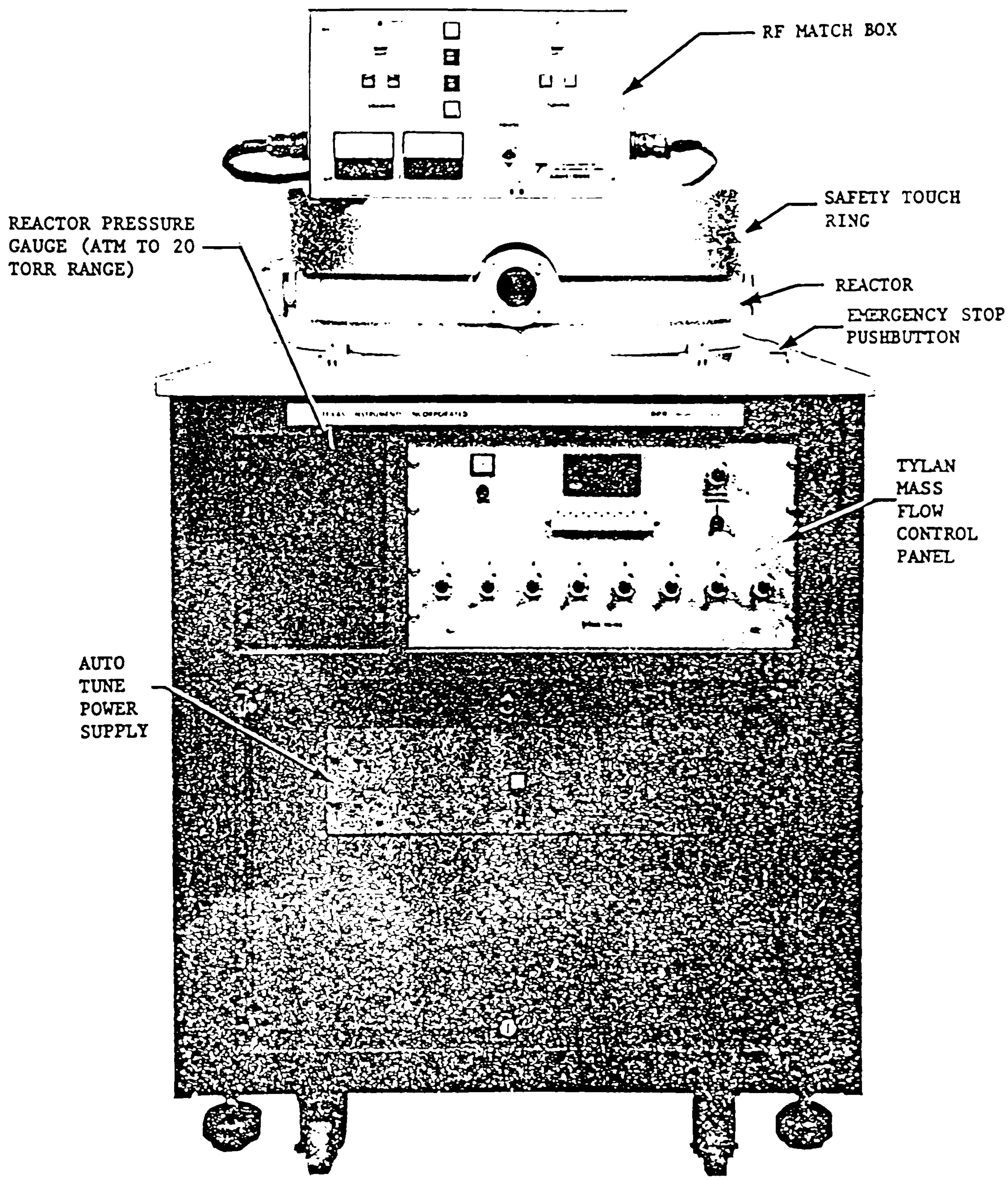


Figure 4.2 Plasma Depositioner Assembly

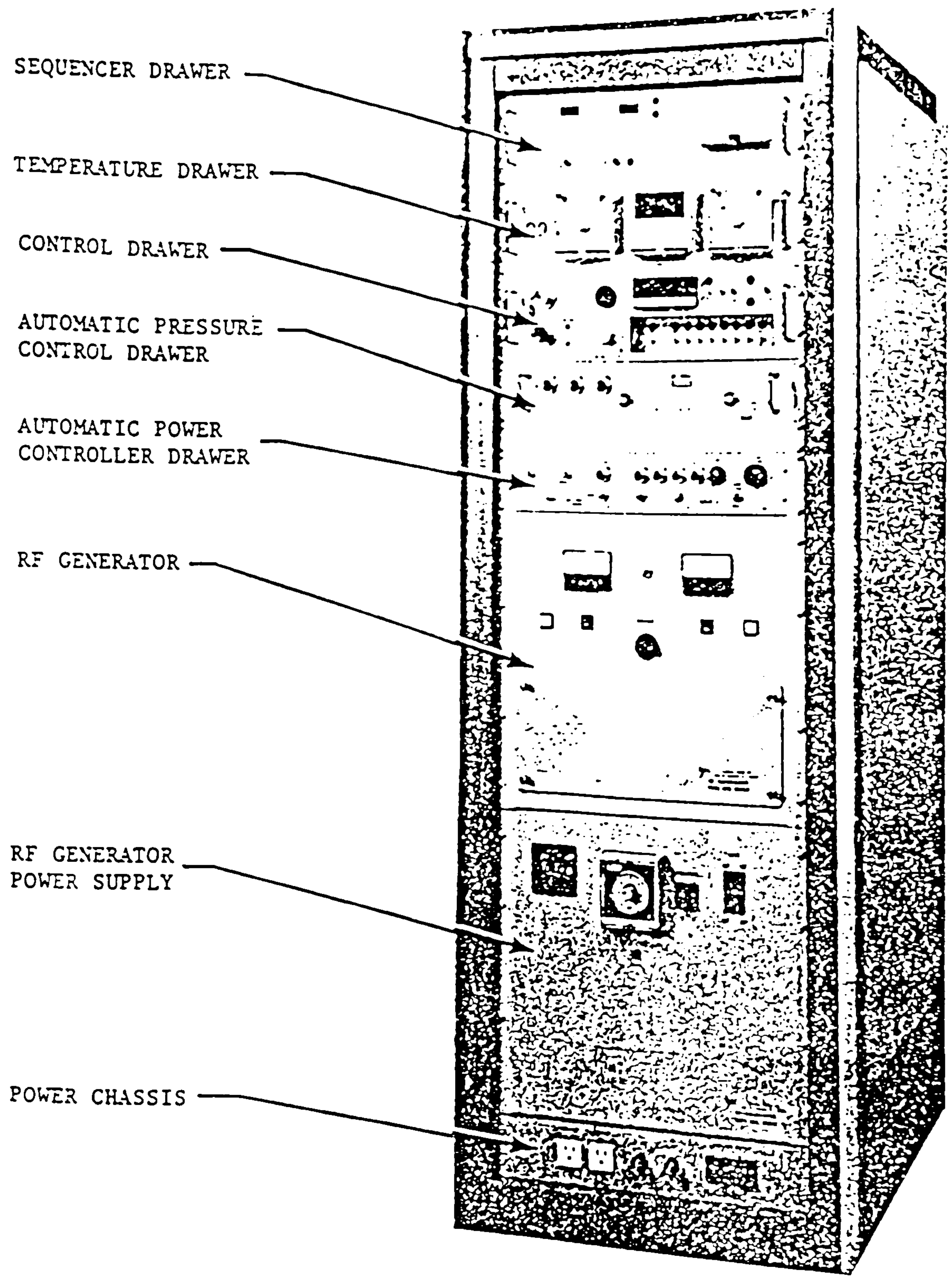


Figure 4.3 Electrical Cabinet

4.1.1 Gas and Compressed Air System

The function of the gas system is to furnish various gases at selected rates to the reactor chamber. The system consists of necessary piping, valves, mass flow controllers, and gauges to control and monitor the process of etching and deposition. At the depositioner assembly, each process gas is controlled by a solenoid valve, and monitored by a flow meter and pressure gauge. The solenoid valves are actuated by toggle switches (manual mode) or by signals from the sequencer box, activated by the computer, which inturn operate the air valves to permit gas to flow into the manifold. There is also provision for Nitrogen gas to purge the chamber.

Compressed air is supplied to the unit at 70 psi. The compressed air performs three functions. It raises and lowers the reactor cover, operates the air valves that control the pump out rate of the reactor operates the air valves that control the application of input gases to the chamber. Compressed air enters and evacuates the reactor cover control air cylinder through a piping arrangement containing two solenoid valves and an adjustment needle valve. An air cylinder controls the reactor cover. It can also be controlled through a signal from the computer. Also a toggle switch LID UP/DOWN (manual mode) controls the lid. When the switch is in the up position air goes into the cylinder causing the piston inside it raise the lid. In down position the cylinder is gradually vented from the cylinder causing the lid to lower over the reactor chamber.

4.1.2 Vacuum System and Reactor

The function of the vacuum system [3] is to establish the flow rate of the reactant gases over the substrates, control the pressure in the chamber, and remove the gaseous reaction products after deposition or etching process. The amount of vacuum furnished in the chamber determines the velocity of gas across the substrates and the pressure in the gas mixture. Three solenoid-operated valves are actuated by associated Vacuum Valves toggle switches or the computer (through the sequencer), to apply a selected amount of vacuum to the reactor. The amount is determined by the throttle valves associated to each vacuum valve.

The reactor provides a controlled environment in which RF plasma processes take place. The cylindrical design of the reactor chamber permits high volume processing of substrates as result of radially inward flow of the gases within the reactor. The interior of the reactor contains a RF power plate and a heater plate. The RF power plate is the means by which RF power is coupled into the reactant gases. Three circular windows enable the operator to observe the RF glow discharge inside the reactor. The radial flow of gas inside the reactor is shown in Figure 4.4

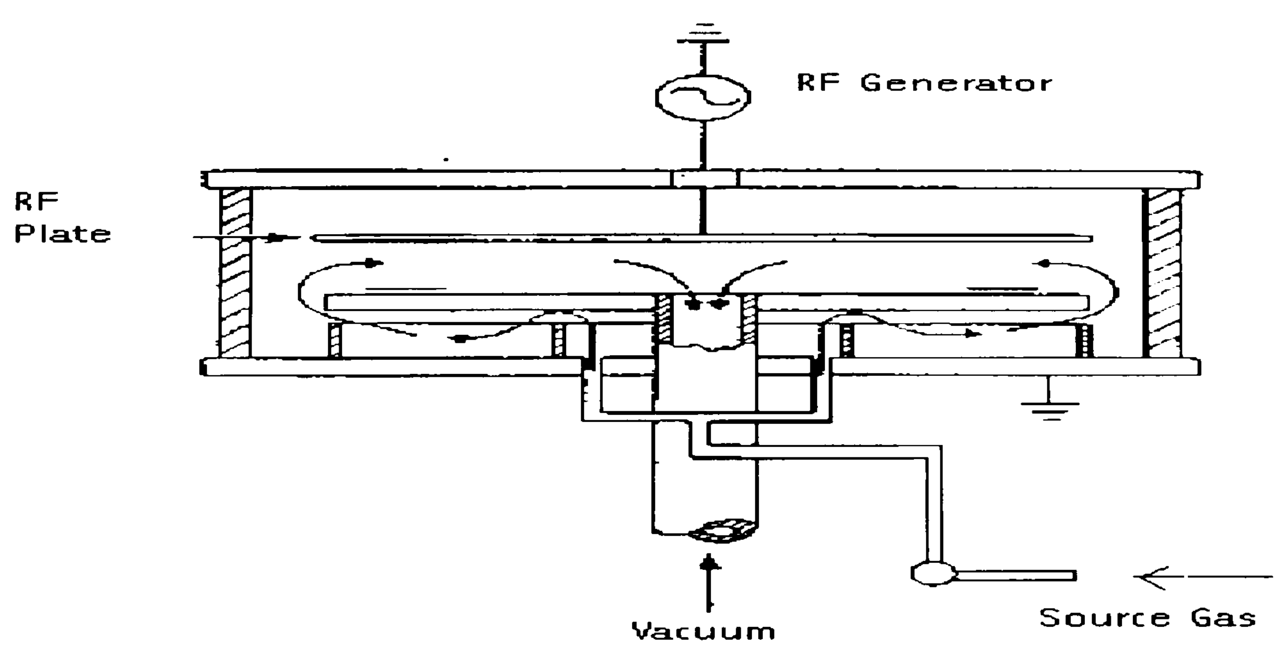


Figure 4.4 Radial Flow of Gas

4.2 Lab – PC+ DAQ Board for the Deposition System

In automating this equipment, two Lab - PC+ DAQ boards [6] are used. The Lab – PC+ is a low cost multifunction analog, digital, and timing I/O board for the PC. The Lab – PC+ contains a 12-bit successive approximation ADC with eight analog inputs, which can be configured as eight single-ended or four differential channels. The Lab – PC+ also has two 12-bit DACs with voltage outputs, 24 lines of TTL-compatible digital I/O, and six 16-bit counter/timer channels for timing I/O.

The Lab – PC+ contains six jumpers and one DIP switch to configure the PC bus interface and analog I/O settings. The DIP switch is used to set the base I/O address. Two jumpers are used as interrupt channel and DMA selectors. The remaining four jumpers are used to change the analog input and output circuitry. The first PC+ board is configured as device1 and the second one as device2. For device 1 the Base I/O address is Hex240 and Hex280 for the other. The DMA channel is 3 for both the devices and the interrupt line is 5 for both the devices. Channels ACH0 through ACH7 are for analog inputs. The Figure 4.5 shows the operational diagram of Lab-PC+. Table 4.1 shows the pin configuration of PC+ board.

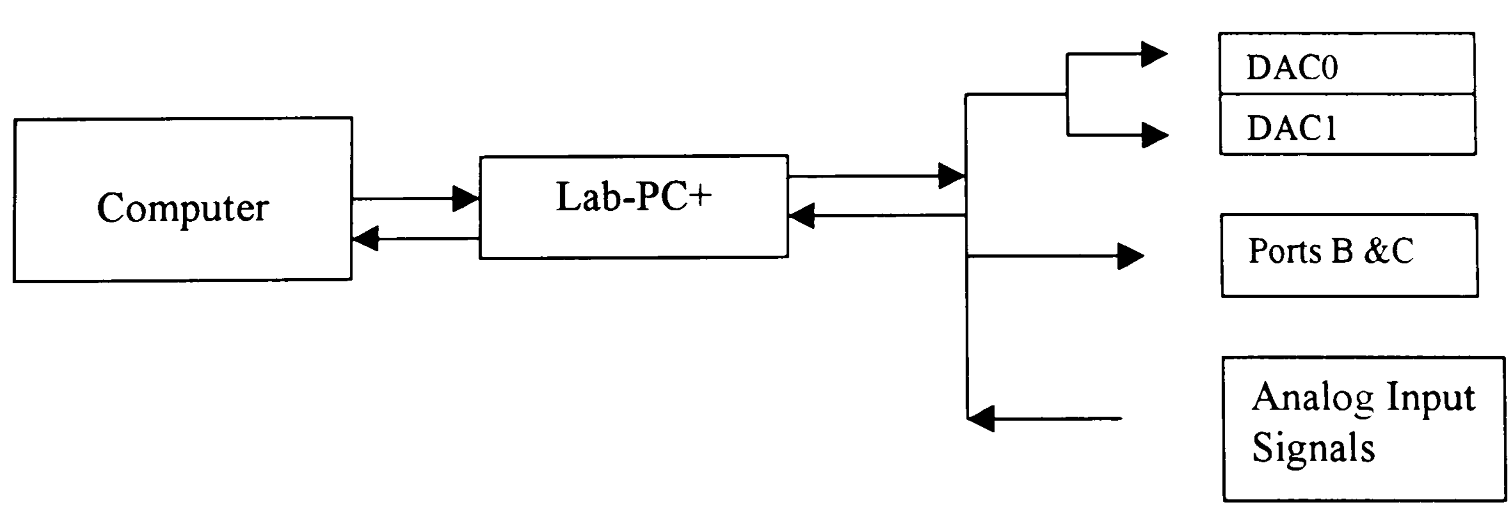


Figure 4.5 Operation of Lab PC+

Table 4.1 Pin Configuration for Lab-PC +

Pin Number	Pin Function	Pin Assignment
1	ACH0	Ar flow Rate
2	ACH1	CF_4 Flow Rate
3	ACH2	Hydrogen Flow Rate
4	ACH3	Oxygen Flow rate
5	ACH4	RF Power
6	ACH5	Pressure
7	ACH6	RF Impedance
10	DAC0 (device 1)	Setpoint for pressure
12	DAC1(device 1)	Setpoint for Ar Flow rate
11	AGND	Analog Ground
13	DGND	Digital ground
14	PA0	Argon Relay
15	PA1	CF_4 Relay
16	PA2	Hydrogen Relay
17	PA3	Oxygen Relay
10	DAC0 (device 2)	Setpoint for CF_4 flow rate
12	DAC1(device 2)	Setpoint for H_2 flow rate

The digital I/O consists of three ports (ports A, B, C). They are eight-bit bi-directional ports. The analog output channel DAC0 on device1 is used to control the pressure setpoint for the chamber pressure. The output channel DAC1 is used for controlling Ar gas flow rate setpoint. Similarly, the DAC0 and DAC1 channels on device2 are used for controlling CF4 and Hydrogen gas flow rate setpoints. The port A is used to trigger the relays to switch on the gas solenoids.

4.3 Gas Control System and Sequencer Box

The sequencer box originally had RAM chips and EPROMs [3], which had to be programmed for each run to perform operations in sequence (etch, ash, deposit). It was tedious and has been replaced with solid state relays actuated from the computer. The sequencer box is a control device designed to drive the solenoids in the depositioner assembly and actuate other signals. It has a 5 VDC power supply and solid state relays. The DAQ boards residing in the computer send the signals to turn the relays on or off. Each relay controls the application of 115VAC to a depositioner function (solenoid valve). The sequencer box is used if automatic operation is needed.

Figure 4.6 shows the operation. In plasma etcher the driver circuit was used to switch the solenoids, on or off. The deposition system uses 120 VAC to operate the solenoids. The sequencer box helps in this operation. The digital outputs from the PC+ are used to trigger all valves and solenoids via the relays in the sequencer box. The sixteen control relays have input rating of 5 VDC and output rating of 5 VDC. This output is used to trigger the next stage, the solid-state relays. The solid state rely is DC controlled and uses SCR switching. When these relays are switched on, they send 120 VAC to the solenoids causing them to turn on.

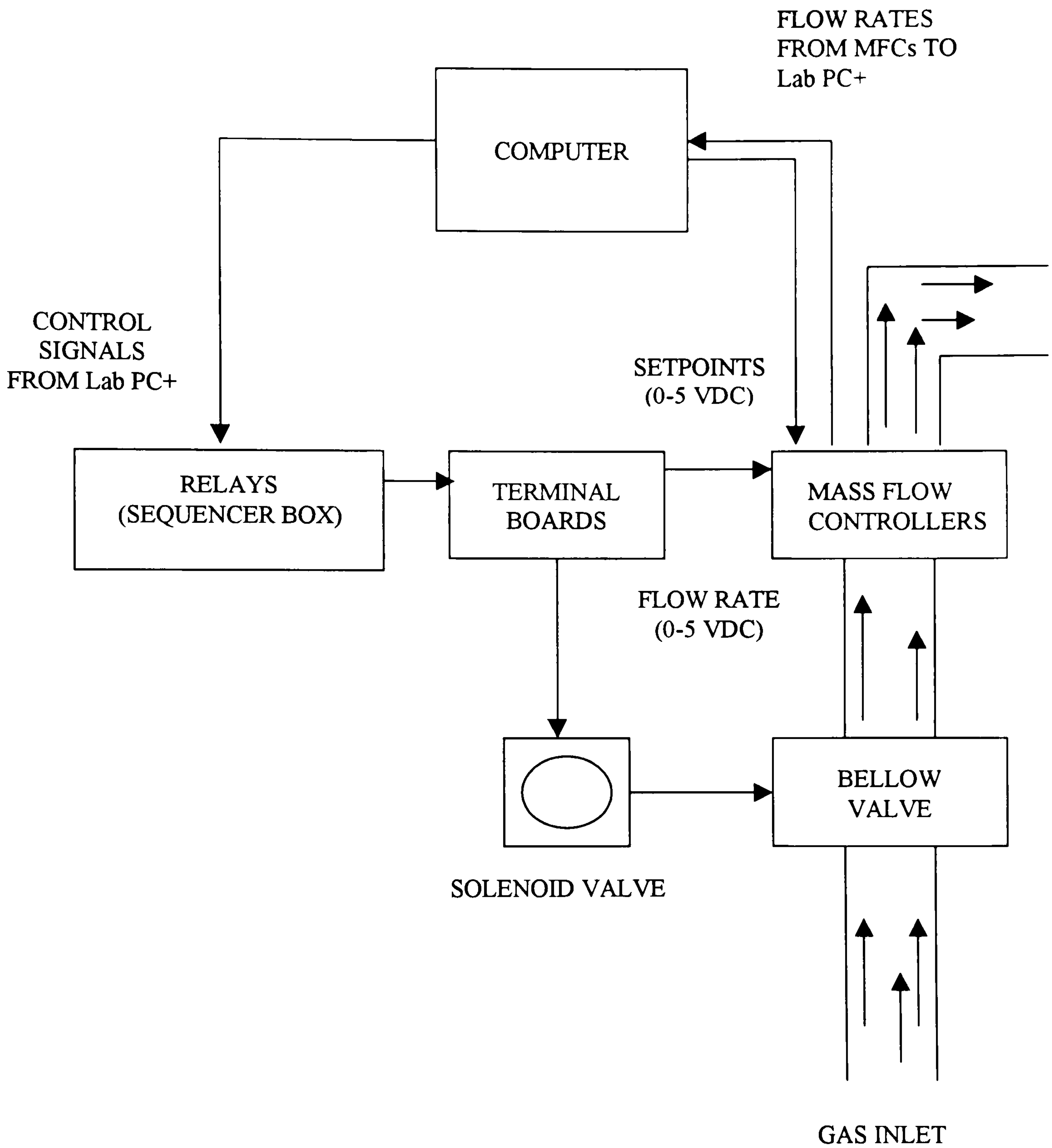


Figure 4.6 Gas Control System

4.4 Control Program for Deposition System

The software for the deposition system is also divided into three. The algorithm explained for the generic approach is used to design the program. But instead of using two DAQ boards, only one board, i.e., a Lab-PC+ is used. The pin configuration of PC+ is shown in Table 4.1.

In the program for the Deposition System, provision for three more gases was given. The gas selection.vi is shown in Figure 4.7

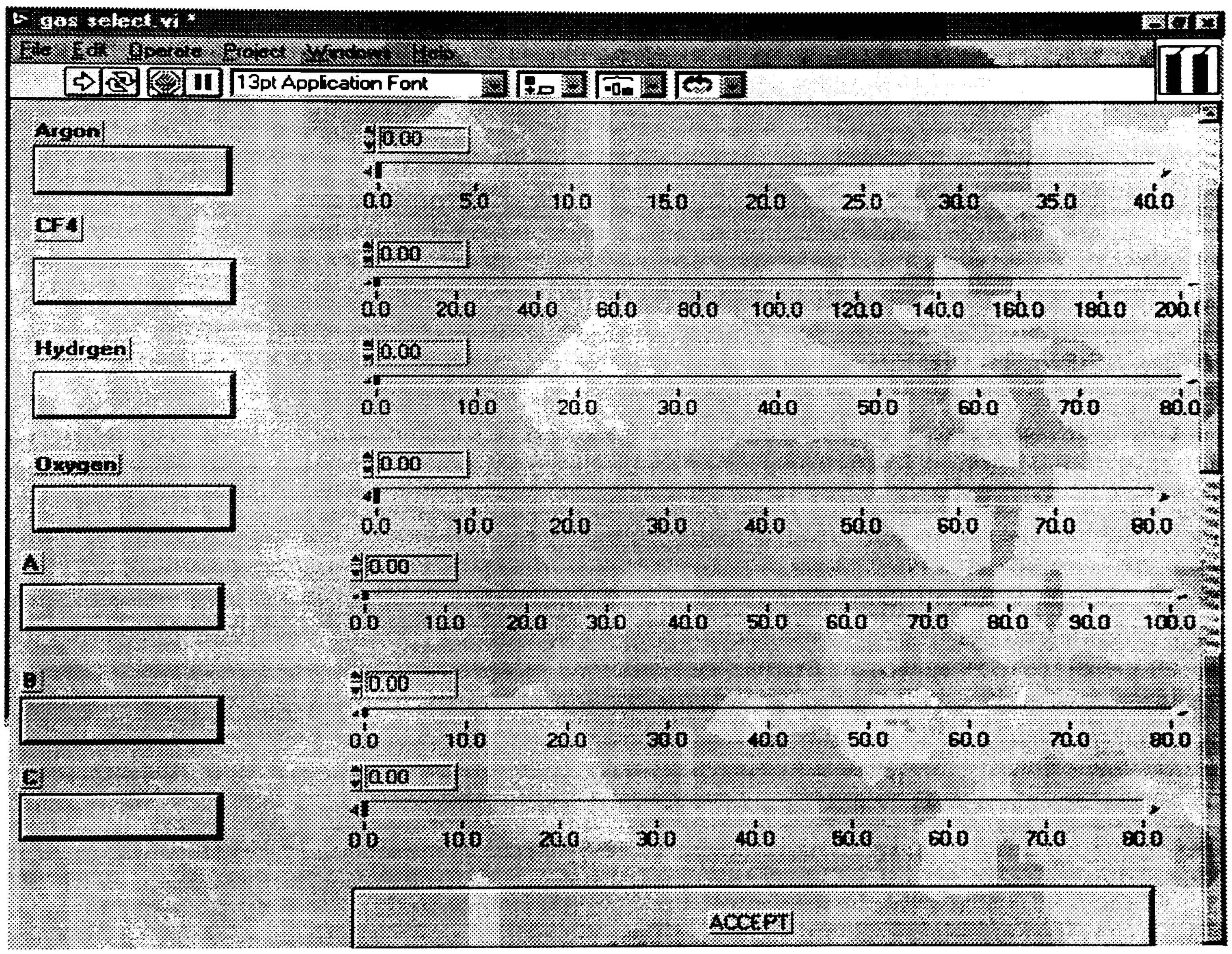


Figure 4.7 Gas selection.vi

As in the previous program, the Gas number, flow rate value, power, and pressure are bundled together and passed to the Initialize system.vi. For communicating with PC and to send the Analog signal out, it is not necessary to specify the address of the DAQ board, but we need to specify the device number. To send out the Analog signal, a sub VI called 'Analog Output Update Channel.vi', explained in Chapter II, is used.

Figure 4.8 shows frame '0' i.e. initialization of Pressure. It shows the equation and the device number, in this case it is '1'. Frame '1' shows the setpoint of Argon Flow rate. Another sub VI called 'write to digital Port.vi ' is used to switch on the relays in the sequencer box. Figure 4.9 shows the Flow rate screen for Argon Gas.

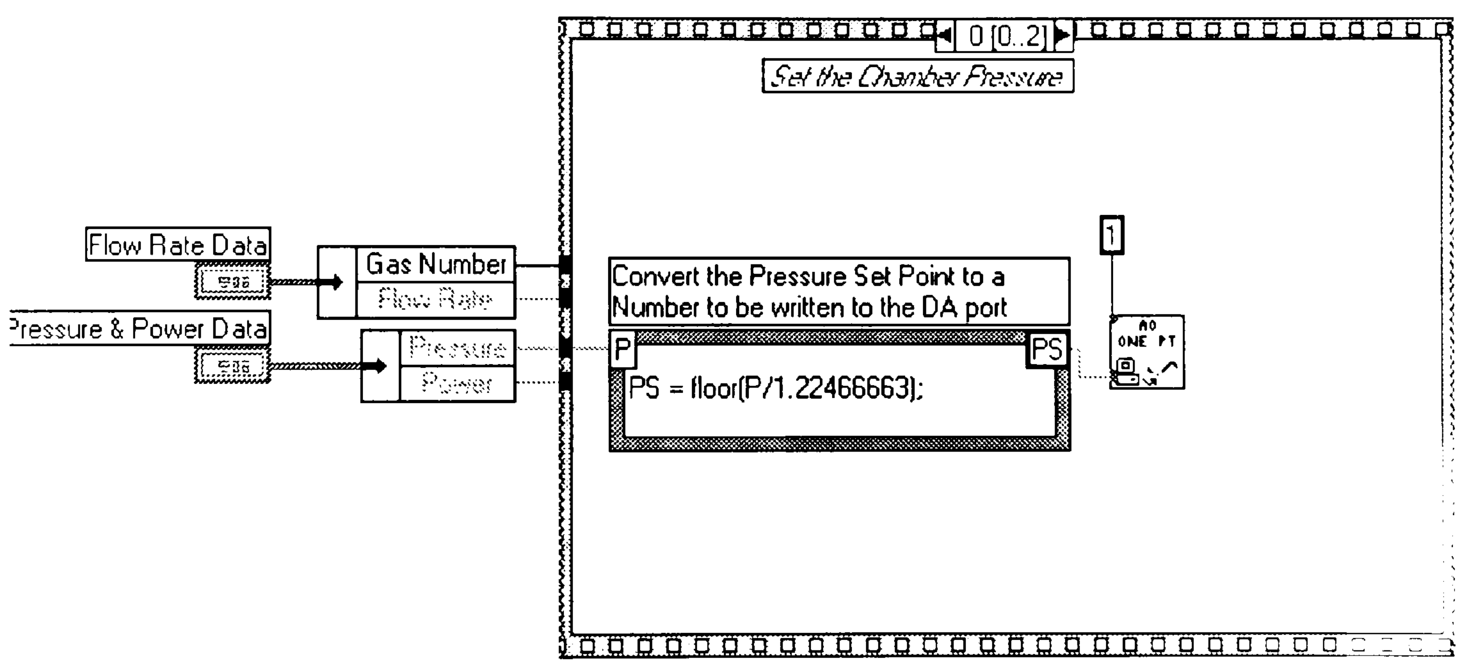


Figure 4.8 Pressure Initialization

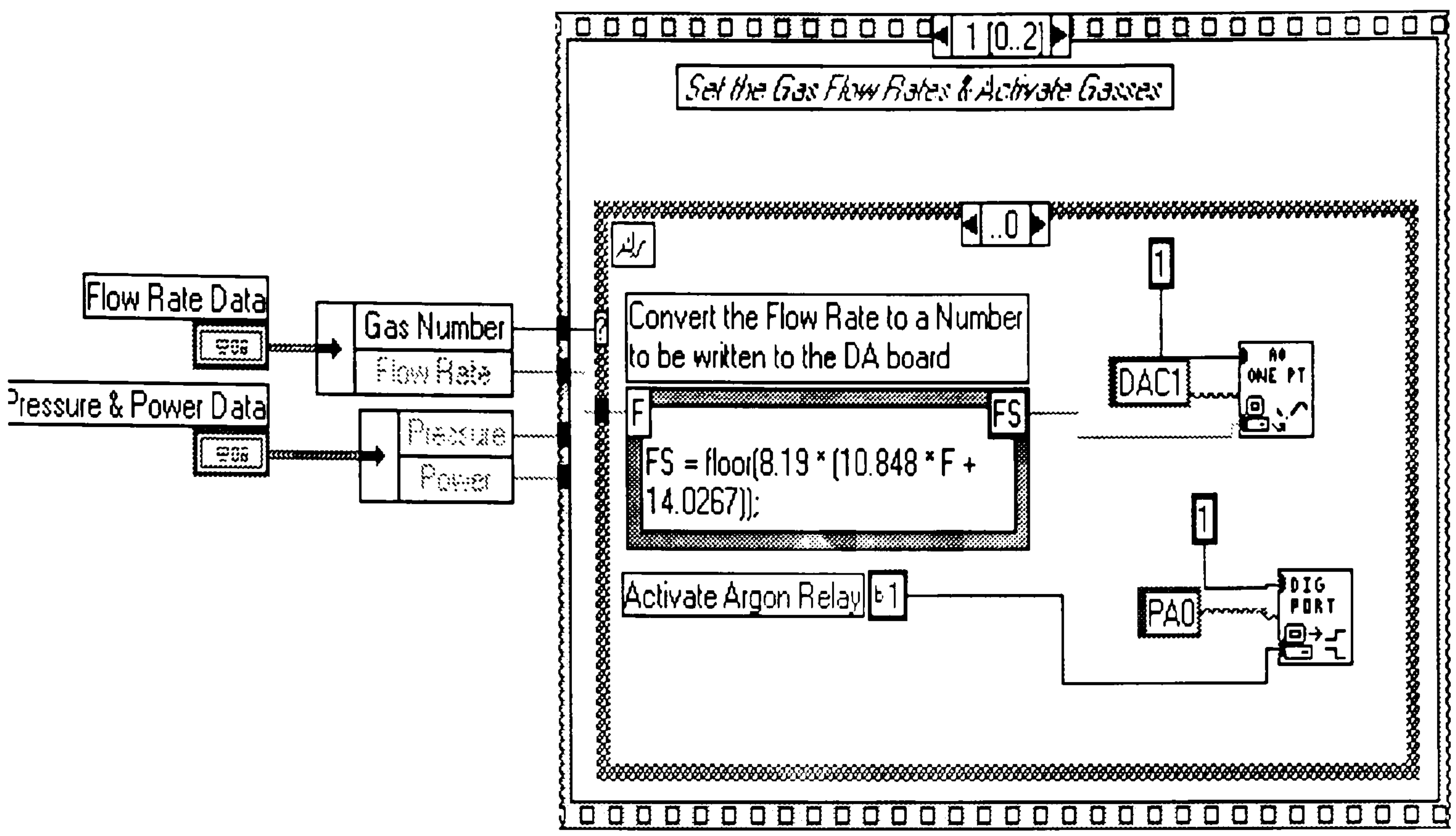


Figure 4.9 Frame no '1' of Initialize system.vi

So once the parameters are set in the first stage, the control goes to the second stage to get the feed back signals from the machine into the 'Acquire runtime data.vi', which is explained in the monitor stage for the Plasma Etcher. The shutdown stage is explained in Chapter III. In the shut down stage, binary 0's are written to all the digital channels and the setpoints are made zero to the Analog output channels, using the analog output.vi and the write to digitalport.vi. Finally the system is purged.

The next chapter, Chapter V, discusses the results obtained and the measurements taken.

CHAPTER V

MEASUREMENTS

The automation approach was implemented on two systems, namely a Plasma Etcher and a Plasma Deposition system. The LabVIEW control program takes the setpoint values from the user, converts them to equivalent volts or millivolts, sends the signals to the controllers on the machine through the D/A Board, reads the parameter values from the machine through the A/D board and displays it for the user on the computer.

For the Plasma Etcher, different setpoint values for the pressure were set and their corresponding voltages to the throttle valve controller were measured. These values are tabulated in Table 5.1. The corresponding runtime values are also shown in the table.

Table 5.1 Setpoints and Runtime Values for the Pressure

Pressure setpoint (millitorrs)	Setpoint (milliVolts)	Runtime values (millitorrs)
50	46	52
75	71.3	75
100	94	102
125	120	123
175	171.6	178

Different setpoint values in sccm (Standard Cubic centimeters) were set for the Mass Flow Controllers and their corresponding voltages were measured. The runtime values are shown in the Table 5.2. The data is taken by using CF4 (Freon) gas.

Table 5.2 Setpoints and runtime Values for the Mass Flow Controllers

Flow Rate setpoint (SCCM)	Setpoint (Volts)	Runtime values (SCCM)
0	0	0.01
40	1	43
80	2	82.7
120	3.1	123
160	4	164

The deviation between input values and runtime data is less than 5 percent and within the tolerance level. Provision is given in the control program of both the systems to monitor the RF power and Impedance. The objective is to implement and validate the automation approach and be able to operate the systems using DAQ Boards, external interface boards controlled by LabVIEW. The control program is written in a modular approach, so the user can make necessary changes to it and accommodate the control of extra parameters on the system.

Figure 5.1 shows the front panel of the plasma deposition system. The snap shot is taken when the system stabilized the Pressure and gas flow rate. Normally the runtime data stabilizes within a very short period of time. It is possible to view the dynamic changes in the parameters too. Figure 5.2 is taken when the throttle valve controller was

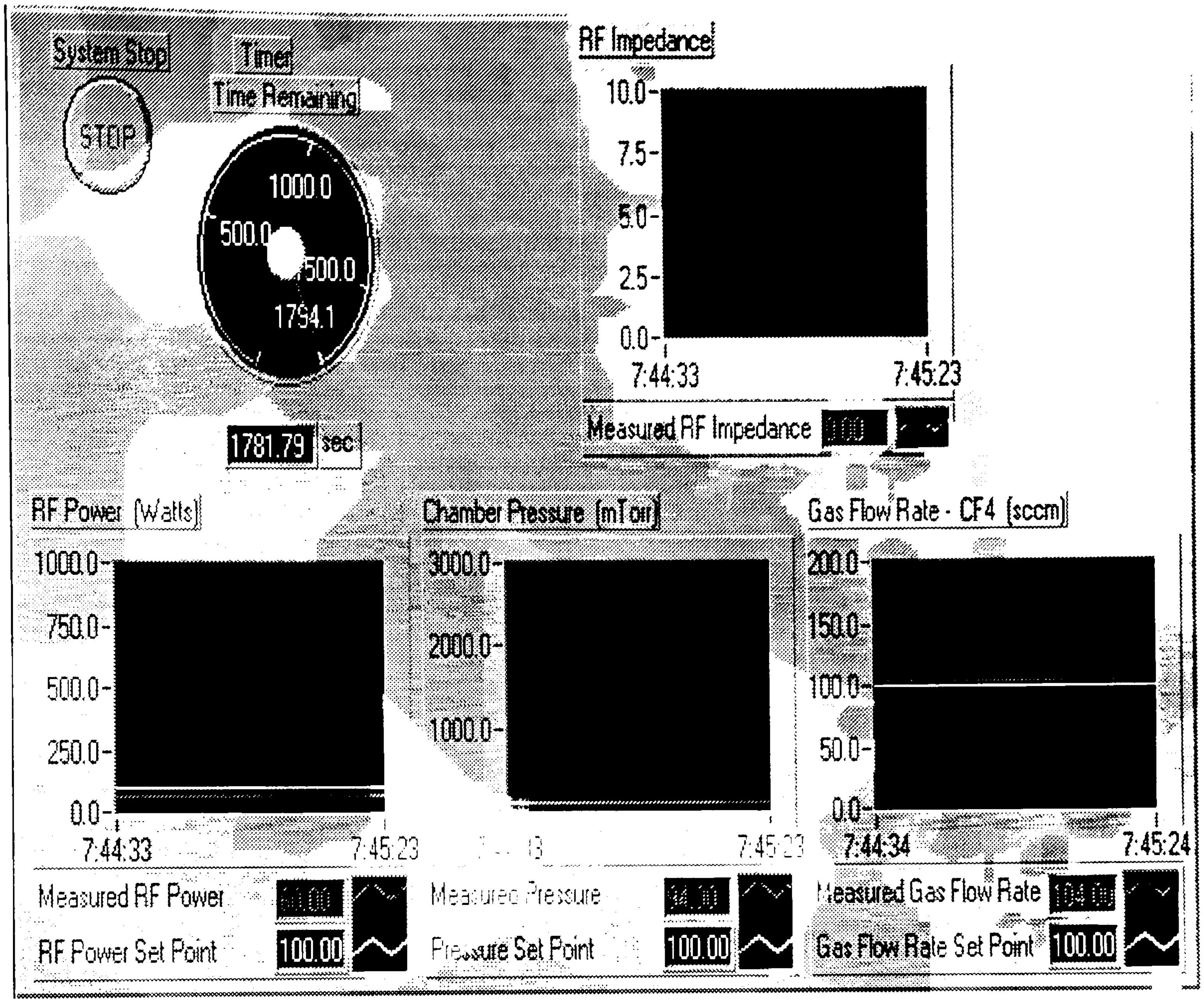


Figure 5.1 The front Panel when the parameters are stabilized

stabilizing the pressure in the chamber. Figure 5.3 shows the fluctuations when the MFC was controlling the gas flow rate according to the setpoint value.

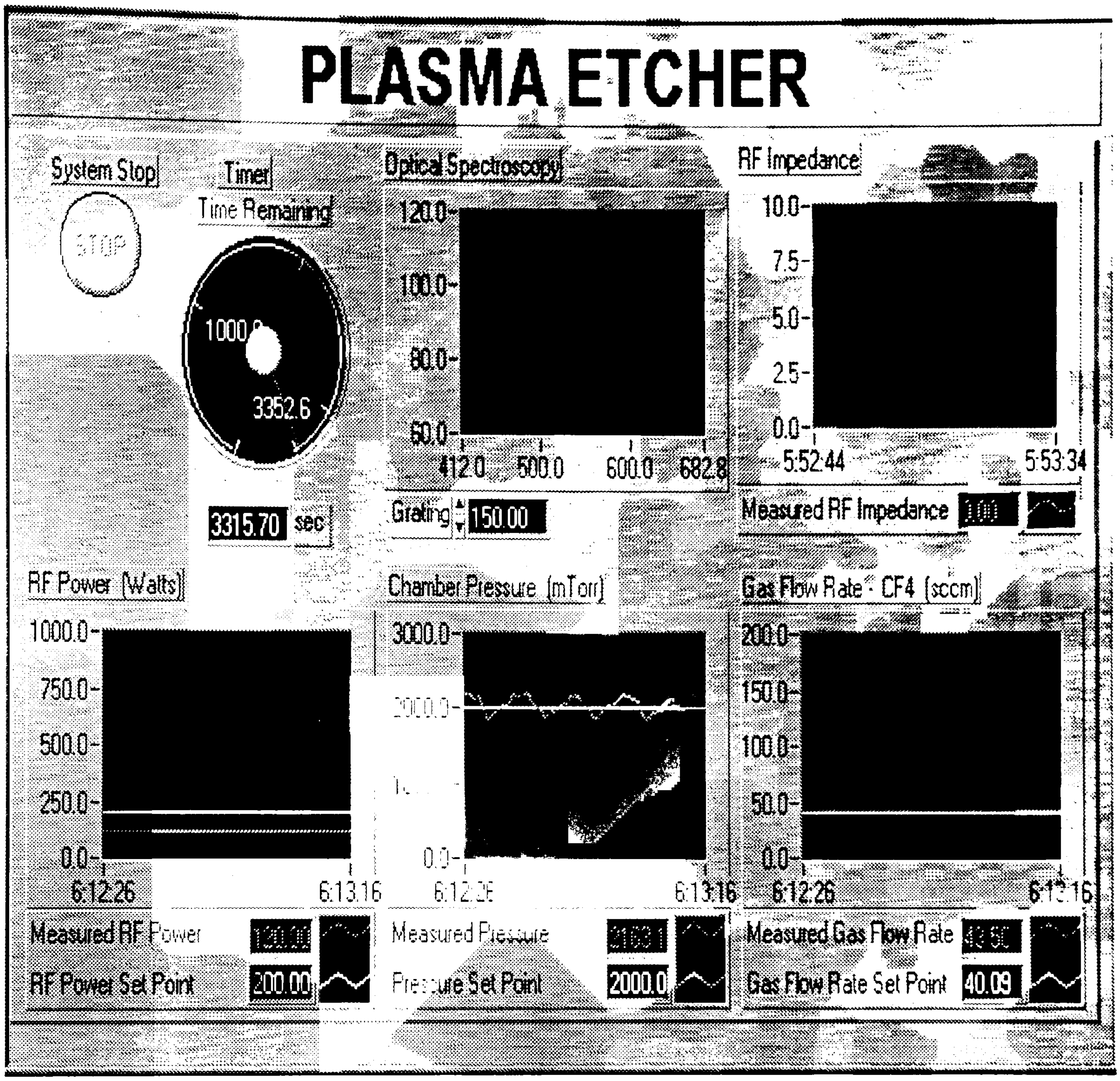


Figure 5.2 Pressure Stabilization

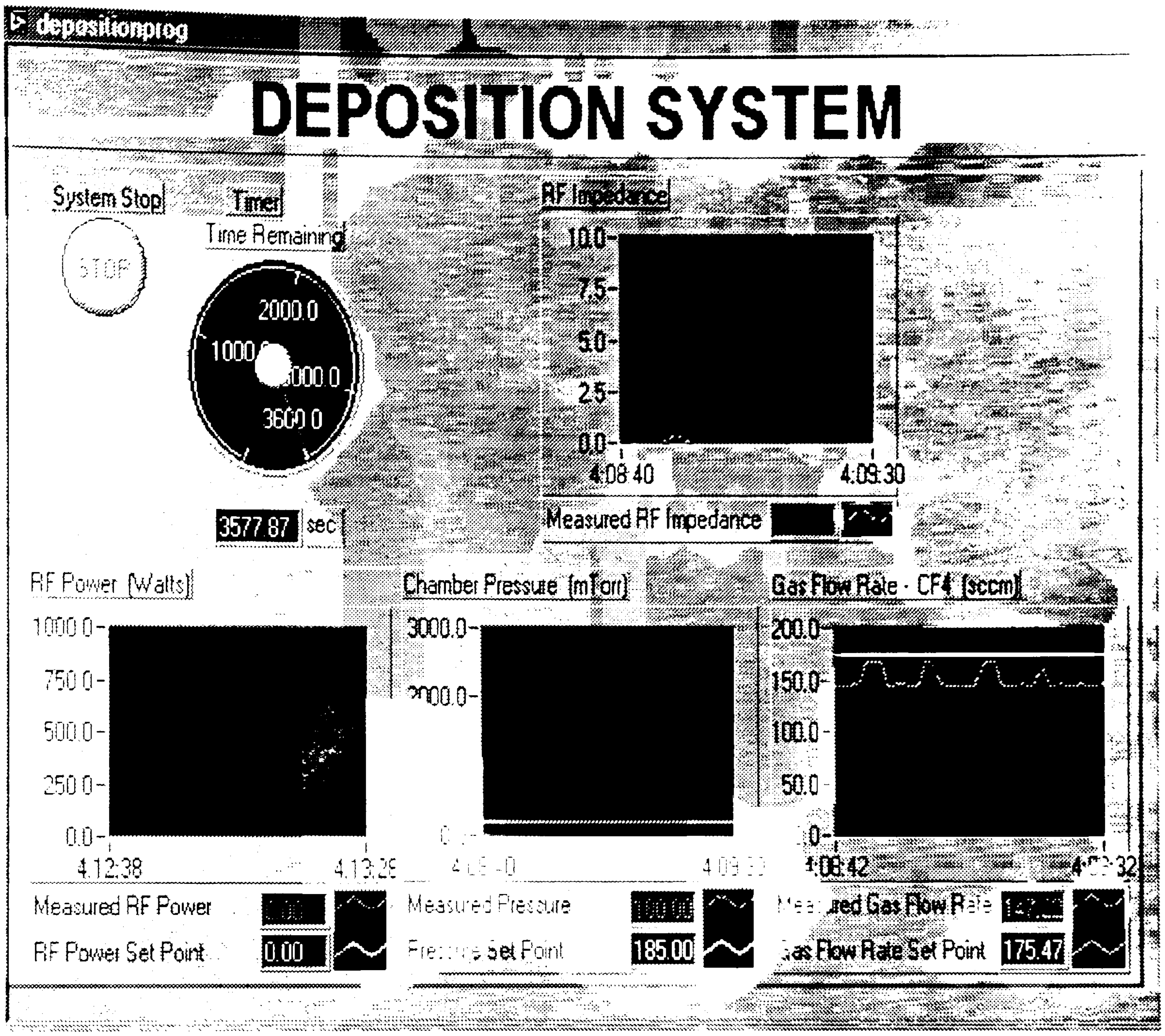


Figure 5.3 Flow Rate Stabilization

Figure 5.4 shows the spectrum of a He-Neon Laser. The spectrum has a maximum intensity at 632.8nm. This proved that the GPIB is able to read the information from the spectrometer. It can be concluded from the data and figures that, the LabVIEW control program is fully functional and efficiently controls the parameters and their controllers, using DAQ Boards and external Interface boards.

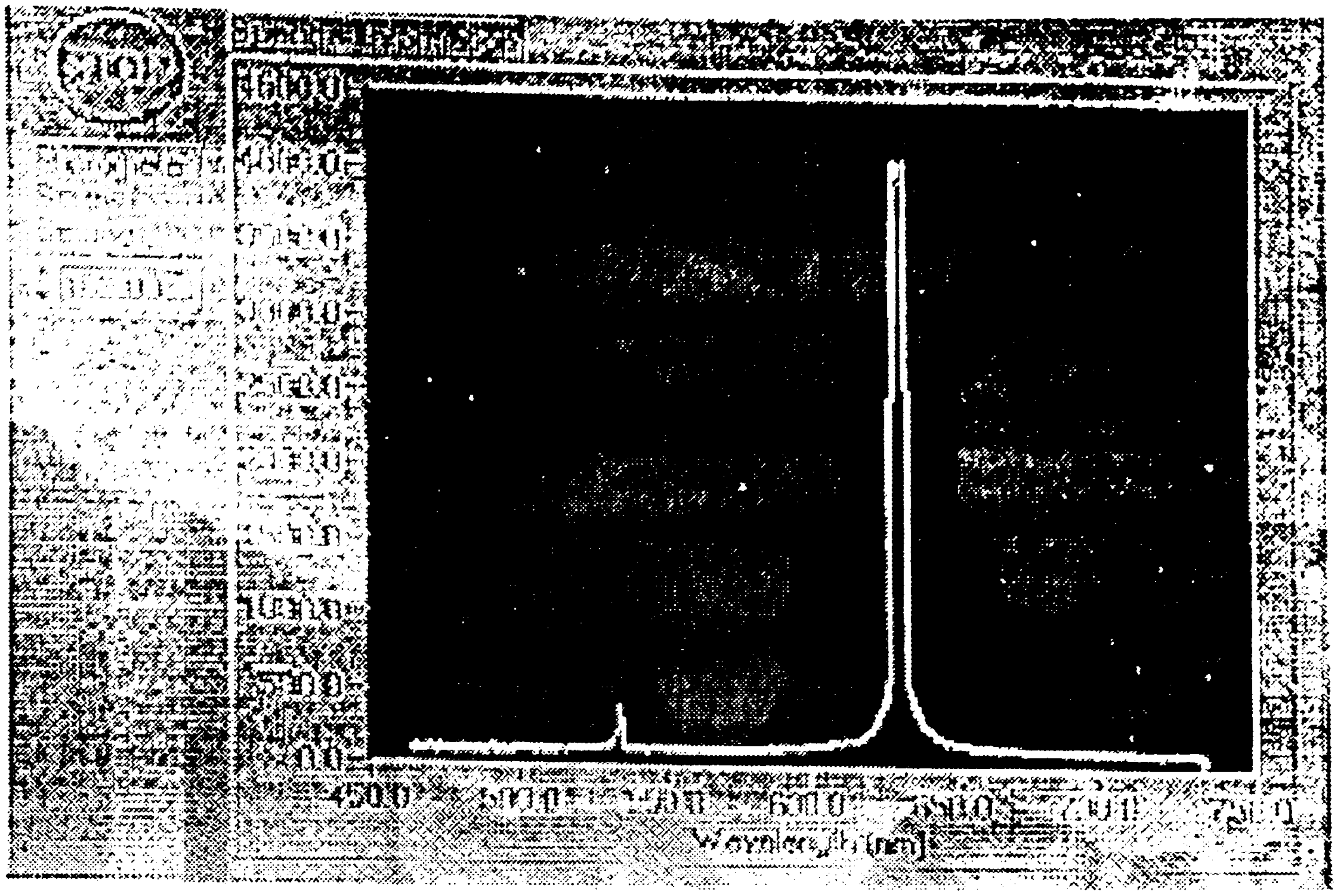


Figure 5.4 Spectrometer Reading

CHAPTER VI

CONCLUSION

This methodology of automation, to control a process using DAQ Boards and External Interface Boards, controlled by LabVIEW, was implemented and verified on two semiconductor processing systems, namely a Plasma Etcher System and a Plasma Deposition System.

The control program for both the systems is designed in a modular approach. Changes can be made to the system and the program very easily. Provision has been given to monitor Power and RF Impedance. Provision has to be made on both the systems to apply temperature to the substrate and cooling water too.

This generic approach for automation can be extended to any semiconductor processing system. The user has to determine the parameters that affect the process, their corresponding controllers on the machine, along with their specifications. Then DAQ Boards have to be selected based on the number of A/D and D/A channels, sampling rates and the External Interface board has to be designed according to the specifications of the controllers on the machine. Finally the control program has to be designed making use of the tools and the approach discussed. Improved processing performance can be achieved by using such a setup and the user will have efficient control over the process.

This idea of automation has many advantages over conventional systems designed using microcontrollers and EPROMS. First, the user intervention is less compared to those systems. The cost of building the system and its automation is reduced. Installation and fault location are easier. The industry has a number of DAQ Boards available and the user will have ample choice to make a proper selection. Measurements and results can be obtained with a high accuracy and precision.

The methodology developed has been implemented on a project called 'Web Interface Design For A Plasma Etcher,' by Mr. Tasnim Murad Hossain, where the setpoint values for the parameters are set from a web page and the controlling of the system is done from the Internet.

This approach should be implemented not only on Semiconductor Processing Equipment but also on systems like, Hybrid Electric Vehicle, Fuel Cell, where results and measurements can be obtained with high accuracy and efficiency.

The advantages of such a generic approach are that system monitoring and control are easier to understand and modify, because of LabVIEW's flexibility and ease of programming. Excellent control can be maintained over process parameters, because of the real-time feedback control system. This approach can be implemented without losing the integrity and the safety parameters of the equipment.

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APPENDIX

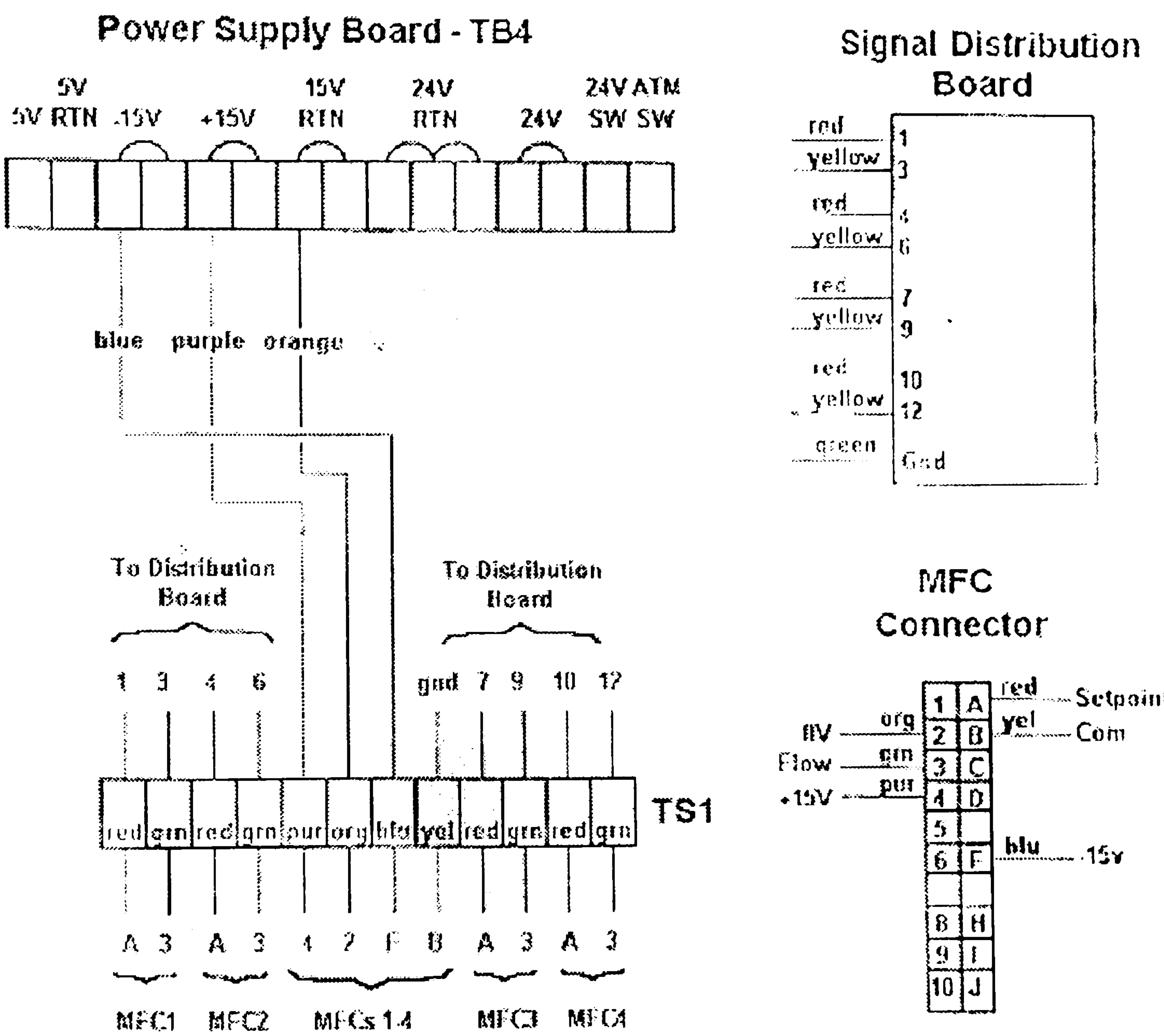
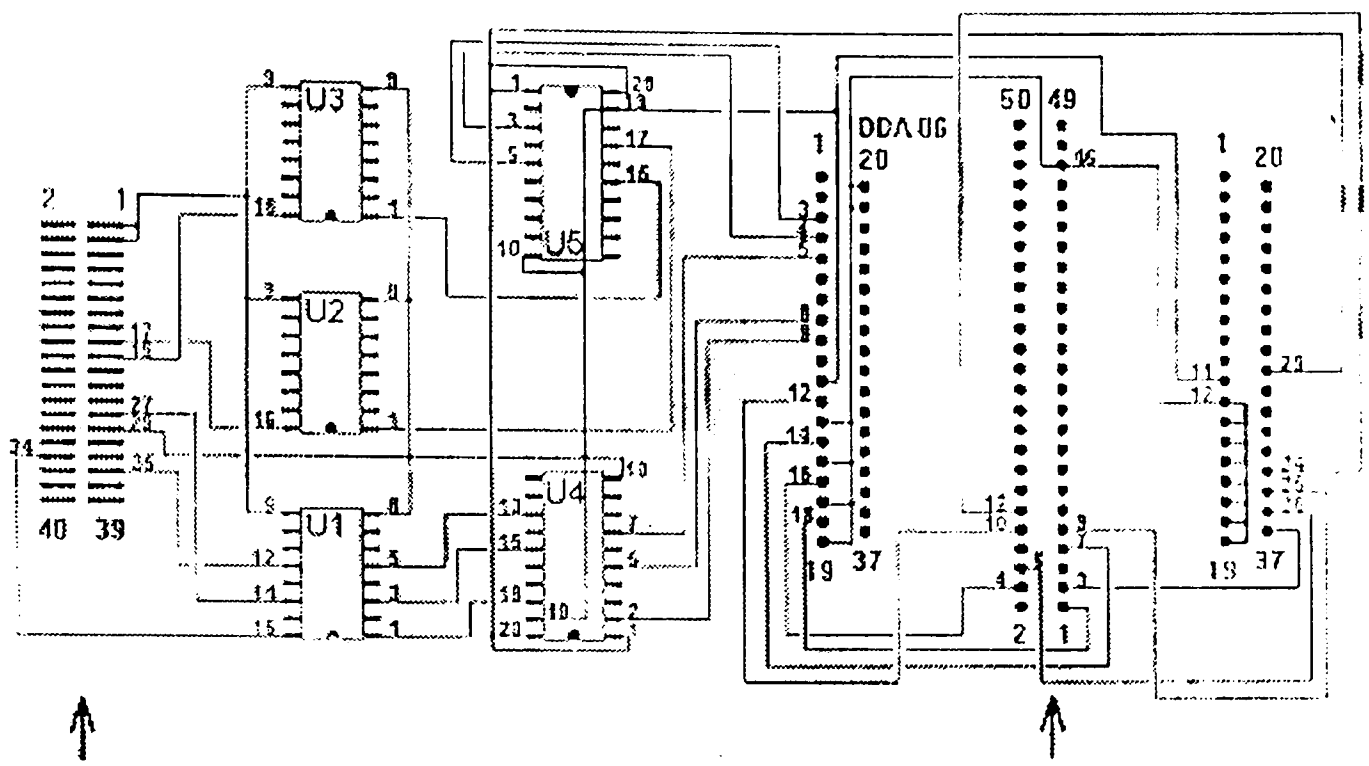


Figure A.1 Mass Flow Controller Wiring



SOLENOID CONN.

PIN#	ID
1,3	+24V
17	A17
19	A18
27	A16
29	Dig Com
34	CN29
35	A15

* U1-U3 – ECG 2013
U4-U5 – SN74LS245N

SIGNAL CONN.

PIN#	ID	
1	MFC1	SETPOINTS
4	MFC2	
7	MFC3	
10	MFC4	
3	MFC1	FLOW
6	MFC2	
9	MFC3	
12	MFC4	
45	Ana Com	

Figure A.2 Gas Control Circuitry

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