ABSTRACT

GRAPHICAL USER INTERFACE FOR THE DSP: USING TEXAS INSTRUMENTS TMS320C31 AND LABVIEW

by
Tahir Nazir

Digital Signal Processors (DSP's) have become very popular due to their ease of operation, economic value, adaptability and availability. However, the development environments for the DSP are still the archaic Assembly and C language programming. It is tedious, error prone and time consuming to develop and use DSP applications using these compared to Graphical User Interface development tools if available. In the modern age programming is very heavily done in object oriented graphical languages like the Visual C++ and Visual Basic. Windows also gives a good graphical user interface.

LABVIEW with its readily available ensemble of good analysis, programming and development libraries and engineering tools was a good candidate. G programming also gives ease of operation and relative economy in programming time, along with good capabilities for hardware interfacing.

We have used Code Interface Node programmed in C language act as a bridge between the LabVIEW and DSP and then carrying out the analysis in the LabVIEW and using the DSP for collecting of data. The complete DSP control and monitoring is carried out by the LabVIEW along with acquisition of data collected by the DSP.

The real world interface and analog to digital conversion is carried out by the DSP and LabVIEW is used to analyze and present the data in a more user friendly and graphical manner. The Use of LabVIEW has significantly reduced the time required to carry out a simple test, by eliminating the need to use different platforms to develop and execute the DSP program, and then collect data, and finally to analyze the data.

GRAPHICAL USER INTERFACE FOR THE DSP: USING TEXAS INSTRUMENTS TMS320C31 AND LABVIEW

by
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APPROVAL PAGE

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To my family, friends and teachers

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INTRODUCTION

1.1 Objective

The objective of this thesis is to present the application of LabVIEW as a graphical User interface (GUI) for the Digital Signal Processor. The LabVIEW version 5 was used to carry out G language implementation of user interface. Code Interface Nodes (CIN's) were used to exchange necessary data with the DSP. The DSP programming was carried out in C language.

1.2 TI TMS320C31 DSP

The TI TMS320 family of Digital signal Processors combines the flexibility of high speed controller with the numerical capability of an array processor. Thus an impressive and economical alternative to VLSI and multichip bit-slice processors for signal processing. TMS320 family offers both Fixed point and Floating point DSP generations.

The Dalanco SPRY model 310 data acquisition and signal processing board was used as the housing of the DSP. This board provides us with two D/A converters and four A/D converters. The relationship is expressed in Fig 1.1

1.3 LabVIEW

LabVIEW is a program development environment, it is different from other program development environments for it uses graphical programming language rather than text base language. LabVIEW is a general purpose programming system with extensive libraries of functions for any programming task. LabVIEW includes libraries for data acquisition, GPIB and serial instrument control, data analysis, data presentation, and data storage.

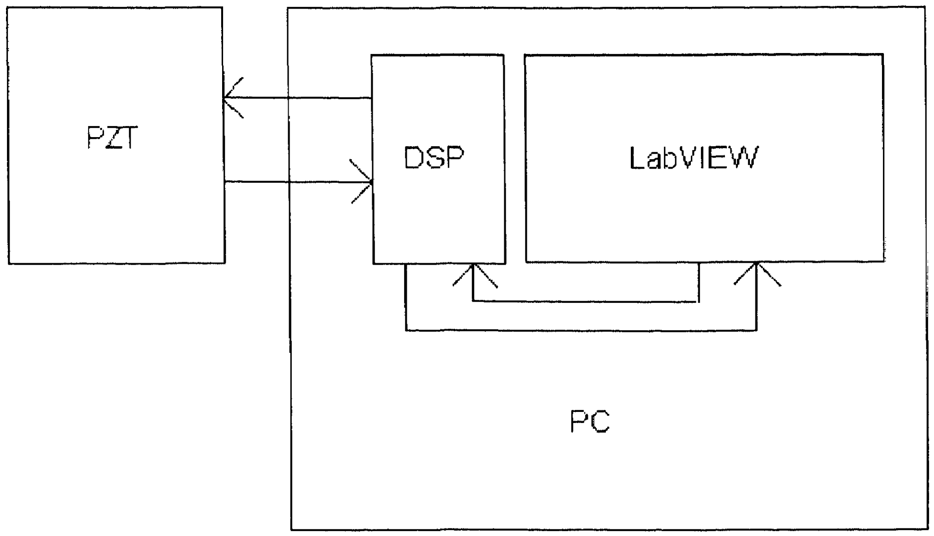


Figure 1.1 The Block diagram representation of our system.

LabVIEW programs are called virtual instruments (VIs). These VIs are similar to the conventional programing language programs. A VI consists of three inter-linked items, the interactive user interface (Front Panel), a dataflow diagram (Block Diagram) that basically is the G language source code, and an icon to connect the program to other high level VI programs. The icon works like a graphics parameter list to provide connection and data exchange between VI programs.

LabVIEW adheres to and promotes the modular programming concept. Thus we can develop an hierarchy of VIs and subVIs which each perform a task leading to the end result. This makes debugging easier as we can execute each subVI by itself. These subVIs can also be used as a library and recalled and included in other VIs which need similar functions.

G is easy to use graphical data flow programming language on which LabVIEW is based. Scientific calculations, process monitoring and control, test and measurement and a wide variety of applications can be developed in G.

1.4 Organization of Thesis

Chapter 2 of this thesis discusses the Graphical User Interface programing, and concepts involved in such a task.

Chapter 3 discusses the LabVIEW development environment and the functions used for our purposes. It explains mainly the different VIs in LabVIEW which were used in our development of the GUI for DSP, and also some relevant discussion on the CIN programming environment.

Chapter 4 discusses the TI TMS320 family of the DSPs and the Delanco SPRY model 310 board we have used to perform our tasks.

Chapter 5 discusses the plant used for our work. We used PZTs as our test subject for the application. Experiments to carry out studying of the PZT behaviour were implemented using the LabVIEW and DSP working in tandem. Four experiments were mainly implemented to study the hysteresis characteristics of the PZT. To find out the range of displacement of the PZT, leading to a measure of the scale of PZT displacement to applied voltage. The plant used for our testing is also included in this chapter.

Chapter 6 discusses the actual implementation of the experiments. It covers discussions on considerations for the front panel design, the Block diagram programming, the Code Interface Node programing and the DSP programs.

Finally in chapter 7, the conclusion of this work along with future directions for research are provided.

CHAPTER 2

GRAPHICAL USER INTERFACE

2.1 Life Cycle of Software Development

The software development life-cycle approach has evolved over the years to a structured approach from a waterfall model. The structured development may include survey, analysis, design, implementation, acceptance test, quality assurance, user documentation, final installation, and interactions between these activities.

Survey includes feasibility study and the study of the possible approaches towards solving the issue. The System analysis has the purpose of providing guidelines as to user and user activities. To develop user profiles, the analysis looks at the users frequency of operation, computer skills, and general capabilities as to the system.

Software design activity consists of decomposing the system into smaller easily manageable sub systems. For GUI applications, adopting a dialog independent software would require partitioning the system into GUI, and application functional core subsystem. The subsystems can then be developed separately.

Implementation activity involves actual coding and integration of the subsystems into a complete functional system. Testing can be started once the complete system has been implemented. A test plan is developed with a set of exercises for the system to perform. These exercises verify that the system performs to the desired specifications and requirements.

2.2 GUI Development

User role is very dominant in the success of the GUI systems. We prioritize classes, identify concurrent classes, and prioritize the task scenarios in the task model. We consider the system level design for error prevention and recovery behaviour. The results of analysis activities may need revision with time based on new findings. Task model is revised to verify that the new finding don't need redesign of the task model. We then map our user interface to style specific GUI designs. We identify common interaction models. We attempt to retain the similarity of operations as much as possible between different layers of application.

2.3 GUI Implementation

System is decomposed for implementation. There can be different approaches of decomposition like:

- Functional decomposition
- Data flow decomposition
- Entity relationship decomposition
- Object oriented decomposition

The subsystems based on any of the decomposition models are all interconnected in some fashion. These interactions influence the runtime dynamics of the system. Each of the decomposition may employ more than one interfacing mechanism. Some of the basic interfacing mechanisms worth mentioning are:

- Sequential procedural call
- Message passing
- Event Responses

A GUI application consumes extensive graphical resources. The performance depends on the following:

- Windows

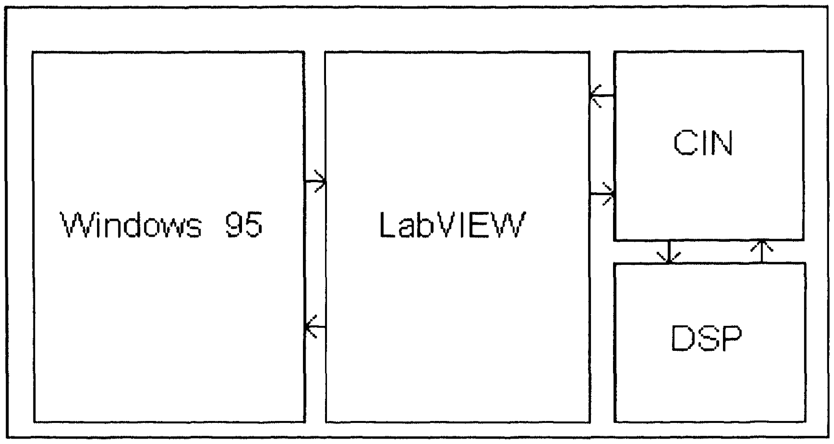


Figure 2.1 The Block diagram of data flow.

- mouse pointer
- Icons and Bitmaps
- Colors
- Fonts and Text strings
- Graphic drawing primitives

2.4 Our GUI Structure

We used LabVIEW version 5 running on a Windows 95 operating system. The attached Figure 2.1 represents the data flow for our GUI software.

Windows 95 was selected as an operating system to run the LabVIEW meaning the monitor, keyboard, mouse, timing of operations and all *operating system* components are commanded and controlled by Windows 95. LabVIEW hands over all it needs to display at monitor to Windows 95, and receives all keyboard and mouse instructions from Windows 95.

The systems functionality is decomposed between LabVIEW, CIN, and DSP, The DSP mainly interfaces to the physical plant through DACs, and ADCs, it collects and performs some data manipulations and stores the data in the memory locations. The CIN accesses these memory locations directly using the C language commands

```
 outp, outpw, inp and inpw
```

which write or read data from the ports as specified in these commands.The format for these commands is:

```
outp(Address, Value)
variable=inp(Address)
```

The output commands writes the data of the variable in position *Value* at the address in the *Address* position. The input commands need a variable in which the read value from the *Address* is to be stored.

LabVIEW exchanges the data with the CIN by references and as handles and then processes and displays the data after further analysis or manipulation.

Windows 95 is not a realtime operating system and thus applications running on this operating system cannot be real time. The Windows 95 allocates time slots to each function active at a particular instant of time. The next time slot can be awarded at any instant without relationship to the applications previous time slot. Meaning that the same routine might run for a few milliseconds in one second or not at all during a whole second. Depending on the priorities decided by Windows 95 operating system.

2.4.1 An Example of Our GUI

As an example let us discuss the development of one of our GUI interfaces with the user. The survey part of our development life cycle is that we need an experiment to determine the hysteresis characteristics of a plant. Study and analysis of our problem reveals that we would like to control the sampling rate of the DSP while performing the experiment and thus put an integer sampling rate control on our screen. We would also like to control the applied voltage range for which the DSP will perform the Hysteresis test. Our DSP can deliver upto $\pm$ 5 volts, hence a floating point control for voltage is also placed on the screen. We also determine to give the operator the capability to Download the program of DSP into its memory or to execute the program already in the DSP memory.

We also need some feedback to be given to the user, and display the results. Two forms of displaying the results are selected:

- Graphically
- As data displays

Graphically the data of the test is displayed in the form of an XY graph displaying the relationship between the output voltage and the displacement of the system. Output voltage is used for X-axis and displacement for Y-axis. In addition the array of data received by the LabVIEW is also displayed in the form of two array displays, so the exact value of the graph points can be read directly from these data displays. It is also realized that the user might need to save the test results as a reference for a later date, therefore the program also asks the user if he wishes to save the data in the form of a spreadsheet file. The Front panel of the system is displayed in Figure 6.1.

In addition to these developed graphical interfaces, LabVIEW also gives the user some commands like the run, continuous run, stop and pause buttons. The user can also change the screen as to personal needs.

CHAPTER 3

LABVIEW

3.1 G Programming

G is the programming language of LabVIEW. G is a general purpose programming language with extensive libraries of functions for any programming task. G includes libraries for data acquisition, GPIB and serial communications, data analysis, data presentation, and data storage. Conventional program debugging tools are also included so we can set break-points, animate the execution to see the data processing and passage, as well as single step through the program to trap exact locations of errors and for easier debugging.

However, G differs from other languages in that it has graphical interface with the user rather than a text based interface. G programs are called Virtual instruments due to their appearance and performance as imitating instruments. VI are similar to functions of other programming languages.

A VI consists of three parts the user interface for human users, the icon connections for embedding the VI as a subVI, and its source code in the form of a wired Block Diagram. This relationship is further elaborated in Figure 3.1.

With these features G makes use of the concept of modular programming. Distributing the tasks into subVIs which collectively perform the desired task in the block diagram (program) of the main VI.

We can also print our program documentation directly from the LabVIEW. We can print the active window as well as a complete set of documentation. The print documentation feature offers us a number of printing options and also a number of printing destinations.

Another unique feature provided by the LabVIEW is the performance profiler tool. This tool informs us where our application is spending time and the memory it is using. This information is invaluable to identify the hotspots of our application

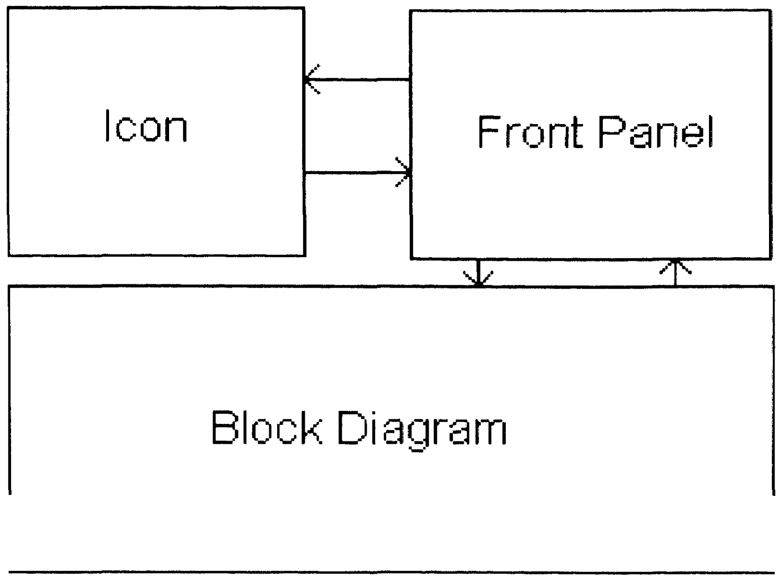


Figure 3.1 Block Diagram depicting LabVIEW VI structure

and to optimize our program. This feature informs us the total time spent by our VI, the time spent by our subVIs, number of runs for the VI, average amount of time spent by the VI, Shortest and the longest time spent by our VI, Time spent on executing the block diagram, time spent on updating the front panel interfaces, time spent in drawing the front panel of the VI. Memory information is provided for average bytes used, minimum bytes used, maximum bytes used, average, maximum and minimum memory blocks used by our VI.

3.2 Code Interface Nodes

A Code Interface Node (CIN) is a block diagram node associated with a section of source code written in a conventional text based programming language. We compile and link the code to form executable CIN, LabVIEW calls the CIN as another of its functions passing parameters to the node and accepting the data provided by the node. CIN are geared for use with code or specific uses which can be accomplished more easily using the conventional programming language.

CINs execute synchronously, meaning all other LabVIEW functions are disabled. However LabVIEW monitors the keyboard, menus and may allow other applications to execute depending on the operating system. CIN object code takes control of the processes that LabVIEW ignores keyboard events, menu clicks, and other diagrams.

A CIN appears as an icon with input and output terminals. The terminals are associated with data in the Node source code and block diagram. LabVIEW calls the code and passes the specified data. The interface for CINs and external subroutines supports a variety of compilers.

Using CIN involves following steps:

- Place the CIN on block diagram.
- Create the necessary input output connections.
- Create a C source code.
- Compile the source code.
- Link the code to CIN.

LabVIEW passes data by reference to the CIN. LabVIEW passes numeric data types to CINs by passing a pointer to the data as an argument. LabVIEW stores Boolean in memory as 16-bit integers, and passes them same as numeric. Cluster is passed by passing a pointer to a structure containing the elements of the cluster. LabVIEW passes array by handle. LabVIEW also provides some functions to use the handle properly.

3.3 Graphs

There are three types of graphs supported by LabVIEW:

- XY Graph
- Waveform graph
- Intensity graph

There are two type of charts supported by LabVIEW:

- Waveform Chart
- Intensity Chart

Each of these graphs and charts accept data of several types. We can customize the appearance of the graph like putting grids, background and graph colors, label and line type etc. We can also scale our graph to display the scaled data.The intensity graph/chart displays three dimensional data in two dimensions.

3.4 Exec Function

It is a special function in the communications block and runs an executable file.

3.5 Fast Fourier Transform

Fast Fourier Transform is used to give frequency domain representation of data. LabVIEW uses the Discrete Fourier Transform (DFT).

For a sampling frequency of f_s Hz, then the time interval between the samples is Δt, where:

$$\Delta t = \frac{1}{f_s}$$

The sample signals are denoted by $x[i], 0 \leq i \leq N-1$. When the DFT is given by:

$$X_k = \sum_{i=0}^{N-1} x_i e^{-j2\pi ik/N}$$

for $k = 0, 1, 2, ..., N-1$

is applied to these N samples, the resulting output $(X[k], 0 \leq l \leq N-1)$is the frequency domain representation of $x[i]$. $X[i]$ has frequency spacing of:

$$\Delta f = \frac{f_s}{N} = \frac{1}{N\Delta t}$$

Δf is known as the frequency resolution. To increase the resolution we can increase the number of samples or decrease the sampling frequency.

Direct implementation of DFT requires N^2 complex operations for N samples. However when the size of sequence is power of 2,

$$N = 2^m form = 1, 2, 3.....$$

Implementation of DFT becomes quite faster and is referred to as Fast Fourier Transform. LabVIEW gives us two types of FFTs, Real FFT and Complex FFT.

3.6 Using LabVIEW for Our System

We discussed the development of the LabVIEW front Panel of Hysteresis testing program in chapter 2, let us continue with the same example LabVIEW's Front Panel Design Toolbox gave us the different *Controls* and *Indicators* these could have been connected to the icon thus providing capability of our Hysteresis test VI to serve as a subVI to other VIs. However, we chose not to do so, our icon just depicts graphically a hysteresis plot.

The Block diagram of the hysteresis VI is shown in Figure 3.2 and 3.3. Basically we have made a case structure which decides which block diagram will

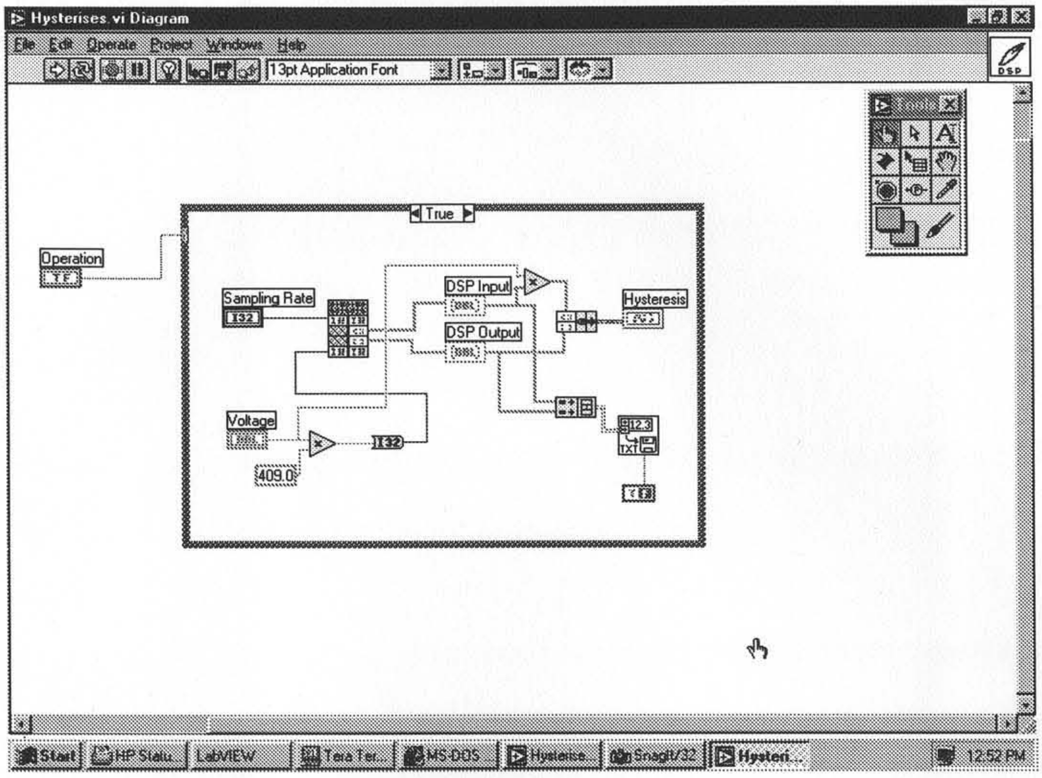


Figure 3.2 The Block diagram of the case true Hysteresis

be executed on the bases of the true/false condition of the *control* connected to it (Execute/Download button). In case of false condition we execute a batch file which downloads our desired DSP program into the DSP memory. In the case of true control signal the other block diagram is executed.

The case true block diagram mainly runs the CIN VI which executes the code for Hysteresis test available in Appendix B and discussed later, The sampling rate and desired operation voltage are handed over to the CIN to be transferred to DSP and the values read by DSP are passed back by the CIN to the Block diagram in the form of arrays. These arrays are joined to form a cluster of data to be passed on to the Graph as well as passed on to the Spreadsheet file saving VI. It is important to note that these wires are color coded by LabVIEW to express the type of the data flow in these *wires.*

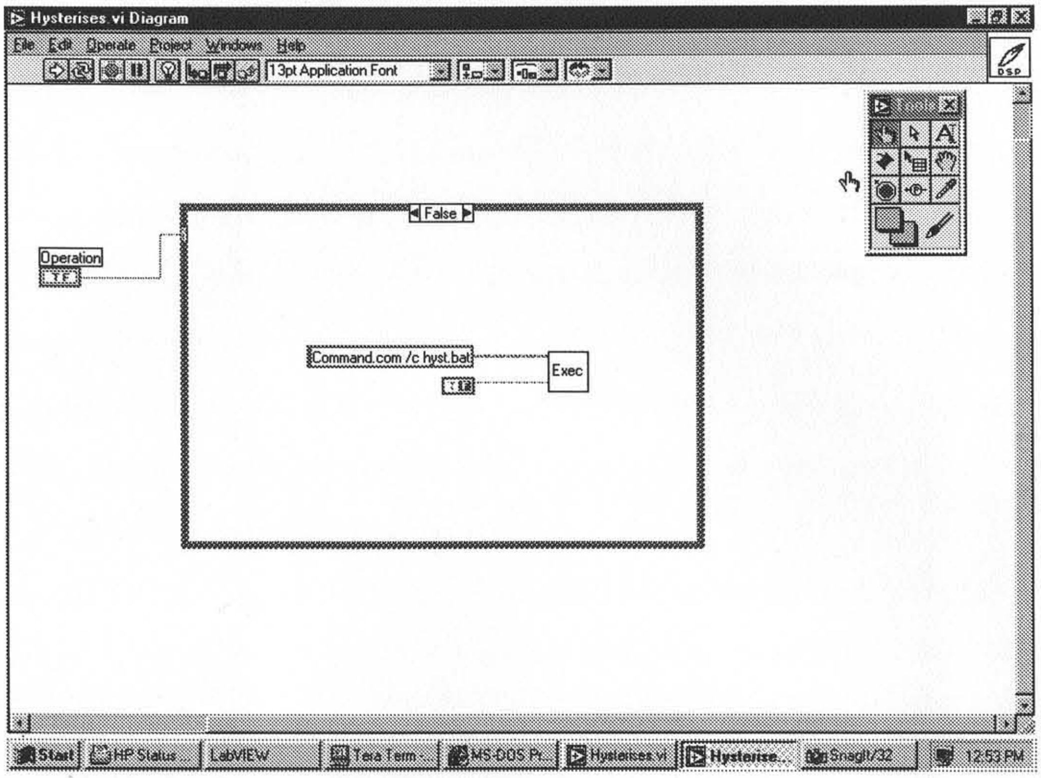


Figure 3.3 The Block diagram of the case false Hysteresis

The diagram should be read left to right. The junction of two or more wires executes when all data required is available to the input of the junction. Example is the multiplication symbol executes only when both multiplicants are available at its input terminal.

The graphic symbols for the different *indicators* and *controls* also show the type of data in abbreviation, e.g. I32 for 32 bit integer and DBL for double precision floating point variables etc.

The Block Diagram screen of LabVIEW also gives the user some additional debugging tools like the single step, show each execution and complete the execution button on the top control panel of the screen. The run, continuous run, stop and pause buttons are also available to the user. This allows us to check the data flow and the execution sequence of our block diagram for troubleshooting purposes.

3.6.1 The CIN for Our Example

LabVIEW provides us with a header file *extcode.h*, that contains typedefs associating LabVIEWs own unambiguous data types like *int16* for 16 bit integer type. This header also defines some constants and types whose definitions may conflict with the definitions of the systems header files. The names of the CIN routines are defined in the header file with words CIN MgErr, it defines the word CIN as either Pascal or nothing, depending on the platform. On PC the standard C calling conventions are used. The MgrErr data type is a LabVIEW data type that corresponds to a set of error codes that the manager routines return.

In our CIN the *stdio.h*, *math.h*, and *conio.h* header files are also included to use the specific commands used in the CIN source code. The Type *TD1* is also defined as a *handle* which consists of an integer variable *dimSize* defining the number of elements in the array and *arg1* the actual memory storage of the data elements. These elements can each be accessed by *arg1[i]* where i is the element number in array.

LabVIEW passes two pointers $*Sampling\_Rate$, and $*voltage$ and reads two handles DSP_Input, and DSP_Output from the CIN. The main body of the CIN starts with defining the variables which will be used by the CIN program to exchange and manipulate the data between LabVIEW and DSP. The defined variables also include the addresses in the DSP memory which the program will access. These addresses are defined in Hex format.

The DSP is put to go or program execution mode by reading from port 0x306. It is important to note that the memory is shared between the DSP and the PC. The variable *numDims* defines dimensions of array.

Function *NumericArrayResize* is used to resize the data handle. This function also accounts for alignment issues. It does not set the array dimension field. The usage is:

Table 3.1 Constants for the typecode argument in *NumericArrayResize* function

Constant	Function
iB	Data is an array of signed 8-bit integers
iW	Data is an array of signed 16-bit integers
iL	Data is an array of signed 32-bit integers
uB	Data is an array of unsigned 8-bit integers
uW	Data is an array of unsigned 16-bit integers
uL	Data is an array of unsigned 31-bit integers
fS	Data is an array of single-precision (32 bit) numbers.
fD	Data is an array of double-precision (32 bit) numbers.
fX	Data is an array of extended-precision (32 bit) numbers.
cS	Data is an array of single-precision complex numbers.
cD	Data is an array of double-precision complex numbers.
cX	Data is an array of extended-precision complex numbers.

```
MgErr NumericArrayResize(int32 typecode, int32 numDims, (Uhandle
*)dataHP, int32 totalNewSize);
```

The variable *typecode* describes the data type for the array that we want to resize. The header file *extcode.h* has defined constants for this argument shown in Table 3.1

The variable *numDims* describes the number of dimensions in the data structure to which the handle refers. Thus, if the handle refers to a two-dimensional array, you pass a value of 2 for *numDims.*

The variable **dataHP* of *extcode.h* defined type *UHandle* is a pointer to the Handle we want to resize.

The variable *totalNewSize* gives the *NumericArrayResize* the new number of elements to which the the handle should refer. For a unidimensional array of 5 elements we pass 5. For a two-dimensional array of two rows by three columns we pass 6.

Caution and care needs to be taken in the use of *NumericArrayResize* function because LabVIEW allocates memory array for the CIN and in case of any misalignment or differences in the way data is handled and manipulated by LabVIEW or CIN can cause LabVIEW to cause system fault and be shutdown by Windows. We have used this in an if statement to terminate the CIN program execution in case the *NumerizArrayResize* function returns an error.

Once we have used *NumericArrayResize* function to allocate memory both in CIN and LabVIEW for our array of data we can define dimSize for our handle. It is important to note that this is not done by the *NumericArrayResize* function.

Now we have defined and declared all the data and memory allocations and we can concentrate on actually acquiring the data from the DSP. We first wait for the DSP to complete its task, this waiting is controlled by the *while* loop. During this waiting period we write the Sampling rate and desired voltage data to the DSP and read the status of the check flag.

The process of reading and writing to the DSP needs some explaining:

1. Page Value is written at port 0x306, this operation is carried out by using the **outp** command. This needs to be carried out specifically every time we wish to read or write to the shared memory, as DSP also is accessing this memory and the page Value keeps changing automatically.

2. The Address of the memory location is written to the port 0x302 the command **outpw** is used.

3. The actual data is writen to or read from the address 0x300 we have used the **outpw** and **inpw** commands to read and write the data.

Once the DSP has completed its execution of routines to perform the test and acquired the necessary data it tells CIN to read the data by giving a value of 1 to the check flag. The CIN then moves on to the for loop in which the collected data is read from the DSP. The data is read as 16 bit unsigned integer by the inpw command. This raw data needs to be manipulated in order to extract the actual data which

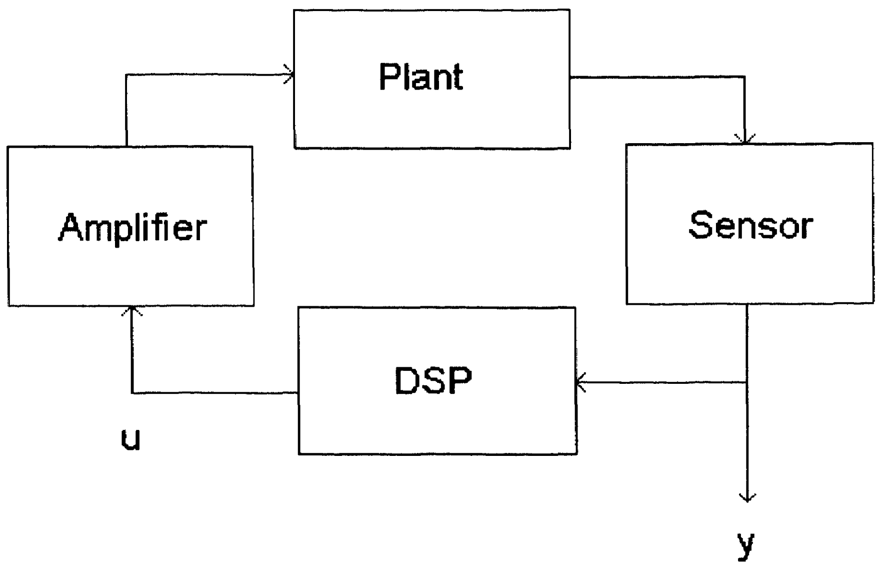


Figure 3.4 The Block diagram of the input output

was stored by the DSP in its memory location. The DSP stores the data in 32 bit memory locations. The process of *decoding* the read data is:

1. The data is stored in the memory locations *u16_bit* or *y16_bit* depending on where it goes, y is the output from the sensor and u the input to the amplifier. The whole flow is expressed more elaborately by the Figure 3.4.

2. First we find out the sign of the data received. If the Most Significant Bit (MSB) is one the data is negative otherwise it is considered to be positive.

3. Data is then moved into *u12_bit* or *y12_bit* by masking and copying only 12 bits of data.

4. If the sign is positive, i.e. *sign* is 0 then the data is directly scaled and stored as the selected element.

5. If the sign is negative then 2's complement of data is calculated, scaled and stored in the selected element.

Once all the data is recovered from the DSP, the check flag is reset to value of zero. and the DSP is halted by reading from address 0x307. Once all these steps are completed the CIN transfers the control of execution back to LabVIEW, which then receives the data from CIN and displays and queries about the saving of the data.

CHAPTER 4
TEXAS INSTRUMENTS TMS320C31 DSP

The TMS320C31 is one of the Texas instruments floating-point DSP family member. The TMS320C31 is a low cost 32 bit DSP that offers the advantage of easy to use floating point processor. TMS320C31 features are identical to those of TMS320C30 device, except that the TMS320C31 uses a subset of the TMS320C30 standard peripheral and memory interfaces. It maintains the TMS320C30s performance while providing the cost advantages associated with 132-pin plastic quad flat packaging. Some key features of TMS320C31 are as follows:

- Flexible boot program loader
- One serial port to support 8/16/24/32-bit transfers
- One 32 bit data bus (24 bit address)
- 132-pin quad flat pack , 0.8 μm CMOS

It can work as a microprocessor or as a microcomputer/boot loader easily selective by the state of MCB/MP pin. These two modes use different kind of memory maps. Special memory locations are used by the loader.

4.1 TI TMS320 Family

The Texas Instruments TMS320 family of digital signal processors is designed to support a wide range of high-speed and numeric intensive DSP applications. These 16/32 bit DSP's combine the flexibility of high speed controller with the numerical capability of an array processor.

The TMS320 family contains microprocessor capable of executing very high throughput as a result of comprehensive, efficient and easily programmed instruction set and highly pipelined architecture.

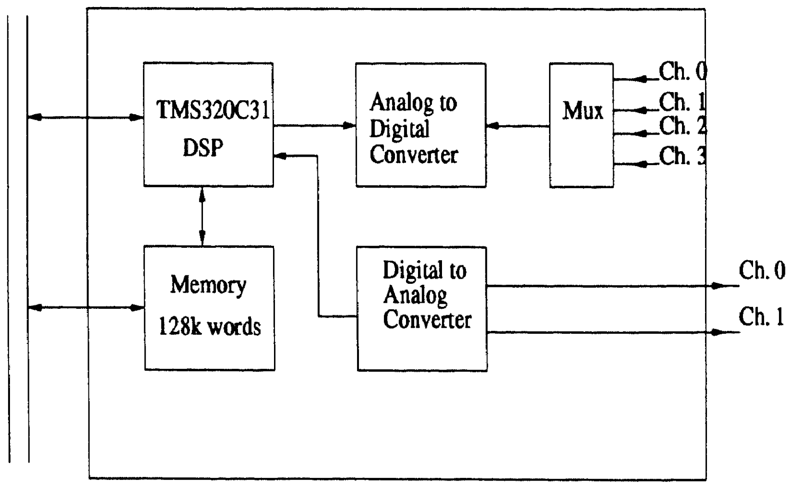


Figure 4.1 TMS320C31 Architecture

4.2 The Delanco Spry Board

The DSP system used for this project was the 'Dalanco-Spry' Data Acquisition and Signal Processing Board - Model 310B. The DSP board has a Texas Instruments' TMS320C31 DSP chip running at 50MHz, a 12 bit DAC, a 14bit ADC with a four channel multiplexer, and 128k words of memory.

The memory on the DSP board is dual ported, i.e. it is accessible at any time to the DSP as well as to the PC via the bus interface. The ADC and the DAC are however accessible only to the DSP. Any data from the ADC and to the DAC must pass through the C31. The DAC is capable of outputting at a maximum rate of 140kHz. The ADC has a maximum conversion rate of 300kHz. The voltage ranges for the ADC and the DAC are $\pm 5\,V$.

A block diagram of the Dalanco-Spry Data Acquisition and Signal Processing Board - Model 310B is shown in Fig. 4.1. The DSP can be programmed in 'C' as well as Assembly, and the DSP Development system is completely compatible with the Texas Instruments Optimizing C compiler for the TMS320C31.

It was however necessary to create a couple of libraries so that all the coding could be done in 'C', with the user completely insulated from the architecture of the board. The DSP application board also has a programmable gain amplifier that

Table 4.1 TMS320C31 Characteristics

Cycle time, for single cycle execution	$40 ns$
Floating point processing speed	$50 MFLOPS$
Instruction execution rate	$25 MIPS$

gives a software programmable gain, ranging from 1 to 1000, facilitating the handling of signals with small amplitudes. The gain to be used is output to the latch along with the channel number.

4.3 The TMS320C31 Digital Signal Processor

The TMS320C31 is a floating point, 32 bit DSP from Texas Instruments. Its key specifications are listed in Table 4.1. The TMS320C31 has, besides the CPU, a DMA controller, an instruction cache, RAM, ROM, Serial port, Timers, etc. all integrated onto the chip. This translates into very high performance for the user. The TMSC320C31 CPU consists of an ALU, a 32 bit barrel shifter, a 32 bit multiplier, Auxiliary Register Arithmetic Units (ARAU s), and several registers in it. The multiplier performs full 32 bit multiplications in just one cycle, and is capable of operation in parallel with the other components of the CPU.The Arithmetic and Logic Unit (ALU) performs single cycle operations on 32 bit integer, and 40 point floating point data. The Auxiliary Register Arithmetic Units ARAU 0 and 1 generate memory addresses in one cycle for the fast generation of memory addresses in the various addressing modes.

The CPU also includes 28 registers in a multiport register file, tightly coupled to the CPU. These are used to store operands right in the CPU so that they are available for the instructions without any access delay. The on chip RAM blocks 0 and 1, are each $1K \times 32$ bits and the ROM is $4K \times 32$ bits. Each on chip memory block can support two memory accesses in a single cycle. The instruction cache is 64 x 32 bits, i.e. 64 words large and maximizes the system throughput by caching the repeatedly accessed code. The cache uses the Least Recently Used (LRU) strategy for updating the cache memory from the main memory.

The TMS320C31 has a full duplex bi-directional serial port. The port can transfer data in 1, 2, 3 or 4 bytes per word. The port can also be programmed in a synchronous mode where continuous transfers can be done, transmitting many words of data without new synchronization pulses. The TMS320C31 supports integer and floating point data. Integer data types supported are 16 bit, 32bit, both signed and unsigned. The floating point data types are short, single precision and extended-precision. The use of floating point operations to manipulate data is of great advantage, as the operation can be performed in a single cycle, while freeing the user of the burden of implementing libraries to perform floating point operations.

The TMS320C31 has a 32 bit timer/counter that can be used for various purposes. It can be driven off an internal clock, i.e. used as a timer, or an external signal may be used to drive the timer, thus acting as a event counter. It can also generate an interrupt to the CPU. The timer in the Dalanco Spry board is used to trigger the conversions of the ADC. The TCLK pin is toggled to trigger the conversion. The ADC performs the conversion and then sends the converted data to the TMS320C31 serial port. Once the data is received the serial port may be read to retrieve the data.

4.4 Initialization

The Dalanco Board needs initialization at startup. The ADC connects to the serial port on the DSP. So the serial port and timer must be set up, and also the latch on the Dalanco Spry Board must be set up. For this the *InitDSP()* function is implemented. The function call prototype is

```
void InitDSP(void);
```

Table 4.2 Word Format for the ADC Latch

b_3	b_2	b_1	b_0
g_1	g_0	m_1	m_0

The function begins by setting up a few pointers. The latch in the Dalanco Spry Board contains the ADC channel number and the gain for the programmable gain amplifier (PGA). This latch is set up, as a default, to set the ADC channel to 0 and a unity gain for the programmable gain amplifier. These are just the defaults, by accessing the latch before each conversion the user can set the gain for the PGA as well as set the channel. The function ReadAdc takes care of the function of setting the channel.

The word format for the LATCH_VAL word is shown in Table 4.2. The bits g_1 and g_0 set the gain of the programmable gain amplifier (PGA),while the bits m_1 and m_0 set the channel for the ADC multiplexer. The PGA gain is set by the value of the word g_1g_0, i.e. $00_2 \rightarrow 1_{10}$, $01_2 \rightarrow 10_{10}$, $10_2 \rightarrow 100_{10}$ and $11_2 \rightarrow 1000_{10}$. The ADC channel gets set to the value of the word m_1m_0, i.e. $00_2 \rightarrow 0_{10}$, $01_2 \rightarrow 1_{10}$, $10_2 \rightarrow 2_{10}$ and $11_2 \rightarrow 3_{10}$. The other bits in the LATCH_VAL are 'don't cares'. Following this the function now sets up the DSP chip registers itself.

The registers set up are the Timer registers, and the Serial port control registers. In the C31 these are memory mapped. To do this a pointer is set up to the register area which in the C31 is at 808000_{16} and the values are written to the registers. This sets up the DSP to ADC communication on the serial port. The *ReadAdc* and *WriteDAC* functions can now be called, to perform analog I/O as desired.

4.5 DAC Usage

The output to the analog channels is written via the DAC. The function call for this is *WriteDAC*(..). The C prototype for this is:

```
int WriteDAC(int value, int channel);
```

This outputs the value to the DAC channel specified. Since the DAC has two channels legal values for channel are 0 and 1. The value passed may be in the range ± 2047. If the value is greater than 2047 it is clamped off to 2047, and if less than -2047, is also restricted to -2047.

This clamping is done by the function *WriteDAC* and need not be performed by the user. This is to avoid problems associated with 'roll over'. If the value is greater than 2047, then it cannot be properly expressed in 12 bits and leads to wrong interpretation of the value. Thus if a value of 4096 is output to the DAC with an intended output value of $10V$, it gets clamped to $5V$ only, since the DAC output is restricted to $5V$. Similar clamping occurs on the negative side.

The function WriteDAC retains the value output to the DAC channel 0 and channel 1. For this reason the declaration for *channel_value*[] is prefixed with static. The reason for maintaining the last value is that actually every time the DAC value is updated, both the DAC values are to be written. In C, it is made to appear as if each DAC is written to separately. While this is more convenient to use, it means that the function *WriteDAC* must know the value of the other DAC previously written. If this value is not stored, then when one DAC is written the other DAC output will be trashed. Clearly this would be unacceptable, and this is overcome by storing the previously output values. So actually the function *WriteDAC* always updates both the DACs, and effectively makes it appear as if only one DAC is updated every time.

The value for the DAC channel 1 must be put into the upper 16 bits, i.e. right justified in the upper 16 bit word. This shifting is done, and then the values for the two channels are '*OR*'ed together and then output via the serial port. Obviously if both the converters are to be updated, then it is more efficient to do so in one call and for this another function call, *WriteDACS*(..) is available. This function call updates both the DAC channels in one call. The prototype for this function is:

```
int WriteDACS(int value0, int value1);
```

The channels 0 and 1 are updated with the values *value*1 and *value*2. This is more efficient if both the converters are to be updated. For instance in our work, the controller writes both the servo commands by calling this function, two calls to WriteDAC are not used.

4.6 ADC Usage

To input analog values from the ADC the function *ReadAdc*() is called. The prototype for this function is:

```
int ReadAdc(int channel);
```

This reads the value from the ADC for the voltage applied on the specified channel. The function returns values ranging from -2048 to 2047 for voltages ranging from $-5V$ to $5V$. The integer data type 'int' on the C31 DSP is 32 bits, while the conversion result is 12 bits.

The necessary sign extension is performed internally and the user does not need to perform any such extension. To read from more than one channel multiple calls to *ReadAdc* are necessary.

Since the ADC on the card has four channels, legal values for channel are from 0 to 3. If the voltage at the ADC input is to be calculated then the ADC output is simply multiplied by the scaling factor 5/2047. The function begins by writing the channel (and the default gain of unity) to the latch. Once the latch is set the function waits for the conversion to be triggered by the TCLK0 pin toggling. This pin is the output of the Timer 0.

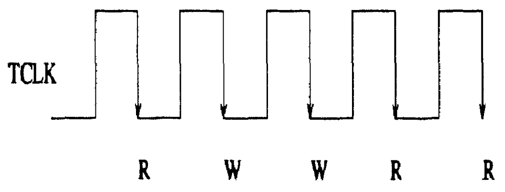


Figure 4.2 Synchronization to TCLK

Whenever the count is complete the pin goes high, stays high for a clock period and then goes low. This event is used for triggering the ADC in hardware. This also is used to synchronize the software to a time source. The timer runs off the DSP clock, in the timer mode, and its accuracy is determined by the DSP clock, which is very good. This is the source of timing in all the control programs written with this library.

4.7 Sampling Rate Determination

To use the above function calls include the file 'd310bio.h' at the start of the program. It is necessary to define the sampling rate for the system. This is done by defining the constant TIMPER0. The functions *WriteDAC* and *ReadAdc* both wait for the falling edge of the TCLK signal in the C31 DSP. A sequence RWWRR synchronizes up as shown in Figure 4.2.

This means that the sampling rate is determined by the value loaded into the Timer 0 of the C31. Also since these functions wait for the falling edge, all the reads and writes get synchronized to these falling edges. The Figure 4.2 shows an arbitrary sequence of reads and writes as it would get executed. The function InitDSP puts TIMPER0 into the Timer 0 count register. The constant must be defined before the file d310bio.h is included, so that the default value is not picked up. The value of TIMPER0 is calculated from:.

$$SampleRate = \frac{SystemClock}{TIMPER0\ numcalls\ 8}$$

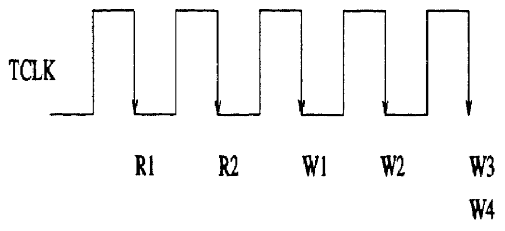


Figure 4.3 Successive Read and Write Events

where *System Clock* $= 50MHz$. The factor *numcalls* is the total number of calls to the functions *ReadAdc* and *WriteDAC* in one execution of the control loop. This is to account for the fact that both functions wait for the falling edge of TCLK. So, for example if TCLK has a frequency of 1kHz, and if the control loop has one *ReadAdc* and one *WriteDAC*, then the loop will run 500 times per second.

The functions WriteDAC and WriteDACS must be distinguished with care, as illustrated in Figure 4.3. The writes W1 and W2 are made using WriteDAC. The writes W3 and W4 are made with the function WriteDACS. Owing to the architecture of the board, such paired writes may be made but paired reads are not possible. The functions thus isolate the user from the unnecessary details of the board architecture but reflect the restrictions that the architecture imposes on the operations to be performed. The sampling rate may also be set dynamically as explained in the following section.

4.8 Runtime Sampling Rate Determination

As explained in the previous section, the sampling rate is determined by the count in the Timer 0 Period Register of the C31. This value is set up by InitDSP, but it can also be altered within the program if the need arises. For this the memory mapped Timer Period Register must be altered. This can be done very simply as follows:

```
int *period;
period=(int *)0x8008028;
*period=TIMER_PERIOD_DESIRED;
```

This changes the rate at which TCLK0 pulses and sets the rate for the reads and writes. Note that if this is to be done repeatedly, e.g. to generate a rectangular wave (duty cycle not 50%) at the output of the DAC, then for good accuracy it would be necessary to start and stop the timer while this is done and also to synchronize the modifications with TCLK itself.

4.9 Data Exchange between the PC and the DSP Card

The data exchange between the DSP card and the host PC is accomplished by calling the functions in the user library provided by the card manufacturer. For more detailed information consult the users guide for the card.

CHAPTER 5
THE PLANT (PZT)

Piezoelectricity means "pressure electricity". Pierre and Jacques Curies discovered it in the 1880's. It is the property of certain crystals , like Quartz, Rochell salt, barium titanate, and many others, that when subjected to pressure these crystals exhibit charges on their surfaces. The charges are proportional to the pressure and appear only when pressure is present. Conversely when electric potential is applied to these materials the dimensions of these crystals change. These materials are also called smart materials.

These crystals are being considered as actuators in micropositioning applications and precision control systems.

5.1 PZT Ceramics Manufacturing Process

The manufacturing process of PZT starts with mixing and milling of raw materials. The milled mixture is then heated to 75% of the sintering temperature. The polycrystallaine, calcinated powder is ball milled once again. Granulation with binder is carried out to improve processing properties. After shaping and pressing the ceramics is heated to 750^o to burn out the binder.

The next phase is sintering at temperatures as high as 1250^oC to 1350^oC. The ceramic block is then finished into the desired shape and tolerance. All processes especially the sintering and heating need to be controlled to very tight tolerances. The smallest change effects the properties and quality of the PZT. The direction of polarization is established during the poling process by a strong electrical field applied between two electrodes. For actuator applications the piezo properties along the poling axis are most essential.

5.2 Advantages of Piezoelectric Positioning Systems

The advantages of piezoelectric positioning systems are:

- **Unlimited Resolution:**

  A piezoelectric actuator (PZT) can produce extremely fine position changes down to the subnanometer range. The smallest change in the operating voltages are converted into smooth movements. Motion is not influenced by striction, friction or threshold voltages.

- **large Force Generation:**

  PZTs can generate forces in levels of 10,000 N.

- **Fast Expansion:**

  PZT offers fastest response time, acceleration rates of more than 10,000 g's can be obtained.

- **No Magnetic Fields:**

  The PZT is related to electric fields and don't produce any magnetic fields or interact with any magnetic field.

- **Low Power Consumption:**

  The PZT consumes energy only during the motion, static operation even under heavy loads does not consume power.

- **No Wear And Tear:**

  PZT does not have any moving parts which will wear and tear and need routine maintenance. It therefore can give satisfactory performance over a long duration of time without any replacement.

- **Vacuum and Clean Room Compatible:**

  PZT does not need to be lubricated and does not wear or abrase, thus is suitable for vacuum and clean room applications.

- **Operation at Cryogenic Temperatures:**

  The Piezo effect is based on electric fields and functions down to almost zero Kelvin with reduced specifications.

5.3 Displacement of Piezo Actuators

Open loop Piezo actuators exhibit hysteresis like magnetic devices, this can be eliminated by closing the loop. Hysteresis is based on crystalline polarization effects and molecular friction. The absolute displacement generated by an open loop PZT depends on the applied electric field and the piezo gain. Piezo gain is effected by the electric field piezo, its deflection depends on its previous operating conditions. Hysteresis is typically of the order of 10% to 15% of the command motion.

5.4 Considerations for PZT Usage

5.4.1 Mechanical Considerations

Every time the PZT drive voltage changes, the piezo element changes its dimensions (if not blocked). Due to the inertia of the PZT mass (plus any additional mass), a rapid change will generate a force acting on the PZT. The maximum force is approximated as:

$$F_{max} \approx \pm k_T \Delta L_o$$

Maximum force available to accelerate the PZT where ΔL_o = maximum displacement without external force, and k_T = PZT actuator stiffness. Tensile forces must be compensated to prevent damaging the PZT. Sinusoidal operation with frequency f and the amplitude $\Delta L/2$, peak forces can be expressed as:

$$F_{dyn} = \pm 4\pi m_{eff} (\Delta L/2) f^2$$

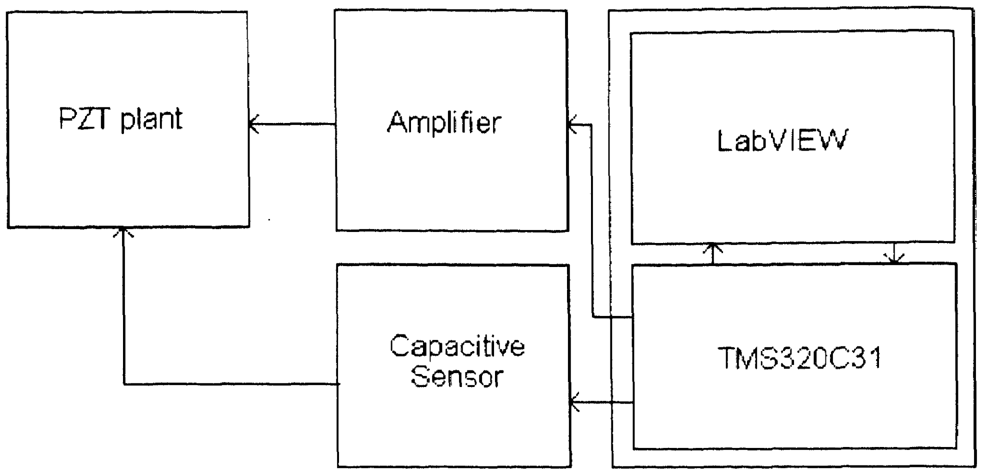


Figure 5.1 The Block diagram of our plant

F_{dyn} is the dynamic force, m_{eff} effective mass, ΔL peak to peak displacement and f the frequency in Hz.

5.4.2 Electrical Considerations

When operated far below resonant frequency PZT behaves like a capacitor where displacement is proportional to the charge. PZT actuator stacks are assembled with thin wafers of electroactive ceramic material electrically connected in parallel. A measure of stack capacitance can be made by:

$$C \approx n\varepsilon_0\varepsilon_{33}A/d_s$$

n is the number of layers, ε_0 dielectric constant in vacuum, ε_{33} relative dielectric constant, A= area of electrodes surface and d_s distance between electrodes.

Every change in the charge or displacement needs a current i:

$$i = \frac{dQ}{dt} = C\frac{dU}{dt}$$

Where i is current, U is voltage, C capacitance, and Q charge. For static operation only leakage current has to be supplied. The high internal resistance limits leakage current to low micro or submicro amp ranges.

5.4.3 Temperature Effects

Thermal stability of the PZT ceramics is better than most other materials. It is characterized by the coefficient of thermal expansion. these coefficients are dependent on the temperature.

PZTs work inside a range of temperatures. Even down to 0 degree Kelvin. However, the magnitude of piezo gain is dependent on the temperature. Near room temperature it is very stable.

5.5 Our Plant

The Block diagram in Figure 5.1 shows our plants components. Our plant consists of a + like structure with 1 inch square in center and four squares one on each of four sides. The target to measure the movement is mounted in the center of the structure. The structure is mounted on a base such designed to allow multilayer stack of PZTs also to make it easy to test them individually. We used individual PZT's to gather information about there performance and then made a four layer PZT plant to do our PI control experiment.

The PZT is excited by using a 1:100 ratio DC amplifier to amplify the DSP outputs of $\pm 5V$.

The displacement sensing of the PZT behaviour is carried out by using a capacitive sensor. The gain of the capacitive sensor is 0.4. The capacitive sensor is excited by a separate power supply of 5 volt DC and gives the deflection in the range of apprx. $\pm 12Vdc$. Our range of expected sensing is well within the capabilities of the capacitive sensor.

The whole system is capable of working at ± 5 volt for communicating with the Delanco Spry 310 board. The board then transfers the data onwards to LabVIEW for further processing.

CHAPTER 6

IMPLEMENTATION

6.1 The DSP Block

The DSP block of the is a VI which can be run at its own as well as connected to other VIs as a subVI. It has an icon which allows it to be connected to three inputs and give one output. The required inputs are:

- Sampling rate and integer input,
- Download / Execute selection a binary selector input,
- Input the data value that has to be written to the DSP, and
- Output the data returned to the LabVIEW by the DSP

When this is run at its own its front panel can be used to give and read the status of the DSP what we are writing to D/A and what is being read back from A/D.

6.1.1 The Front Panel

The front panel of the DSP block is displayed in Figure 6.1 and consists of four components:

- Control input for sampling rate,
- Control input for Data to be sent to DSP,
- Binary control button for operation during the run execution,
- The display for the data sent by DSP.

We can give integer values to the control input for the sampling rate, this value is written to the CIN. The control for input Data sent to DSP accepts floating point

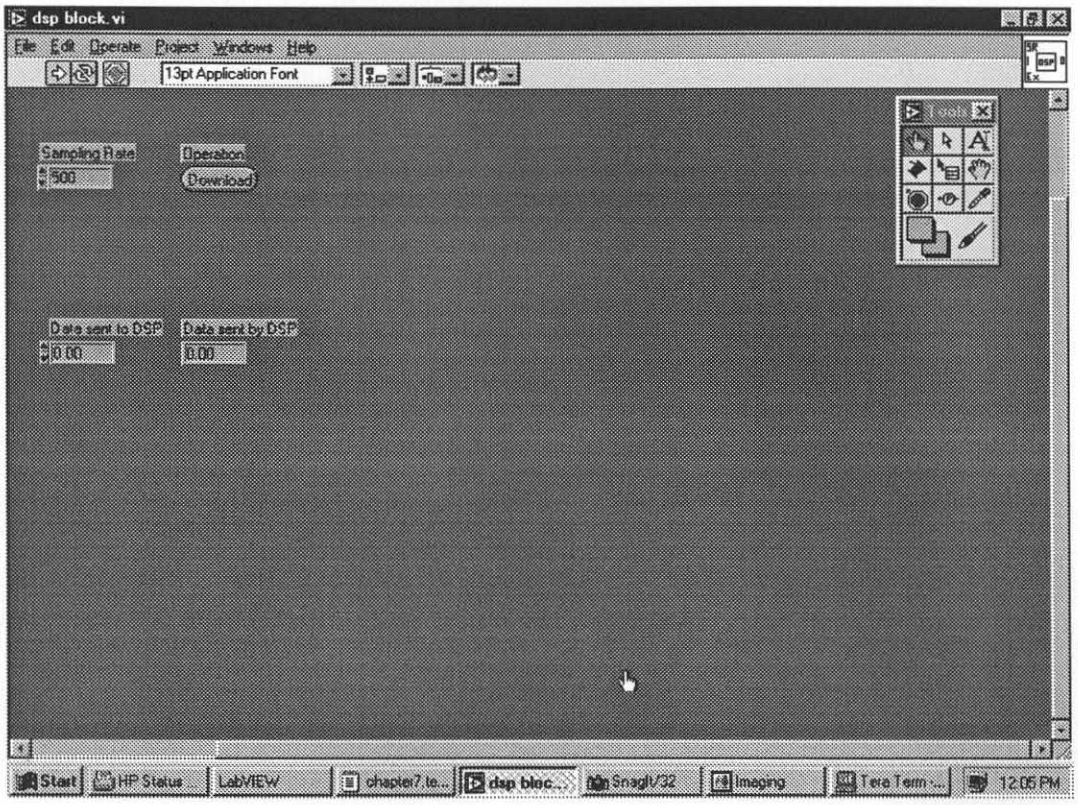


Figure 6.1 The Front Panel of the DSP Block

values for the data or the voltage level which is to be sent to the DSP the value is in volts and has the precision of two decimal places, the display is also configured to display only upto two decimal places. The binary button select whether we want to download the DSP program to interface with the DSP block VI into the DSP or we want to execute the program in the DSP. This is done for convenience as well as better utility of the system. The user is responsible to ensure that the proper interfacing program is in the DSP before executing the DSP block. It is recommended that we should always download once before we actually start the program. The block is configured to download the DSP program when opened and the user has to switch to execute mode before he can start using the DSP block VI. The value read by the DSP is also displayed as voltage with two decimal point precision on the front panel.

This VI can be run only once or can be put into repetitive runs from the control toolbar on LabVIEW. Care should be taken in using the VI as a subVI since we will need to DL the DSP program into the DSP. This VI is written so as to support and provide capabilities for the user to develop his own experiments which use the DSP to read and write one channel each.

6.1.2 The Block Diagram

The block diagram shows that the Sampling rate is written as it is to the CIN. the Data to be sent to the DSP is however scaled as the DSP uses value 409 for outputing 1 volt through the D/A. This called value is provided to the CIN. The CIN can be seen to have two I/O terminals and one output only terminal. The data sent by the DSP is available at the output only terminal and is already properly scaled to give the voltage read by the DSP. This whole logic is enclosed in a case true box and the case value is decided by the download/execute button. Please refer to Appendix A for the Figure A.1 which shows the case true block diagram.

Incase of the case false input from the download/execute button the block diagram shown in the Figure A.2 in appendix A is executed. This calls the batch file dsp.bat which compiles and downloads the DSP program to interface with the LabVIEW DSP block VI.

6.1.3 The CIN

The CIN source code is available in the Appendix B. The CIN takes the sampling rate and writes it down to the DSP memory address 0x01387. Then it writes down the data to be sent to the DSP on address 0x1388. After doing that the CIN waits for the DSP to actually send this data out to the D/A and read data from the A/D. When the check flag is set the CIN reads the data value from the DSP address 0x01389 and ends its execution after resetting the check flag.

6.1.4 The DSP Program

The DSP program to interface with the DSP block VI is available in Appendix C. The DSP program first checks if it is running the DSP at the desired sampling rate then it manipulates and write the data at the address 0x01388 to the D/A. Then reads and stores the data from A/D to the address 0x01389 and sets the check flag.

6.2 Hysteresis with Dither

Hysteresis is defined by Webster's Seventh new collegiate Dictionary as:

> A retardation of the effect when the forces acting upon a body are changed (as if for viscosity or internal friction); *esp*:a lagging in the values of resulting magnetization in a magnetic material(as iron) due to a changing magnetizing force. **-hys-ter-et-ic** *adj*

Hysteresis represent the *history* dependence of physical systems. If something is moved and when released springs back to its original position, if it does not relocate itself exactly on its original position it is exhibiting hysteresis. The term most commonly associated with the magnetic materials. However, hysteresis occurs in a lot of other systems, like bending of fork if pressed to hard etc.

Hysteresis loops happen when we repeatedly wiggle the system back and forth. Some systems can be looped repeatedly and exhibit same or very slightly modified hysteresis, others may not allow us to repeat the experiment. We can pulsate the PZT as much as we like with care of not doing it too fast, but we cannot bend and return the fork. Another important factor is the speed of the repetitions. if this is done very quickly the system may not exhibit its true dynamics. If it is done too slowly then the drifting of the system, as is the case with PZT, may play a role.

6.2.1 The Front Panel

The front panel of the DSP block is displayed in Figure 6.2 and consists of six components:

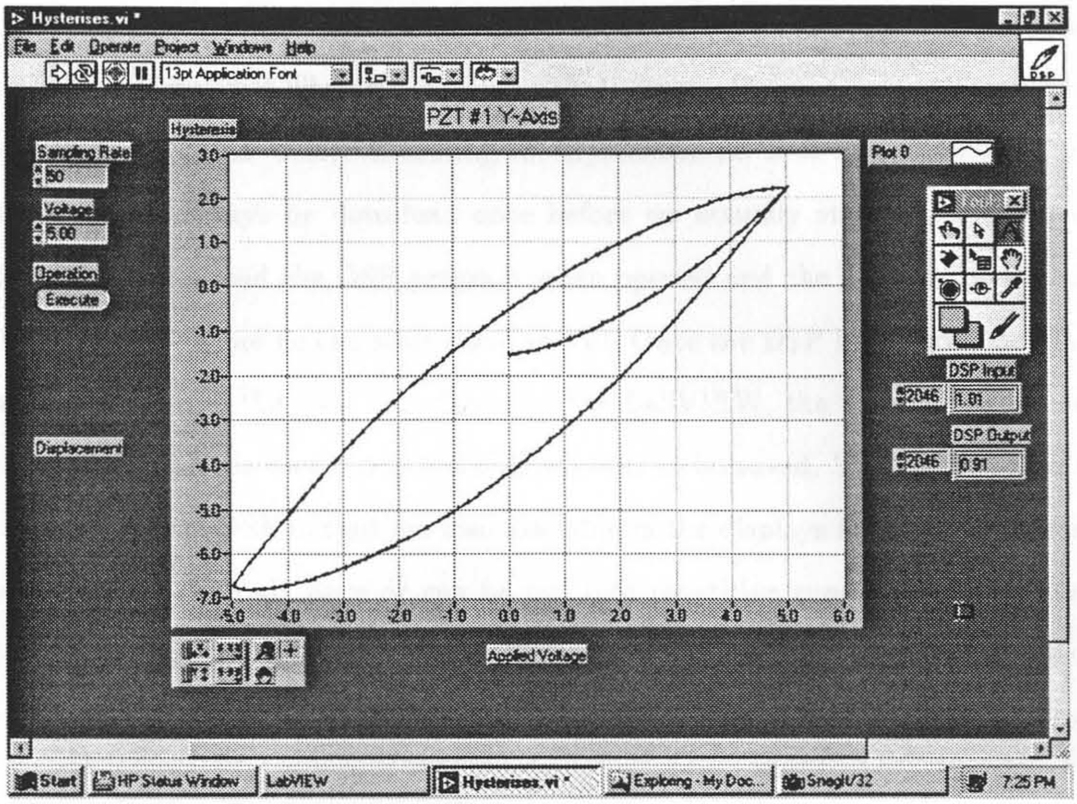


Figure 6.2 The Front Panel of the Hysteresis program.

- Control input for sampling rate,
- Control input for Voltage level to be used during the experiment,
- Binary control button for operation during the run execution,
- The XY graph display for plotting the hysteresis loop,
- The data display for the DSP input,
- The data display for the DSP output.

We can give integer values to the control input for the sampling rate, this value is written to the CIN. The control for Voltage level accepts floating point values for the data or the voltage level which is to be sent to the DSP the value is in volts and has the precision of two decimal places, the display is also configured to display only upto two decimal places. The binary button select whether we want to download the

DSP program to interface with the DSP block VI into the DSP or we want to execute the program in the DSP. The user is responsible to ensure that the proper interfacing program is in the DSP before executing the Hysteresis VI. It is recommended that program should always be download once before we actually start. The block is configured to download the DSP program when opened and the user has to switch to execute mode before he can start using the VI. Once the DSP has carried out the experiment and had the data transferred to the LabVIEW, the data is plotted on the XY graph and the user is a asked if data needs to be saved. The arrays of both the DSP input and DSP output are also available in the displays for these purposes. This VI can be run only once or can be put into repetitive runs from the control toolbar on LabVIEW. This VI cannot be used as a subVI but only as an independent VI. The execution time depends not only on the systems performance but also on the sampling rate being used.

6.2.2 The Block Diagram

Once again the block diagram as shown in Figure A.3 consists of a true false case selection controlled by the Download/Execute button. The true case block diagram shows the sampling rate is directly transferred to the CIN, while the voltage is scaled by a factor of 409.0 and then transferred to the CIN. The voltage has accuracy of two decimal places as it is transferred to the CIN.

The CIN in this case writes back two arrays of data to the LabVIEW which are stored in DSP input and DSP output arrays. These arrays are then combined together to form a cluster of two dimensional data which is then passed on to the XY graph. another two dimensional array is formed which is then passed on to subVI write to spreadsheet. This subVI asks the user the name of the spreadsheet format data storage field. This operation can be cancelled or completed by the user by a file saving dialog box.

Incase of the case false input from the download/execute button the block diagram shown in the Figure A.4 in appendix A is executed. This calls the batch file hyst.bat which compiles and downloads the DSP program to interface with the LabVIEW Hysteresis VI.

6.2.3 The CIN

The CIN creates two handles for the arrays of data which will be transferred between the CIN and LabVIEW. It accepts two pointers one for sampling rate and another for the desired maximum voltage level. An important thing to note is the **NumericArrayResize** function and its not so user friendly interface. Caution needs to be exercised with this function since it causes LabVIEW to crash if not properly handled. This function configures the data structure which will transfer data back to LabVIEW.

The DSP is put into execution mode to perform the experiment. The CIN calculates the hexadecimal value to be transferred to the DSP in order to get the desired sampling rate as writes the result of these calculations to the DSP address 0x01387. The check flag is checked repeatedly until it is set by the DSP marking the complete execution of the experiment. It is important to note that CIN allows non LabVIEW programs to run in the Windows 95 environment.

Once the DSP confirms that the necessary data has been acquired, the CIN reads the data input to the DSP from the address 0x01388 onwards and the DSP output from address 0x02788 onwards. After necessary data scaling and manipulations the data is stored in the structures to be passed on to LabVIEW. The check flag is rest to 0 and the DSP is halted to stop further execution of the program, as CIN ends its execution.

It is important to note that the execution of this VI depends very heavily on the sampling rate selected, and care needs to be exercised to select a sampling rate which will not allow the dynamics of the system to be wrongly interpreted.

6.2.4 The DSP Program

The DSP program of the hysteresis experiment adjusts the sampling rate of the system to the desired rate passed by the CIN. then it calculates the output signal it needs to send out at that particular instant which depends on the position of the position counter i. It is important to note that the program generates a triangular waveform which goes from 0 to maximum then back through zero to minimum and then again through 0 to maximum desired voltage level. The sampling rate has to be slow enough to simulate DC voltage levels for the system rather than a triangular waveform in practice a sampling rate of 50 samples per second was found to be a good selection.

The DSP program writes the calculated value out in array starting from address 0x02788 and then copies the value from A/D converter to the array at address 0x01388 onwards. One the complete route for the hysteresis is completed the DSP program sets the check counter thus informing the CIN that it has completed the data acquisition for the desired experiment.

6.3 Range of PZT Displacement

6.3.1 The Front Panel

The range of the PZT plants displacement is measured by giving very low frequency sine wave input to the DSP and reading the maximum and minimum voltage levels and scaled to displacement. Therefore we have the following on the front panel:

- Control input for desired frequency of sine wave,
- Control input for sampling rate,

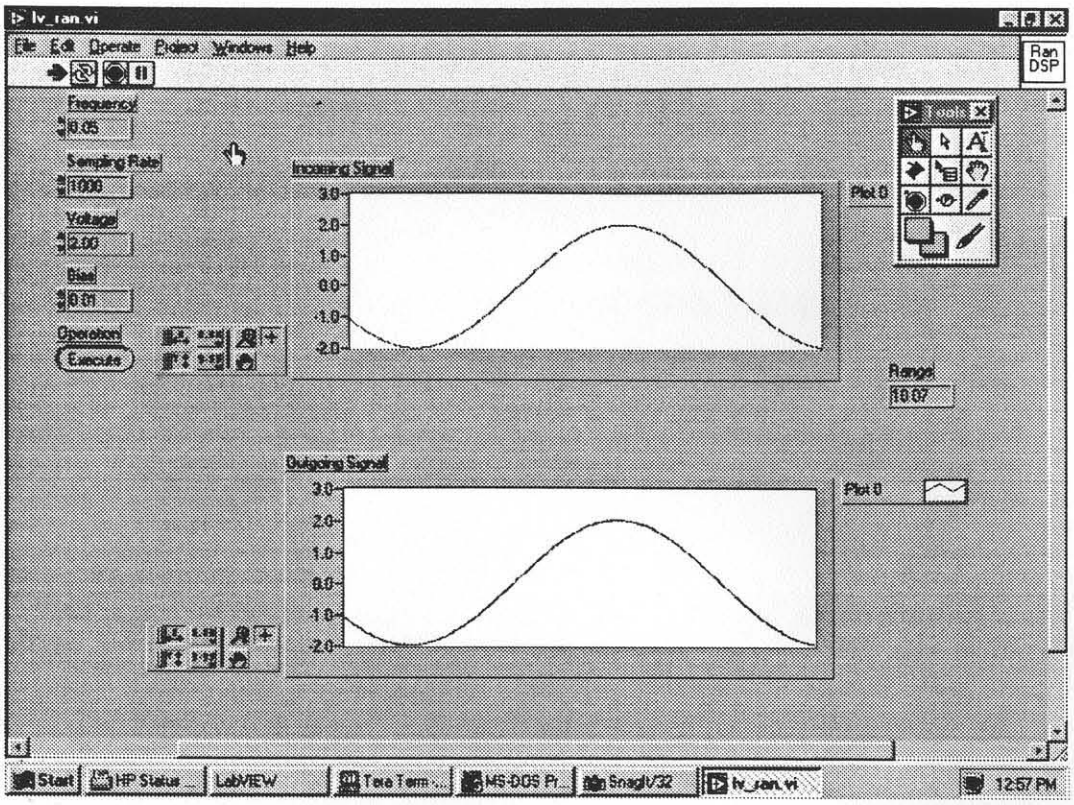


Figure 6.3 The Front Panel of the PZT Range

- Control input for Voltage level to be used during the experiment,
- Control input for bias level to be used during the experiment,
- Binary control button for operation during the run execution,
- The Waveform Chart to display the signal written by the DSP (Incoming Signal),
- The Waveform Chart to display the signal coming back to the DSP (Outgoing Signal),
- The Calculated range.

We can give frequencies with an accuracy of two decimal places, the fractional Hz capability is necessary since the experiment needs to be carried out at the slowest possible speed. The sampling rate has to be given in integer form. Voltage input control is provided to accept voltage with accuracy of two decimal places. The binary button can select whether we are going to Download the program into the DSP or we are going to execute the program in the DSP.

It is important to note a few things here:

- The display of the data on the two waveform charts consumes a lot of resources as well as time causing this particular VI to be excruciatingly slow.
- The display will become garbled and not easily understandable at relatively higher frequencies.
- The fastest acceptable frequency cannot be ascertained as it depends heavily on the applications running under windows, and the system hardware being used.
- The higher sampling rate can cause the DSP and the display to get asynchronized and the realtime effect can be lost.

Once the sine wave cycle has completed the PZT has passed through the maximum and minimum levels of its displacement the range of PZT displacement can be read from the display Range. Figure 6.3 shows the Front Panel.

This VI is a stand alone VI and cannot be connected to other VI's as a subVI. It has to be run on the continuous run mode in the LabVIEW because we need to run CIN each time we need new data and also necessary to keep the realtime operation going.

6.3.2 The Block Diagram

The block diagram shown as Figure A.5, writes the sampling rate without any manipulation to the CIN, however the Frequency, Voltage and Bias levels are scaled by a multiplying factor of 100 before being passed to the CIN. The CIN consists of four integer input output terminals and three floating point output terminals. The data coming from the CIN is already scaled and is displayed as it is on the charts and in the range data display. This whole block is in a case true selection of the download/execute button.

Incase of the case false input from the download/execute button the block diagram shown in the Figure A.6 in appendix A is executed. This calls the batch file range.bat which compiles and downloads the DSP program to interface with the LabVIEW Range VI.

6.3.3 The CIN

The CIN puts the DSP in execute mode and then writes the desired frequency, sampling rate, voltage and bias level to the DSP. then when the DSP gives the check flag the new values for both input and output charts are read and the range as determined by our algorithm in the DSP is also read after which the check flag is reset. It is imperative to notice once again that this experiment is supposed to run at slower speeds.

6.3.4 The DSP Program

The DSP program accepts the sampling rate at address 0x01387, frequency at address 0x0138b, bias at address 0x0138c, voltage at address 0x0138d, and gives the range at address 0x0138a, input to the plant at address 0x01388, and output from the plant at address 0x01389.

The desired sampling rate is set, and from this sampling rate information the sampling time T_s is calculated. The θ is then calculated as follows:

$$\theta = 2\pi f_s t = 2\pi f_s n T_s$$

This theta is then used to calculate the sine waveform, and the sine wave is multiplied with the desired voltage and the bias is added before it is sent out to the plant. The number n is incremented each time until the θ reaches a value of 2 π then n is reset since:

$$sin 2\pi = sin 0.$$

The range is calculated as the difference between maximum and the minimum voltage sensed by the PZT displacement sensor scaled and then written to the address.

6.4 Resonant Frequency Determination

The conditions of dynamic stability instability are commonly expressed in mechanics of vibrations in terms of frequency relationships and the related mechanical phenomenon is called resonance. Systems with constant coefficients in their DE's have most generally the frequency relationship of form:

$$\nu = (p/q)\omega_j$$

where ν is the excitation frequency, ω_j is one of the natural frequencies, and p and q are usually small relatively prime numbers. The motion of the system in the vicinity of ν are resonance oscillations, with amplitude a_j of one mode corresponding to the natural frequency ω_j. The frequency ν is called the critical frequency.

For the systems whose governing DEs of motions have periodic coefficients, the frequency relationships are of the following form:

$$\nu = (1/p)|\omega_i \pm \omega_j|$$

and for nonlinear systems:

$$k_o\nu = \sum_{r=1}^{n} k_r\omega_r$$

which is a linear combination of ν and natural frequency ω_j, where k_o is a positive integer and k_r are integer.

Practical steps in solving the problems of resonance oscillations are :

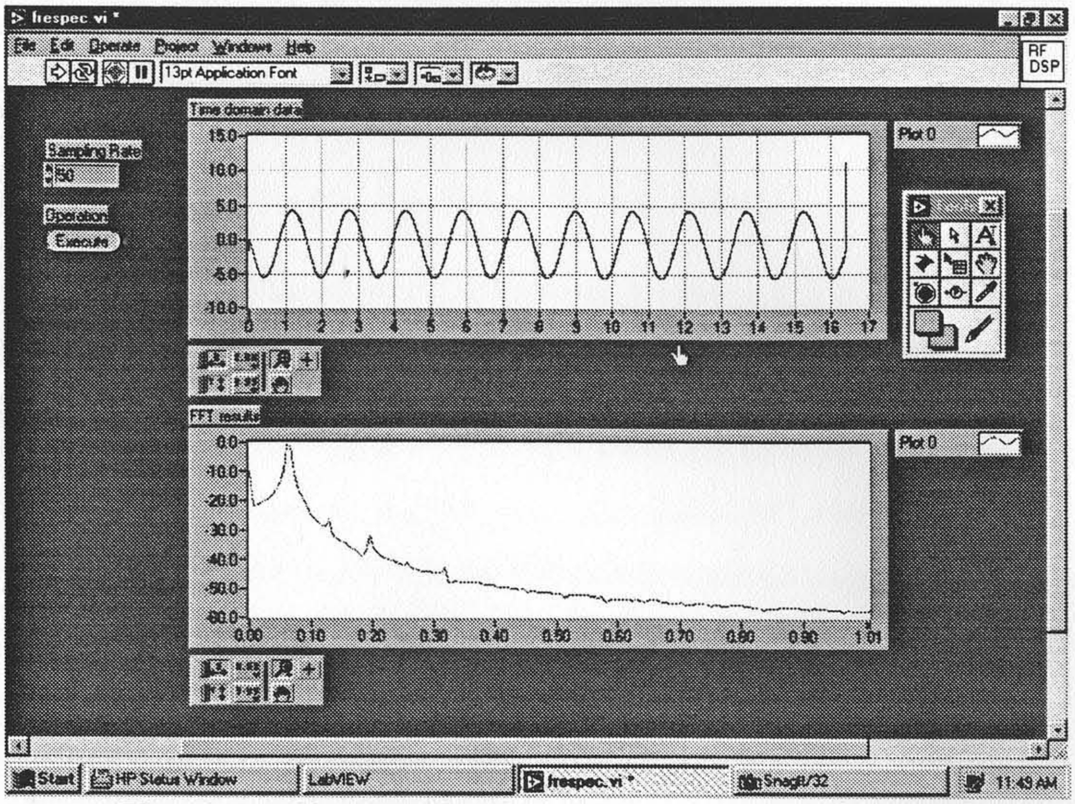


Figure 6.4 The Front Panel of the Resonance Frequency

- Set up DEs of motion
- Obtain and normalize temporal DEs of motion
- Apply asymptotic representations of solutions
- Solve DEs for phase and amplitudes
- Determine stable / unstable regions
- Discuss effects of various system and external excitation on resonance modes of resonance oscillations

6.4.1 The Front Panel

The front panel of the resonance frequency determination is displayed in Figure 6.4 and consists of four items:

- Control input for sampling rate,
- Binary control button for operation during the run execution,
- The graph displaying the data gathered in time domain
- The display data gathered in the frequency domain

We can give integer values to the control input for the sampling rate, this value is written to the CIN. The binary button select whether we want to download the DSP program to interface with the DSP block VI into the DSP or we want to execute the program in the DSP. It is recommended that we should always download once before we actually start the program. The block is configured to download the DSP program when opened and the user has to switch to execute mode before he can start using the DSP block VI.

This VI can be run only once or can be put into repetitive runs from the control toolbar on LabVIEW. The modes of frequency display are prominent high amplitude peaks which stand out in the frequency domain display. Single sided FFT is carried out and the results are plotted for a sampling of 8192 data points.

6.4.2 The Block Diagram

The block diagram shows that the Sampling rate is written as it is to the CIN. The CIN has one output only terminal. The data sent by the DSP is available at the output only terminal and is already properly scaled to give the voltage read by the DSP. This data is collected by LabVIEW in the form of an array and then the FFT operation is performed, as well as this data is displayed in the time domain data display screen. The array size is determined, and then the single sided data for frequency domain display is extracted. Then this data, which is in real and imaginary parts, is processed for amplitude and phase calculation by the complex to polar VI. The resulting data is divided by 2 if nonzero and then a cluster is formed which is given to the frequency domain display graph. Figures A.7, A.9 show the Block diagrams .

Incase of the case false input from the download/execute button the block diagram shown in the Figure A.8 in appendix A is executed. This calls the batch file range.bat which compiles and downloads the DSP program to interface with the LabVIEW DSP block VI.

6.4.3 The CIN

The CIN puts the DSP in execute mode and then writes the desired sampling rate to the DSP. When the DSP gives the check flag the values for input are read and the check flag is reset. Finally the DSP is halted before the CIN is finished.

6.4.4 The DSP Program

The DSP checks and keeps the sampling rate to the desired sampling rate as given by the CIN. Then it collects data from the input and once all required data is accumulated the DSP sets the check flag.

6.5 PI Control Application

PID controllers are the most widely used practical controllers. The "textbook" version can be described by equation:

$$u(t) = K(e(t) + \frac{1}{T_i}\int^t e(s)ds + T_d\frac{de(t)}{dt}$$

where e is the error, difference between command signals u_c (the setpoint) and process measured output y. K is the gain or proportional gain of the controller. T_i the integration / reset time. and T_d the derivative time. A pure derivative cannot be implemented, because it will give a very large amplification of measurement noise. With this perception only a PI controller was implemented in our case.

The controller can be discretized using any of the standard methods such as Tustin's approximation or ramp equivalance. Tutsin's approximation gives a behaviour such that the pole goes to -1 as T_d goes to zero. The control signal is given as :

$$u(nT) = P(nT) + I(nT) + D(nT)$$

It has the advantage that all three terms can be calculated separately.

The incremental algorithm is obtained by rewriting the control algorithm such that its output is the increment of the control signal. Δu can be calculated as:

$$\Delta u(nT) = u(nT) - u(nT - T) = u(nT) - u(n-1)T$$

we use this to get:

$$(q - a_d)\Delta u(n+1)T = T(q)u_c(nT) - S(q)y(nT)$$

This is called the incremental form of the controller. A drawback of incremental controller is that it cannot be used for P or PD controllers.

6.5.1 The Front Panel

The front panel of the PI control VI is displayed in Figure 6.5 and consists of following:

- Control input for sampling rate
- Control input for reference (setpoint)
- Control input for the Proportional gain KP
- Control input for the integral gain KI
- Binary control button for the download / execution selection

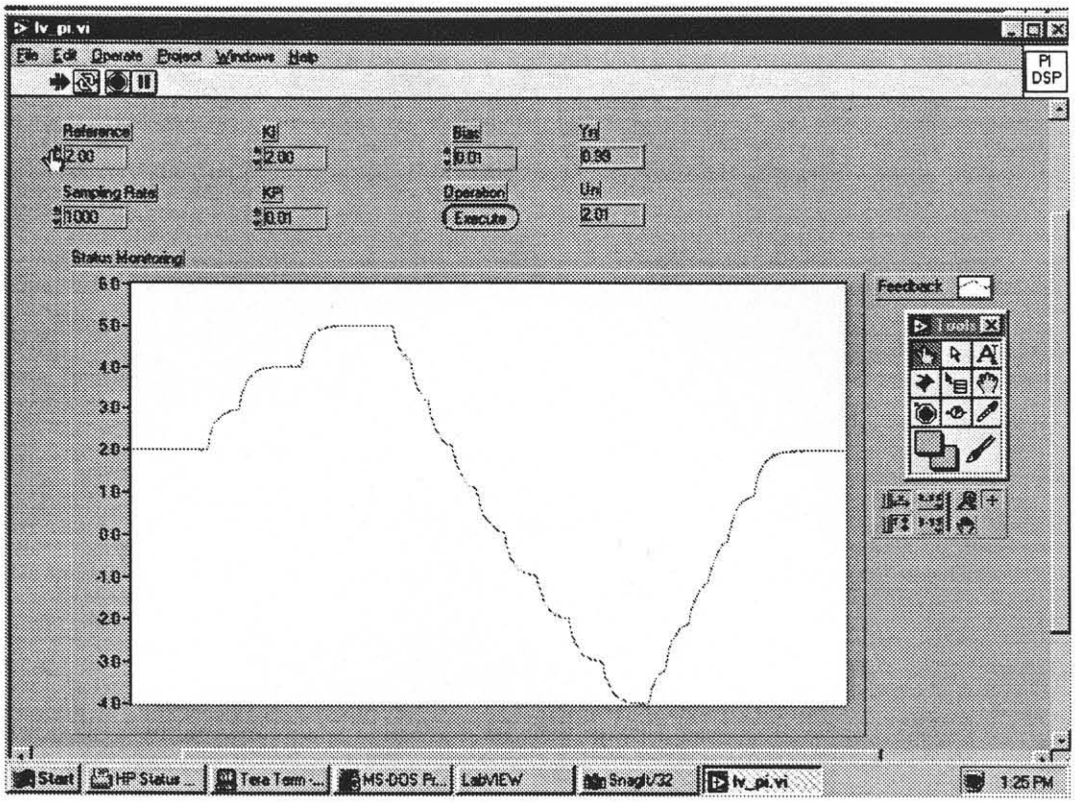


Figure 6.5 The Front Panel of the Proportional Integral program.

- Control input for bias
- Display for the value of y(n)
- Display for the value of u(n)
- Graph of the data received by the DSP, (y(n))

We can give integer values to the control input for the sampling rate, this value is written to the CIN. The control for inputs for KI, KP, bias and reference accept floating point values for the data to be sent to the DSP, the value has the precision of two decimal places, the display is also configured to display only two decimal places. The binary button select whether we want to download the DSP program to interface with the DSP block VI into the DSP or we want to execute the program in the DSP. The data which is most current is displayed as the y(n) and u(n) on the screen as well as the u(n)is plotted so as to facilitate in the tuning of the PI controller.

This VI can be run only be put into repetitive runs from the control toolbar on LabVIEW. Care should be taken in using the VI as a subVI since we will need to DL the DSP program into the DSP. This VI is written so as to support and provide capabilities for the user to develop his own experiments which use the DSP to read and write one channel each and perform a PI control.

6.5.2 The Block Diagram

The block diagram shows that the Sampling rate is written as it is to the CIN. The CIN has six Input/Output terminals accepting the Reference, KI, KP, Bias and the iteration number i. All data except the sampling rate and the iteration number are scaled by a factor of 100 to give two decimal places accuracy. It has two outputs one for y(n) other for u(n). The data sent by the DSP is available at the output only terminal and is already properly scaled to give the voltage read by the DSP. y(n) data is only displayed in the digital format to give a form of feedback as to the output DSP is giving and the u(n) is not only displayed but also plotted to display the actual performance of the PI controller. The Block diagram is shown in Figure A.10.

Incase of the case false input from the download/execute button the block diagram shown in the Figure A.11 in appendix A is executed. This calls the batch file pi.bat which compiles and downloads the DSP program to interface with the LabVIEW PI control VI.

6.5.3 The CIN

The CIN accepts the data from the LabVIEW and passes it to the DSP then it waits for the DSP to signal via check flag that it has actually carried out one sampling of I/O data. Then the y(n) and u(n) are read from the DSP and transferred back to LabVIEW and the check flag is reset for another operation to be repeated.

6.5.4 The DSP Program

The DSP program accepts bias at address 0x0138a, sampling time at address 0x01387, check flag at address 0x01386, u(n) is handled at address 0x01388, and y(n) is handled at address 0x01389, KP at address 0x0138b, KI at address 0x0138c and the reference at address 0x0138d.The sampling time T is calculated. The error e(n) is calculated as difference between the reference and the feedback from plant. KP and Ki are scaled, and then the output for the plant is calculated as:

$$y(n) = (y(n-1) + (KP + KIT)e(n) - KPe(n-1))$$

then y(n) is scaled to stay within bounded limits, and the values of y(n) and e(n) are recorded as y(n-1) and e(n-1) for the next sampling. Finally the check flag is set to inform the CIN that the DSP has completed the task assigned.

CHAPTER 7

CONCLUSION

The goal of our work is to simplify and improve the speed of the experiment. Developing a Graphical user interface using DSP for data acquisition and control applications and the interface for data display and analysis. We were able to reduce the experiment duration for carrying out a simple hysteresis curve by more than 70% by using LabVIEW to directly supervise the DSP operation during the process of data acquisition, set the experiment setpoints, collect the data from DSP and then carrying out the necessary analysis and displaying and storing the data if desired. This also improved the end result in the form of our X-Y graph, as we were able to get better resolution and overall a smoother graphical representation of our results.

Similar time savings were achieved for all experiments. The normal course of carrying out an experiment was to use two or more software platforms to individually perform each and every task of experiment at different stages. Now all the user has to do is press a button.

The most important issue was of performance. LabVIEW software provides us with an excellent tool called the performance profiler. It gives an interactive tabular display of time and memory usage of our application. Our main concern was time and the rate of data exchange.

Table 7.1 Profiles of VI programs

VI Name	VI Time	Total Time	Average	Longest
DSP Block	0.562	0.797	0.051	0.496
Hysteresis	42.521	45.419	4.252	5.211
Range of Displacement	26.496	27.183	8.832	26.441
Resonant Frequency	85.474	87.713	9.497	11.248
Pi Control	27.718	28.009	13.859	27.689

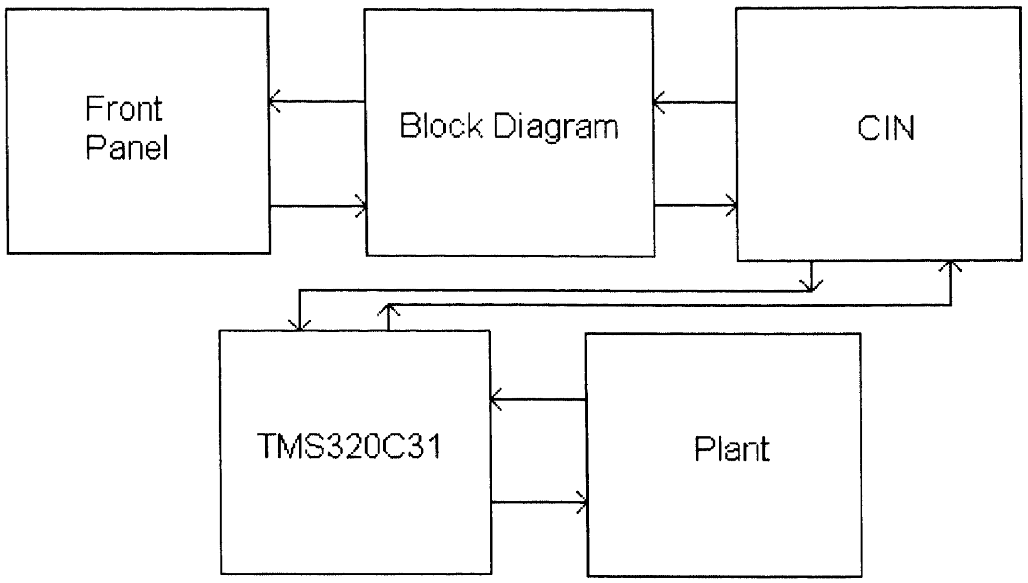


Figure 7.1 The Block diagram of data flow

The Table 7 shows profile of test results of running the VI's for 10 times. Important thing to remember is that the Range of displacement and the PI are real time VI's and therefore their exact number of execution may have varied.

We were able to achieve an average data exchange rate of 15 K during experiments which did not require the data to be displayed on the screen until all analysis was completely carried out. The displaying, specially of the graphs and charts is a very time consuming process and thus the real time display applications like Range measurement and PI control have significantly slower data exchange rates. However, the exact data exchange rate cannot be ascertained for these applications since it varies very drastically as Windows 95 allocates time of execution for each program.

The data flow in our systems is shown as a block diagram in Figure 7.1. All lines indicate the bidirectional flow of data. Each exchange of data is carried out in a certain amount of time. The data on the Front panel is transferred to the memory

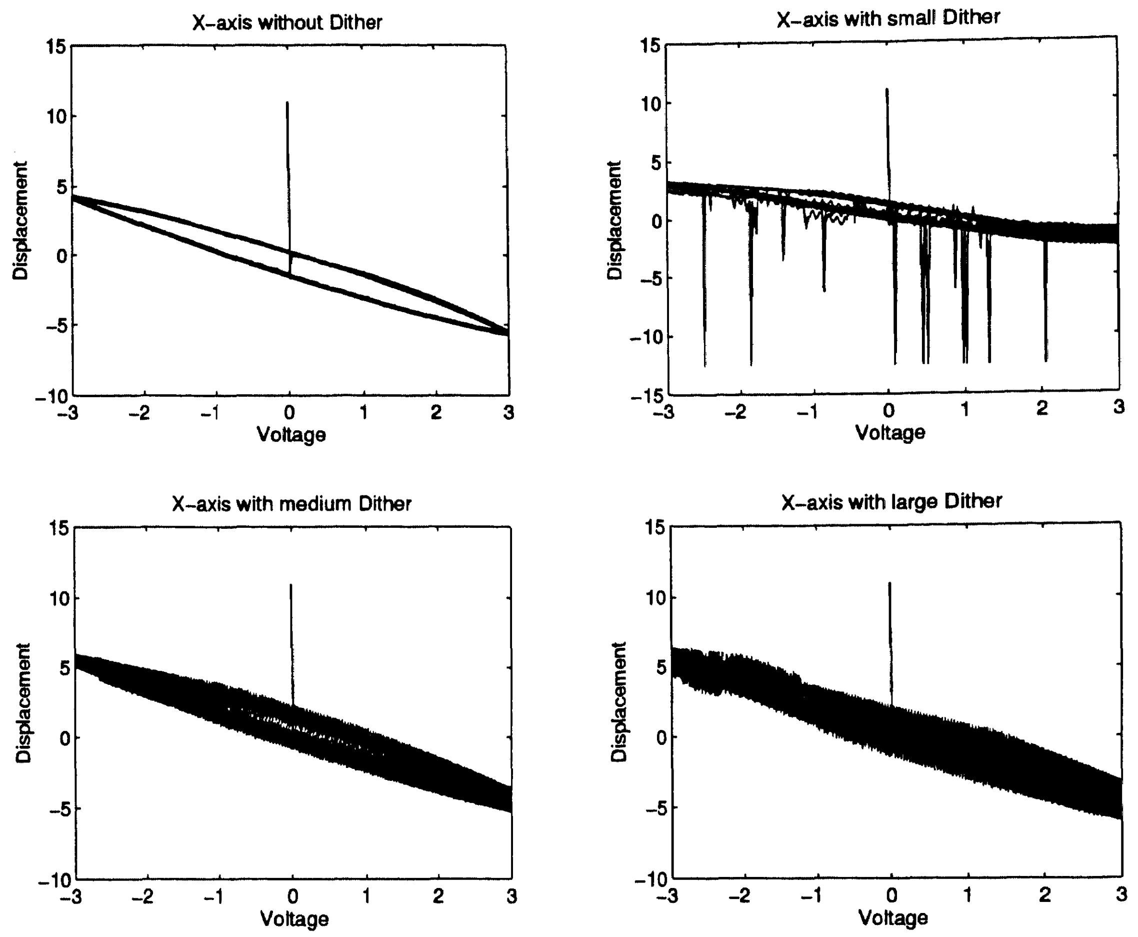


Figure 7.2 Dithering in the X-axis of Plant

location of the data in Block diagram, then block diagrams data is exchanged with CIN in the form of pointers and handles, and the data exchange between the DSP and CIN is actual I/O just like it is in case of the DSP and the plant.

7.1 Dithering

It is well known that the PZT voltage-displacement response exhibits hysteresis type of nonlinearity. This hysteresis loop has more of a ovular shape than the classical hysteresis shape.

A dither is a high frequency signal introduced into a nonlinear system in order to linearize its performance. By sweeping back and forth quickly across domain of a

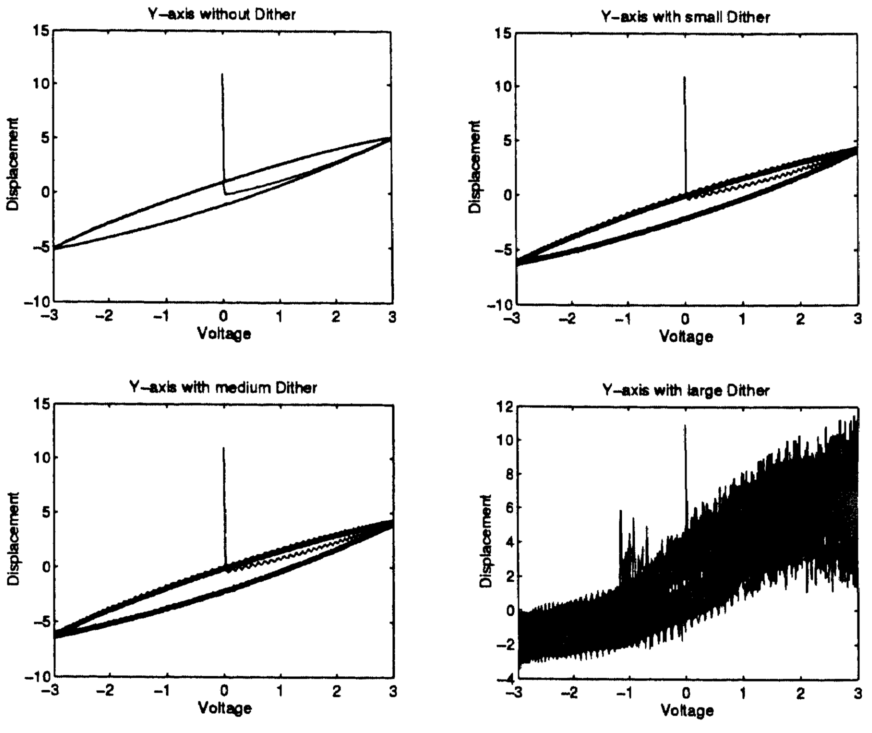


Figure 7.3 Dithering in the Y-axis of Plant

nonlinear element, a dither sort of averages the nonlinearity. This averaging action can reduce the nonlinearity in the system.

We calculated the dither by selecting the frequency of the most prominent resonance mode, and dividing it by the bandwidth required for a 3 dB drop. This gave us the Q factor. Then depending on this Q factor we calculated the approximate voltage to introduce different magnitude dithers into our system. We used dithering for 1μm (small), 5μm(medium), and 10μm(large) dithering signal.

Dither has the effect of attenuating the harmonic components of the fundamental waveform applied to it. The effects of the dithering on the harmonics were checked using the VI for Resonant Frequency response. A sine wave of 1 volt amplitude was applied and the harmonics introduced by the nonlinearity of the PZT were attenuated using the dithering. One of the results of dithering is shown in Figure 6.4.

Table 7.2 Effects of Dithering on Harmonics

Frequency	0.0064 Hz	0.192 Hz	0.256 Hz
Without Dither X-axis	-6 dB	-26.6 dB	-33.5 dB
With small dithering X-axis	-6.5 dB	-26.6 dB	-39 dB
With medium dithering X-axis	-5.9 dB	-34.5 dB	-30 dB
With large dithering X-axis	-5.4	-35 dB	-39 dB
Without Dither Y-axis	-0.5 dB	-31 dB	-44.3 dB
With small Dither Y-axis	-0.5 dB	-33.5 dB	-48 dB
With medium Dither Y-axis	-0.3 dB	-33.6 dB	-49 dB
Without Dither Y-axis	-0.6 dB	-19 dB	-24 dB

These results in Table 7.1 point to the fact that we need a bigger dithering amplitude to completely attenuate the harmonics, on the other hand bigger dithering also causes a lot of additional oscillations to be introduced into the system. The ideal amplitude of the dither cannot be ascertained.

7.2 PI Completely Programmed in LabVIEW

A complete PI control algorithm was implemented in the LabVIEW using the DSP Block VI as a subVI to implement a single loop PI control. The maximum operating frequency was 1000 samples per second, the PI algorithm was developed with a built in one sample delay. The DSP Block gave us the values of the Un and Yn which were stored in the shift registers. Thus using the yn-1, yn-2, en-1 and en-2 to implement the discretized PI control completely in the LabVIEW. The Block diagram is available in Figure 7.5

The usual Sampling rate, Operation contrl, KI, KP, Yn, Un and a chart diplaying the current status were implemente din the front panel as in Figure 7.4.

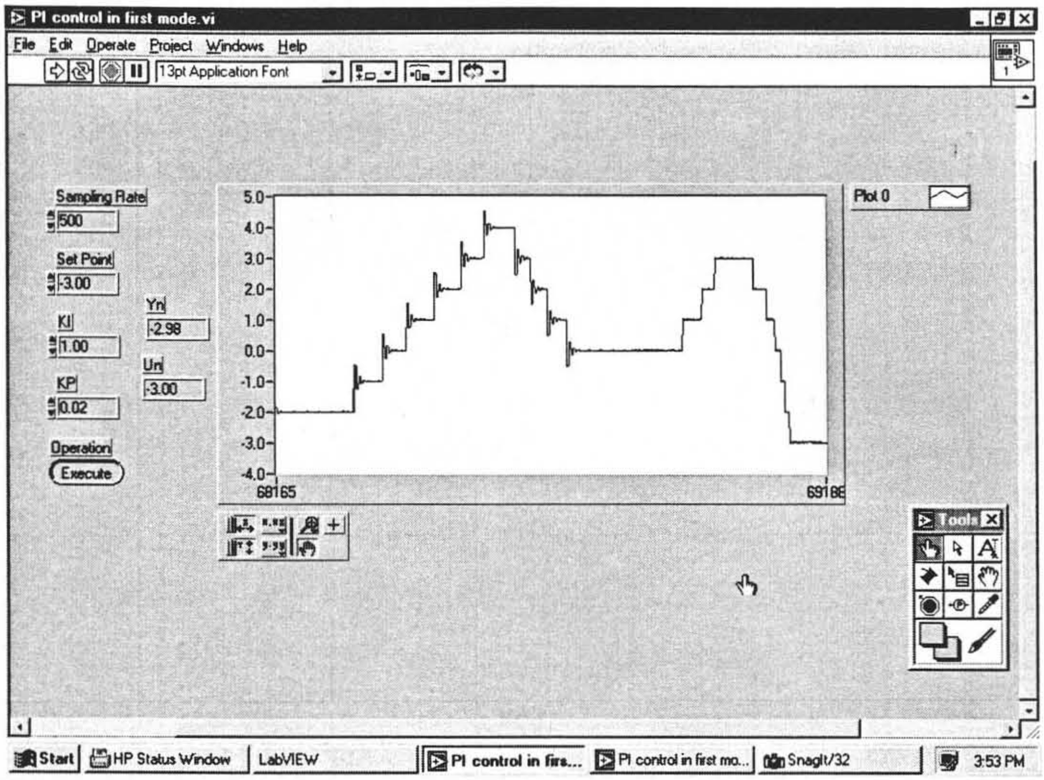


Figure 7.4 The PI control system completely programmed in LabVIEW

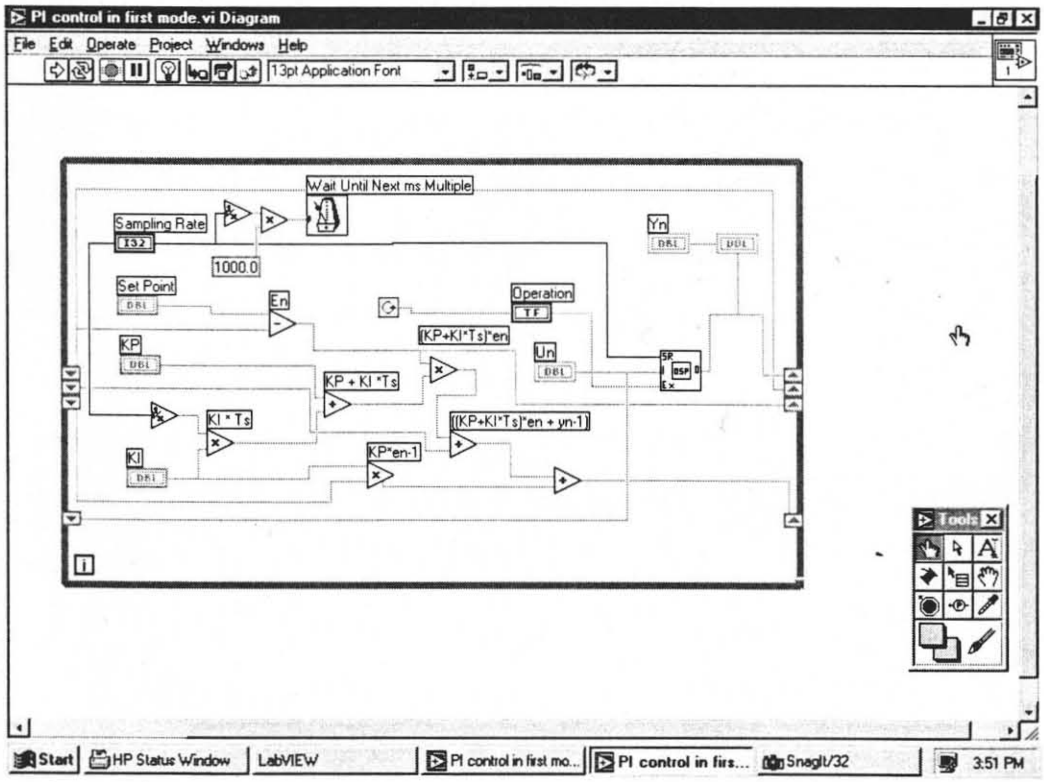
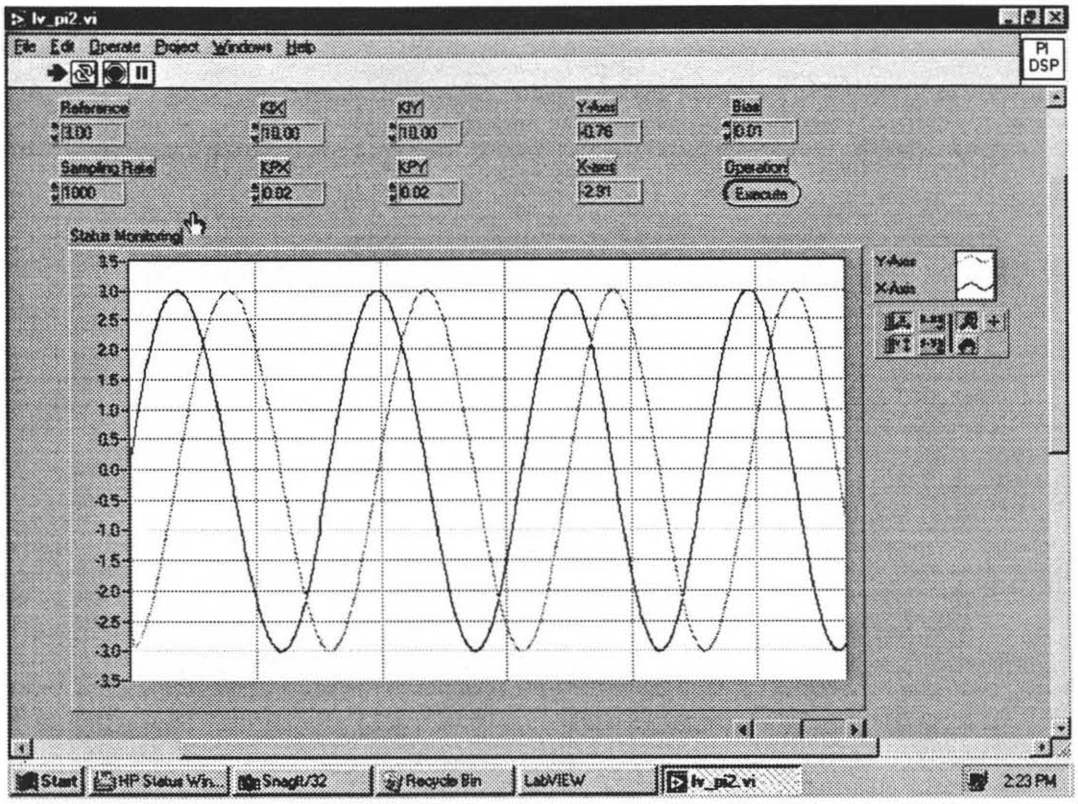


Figure 7.5 Block Diagram of PI control system completely programmed in LabVIEW



Reference 3.00
KIX 10.00
KIY 10.00
Y-Axis -0.76
Bias 0.01
Sampling Rate 1000
KPX 0.02
KPY 0.02
X-axis -2.91
Operation Execute

Figure 7.6 The Two PI control system

7.3 Drawing a Circle with PZT

The use of PI control was enhanced to control two axis of the PZT structure, also instead of single layered PZT we used a four layered PZT stack to draw a circle. The PZT is driven by two sine waves with a $\pi/2$ radian phase difference as in Figure 7.6.

This was achieved by giving the PI controllers the sine waves as a reference. The PZT was driven thus to move in a manner as to draw circles. We were successful in drawing circles from 25 nano meters to almost 11.25 μm. However, beyond this range the capacitive sensors, ADC, DAC and our software started to saturate and the circular motion of PZT could not be monitored properly. A circle of 3.0 μm is shown in Figure 7.7

The GUI was developed to be easy to use, aesthetically pleasing, and accurate. The experiments performed were found to give satisfactory results. With extensive data exchanging and data conversions during the data transactions and also the use

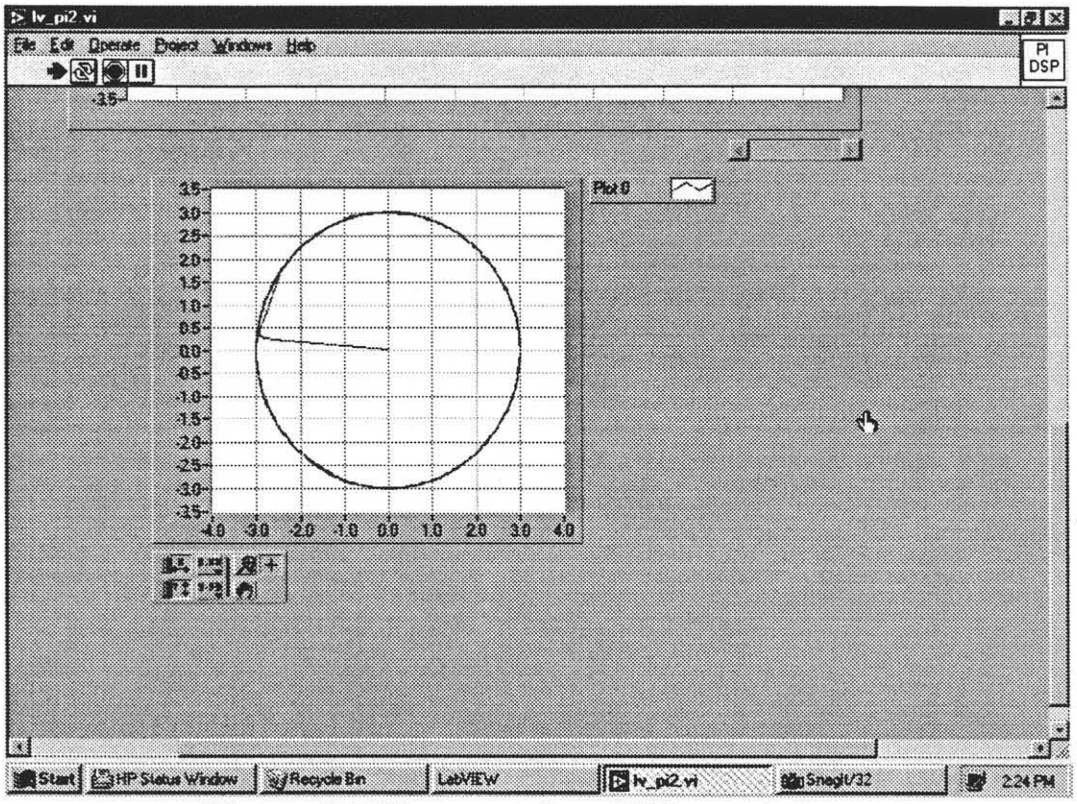


Figure 7.7 The output from PZT as a circle

of 12 bit capability of the DAC/ADC we were able to perform operations with 95% accuracy in the worst case scenarios.

The future of the work can span more experiments to be incorporated in the system. The improvement of the graphic display experiments, developing and implementing the experiments using the DSP Block which do not need any code to be written in the DSP. Incorporating other control algorithms. Studying and further improving the dithering technique for the PZT. Improving the performance of the interface to higher frequencies of data exchange.

APPENDIX A

THE BLOCK DIAGRAMS

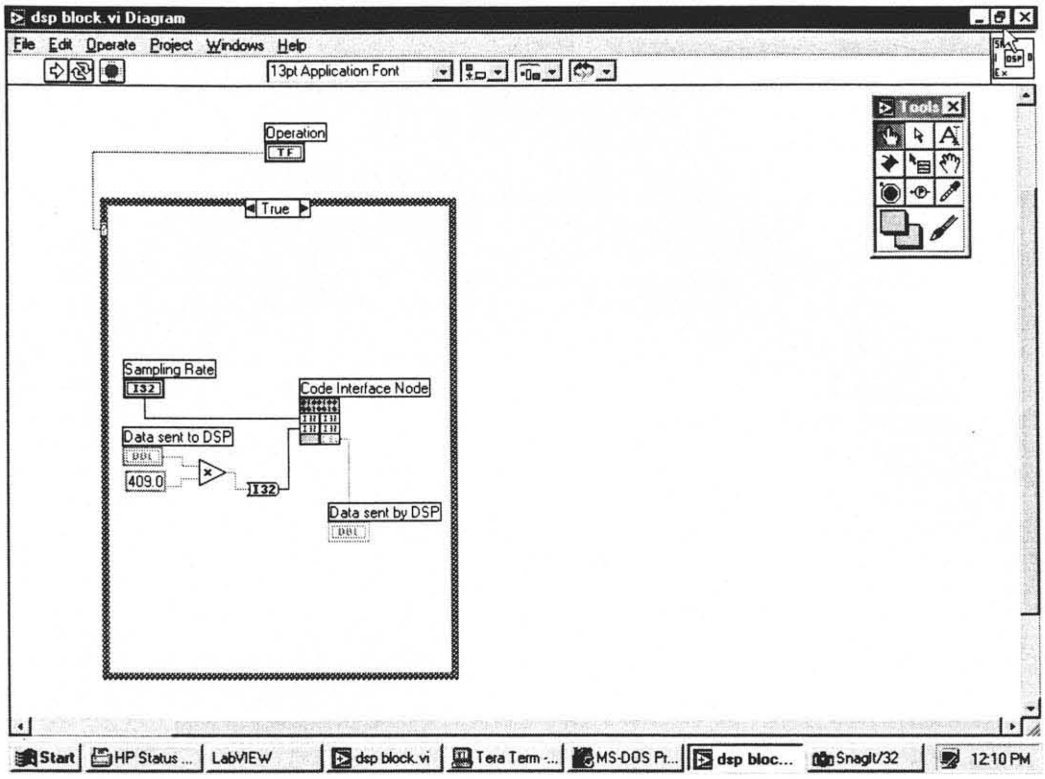


Figure A.1 The Block diagram of the case true DSP Block

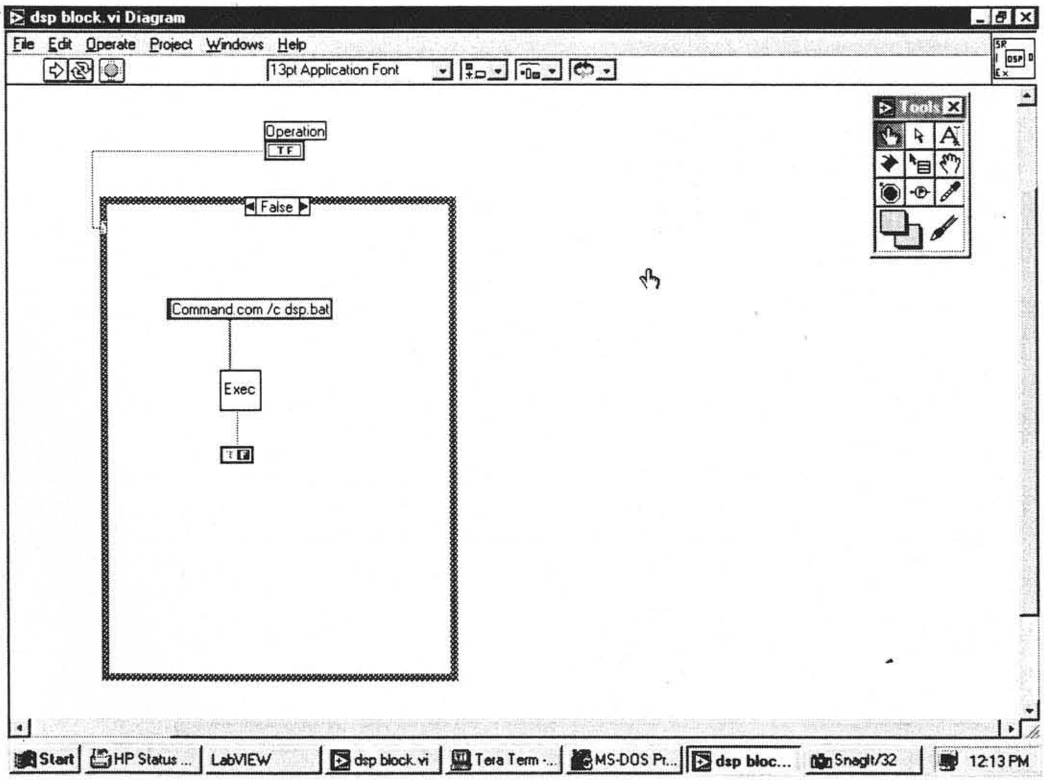


Figure A.2 The Block diagram of the case false DSP Block

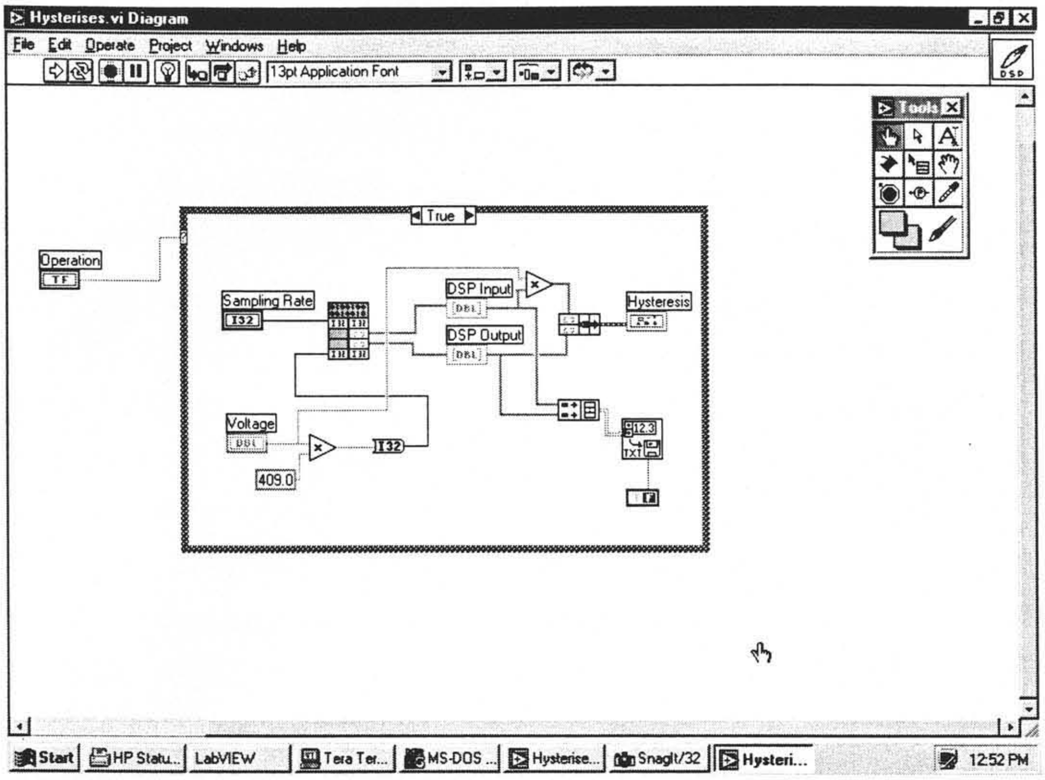


Figure A.3 The Block diagram of the case true Hysteresis

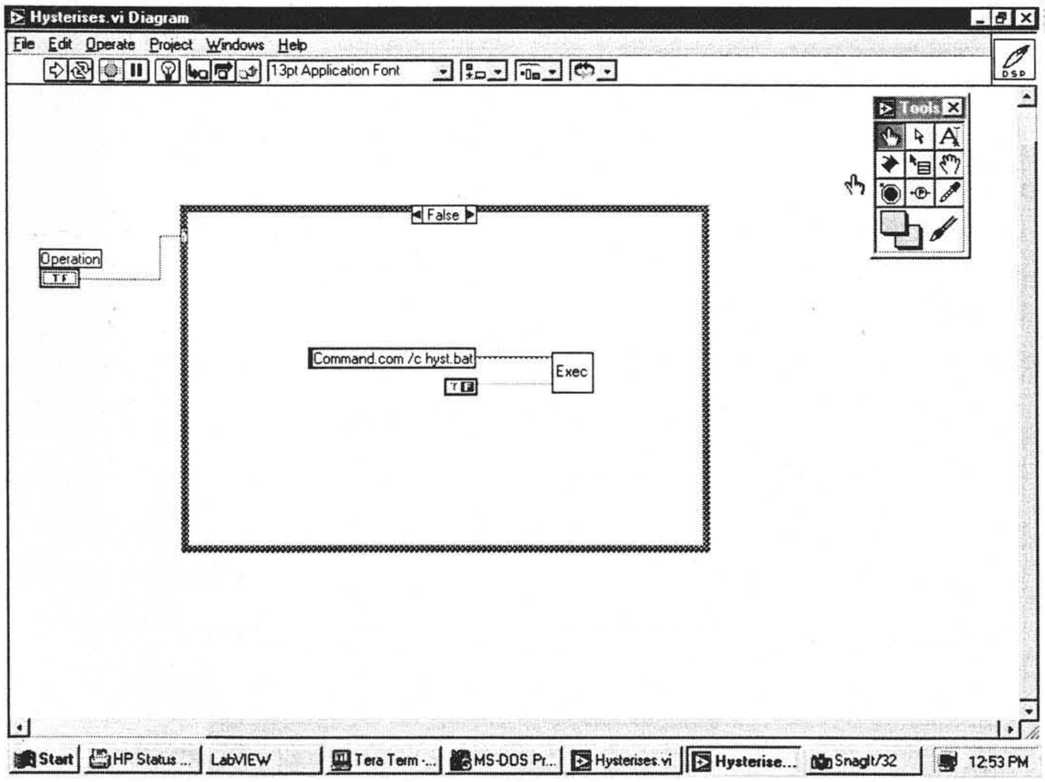


Figure A.4 The Block diagram of the case false Hysteresis

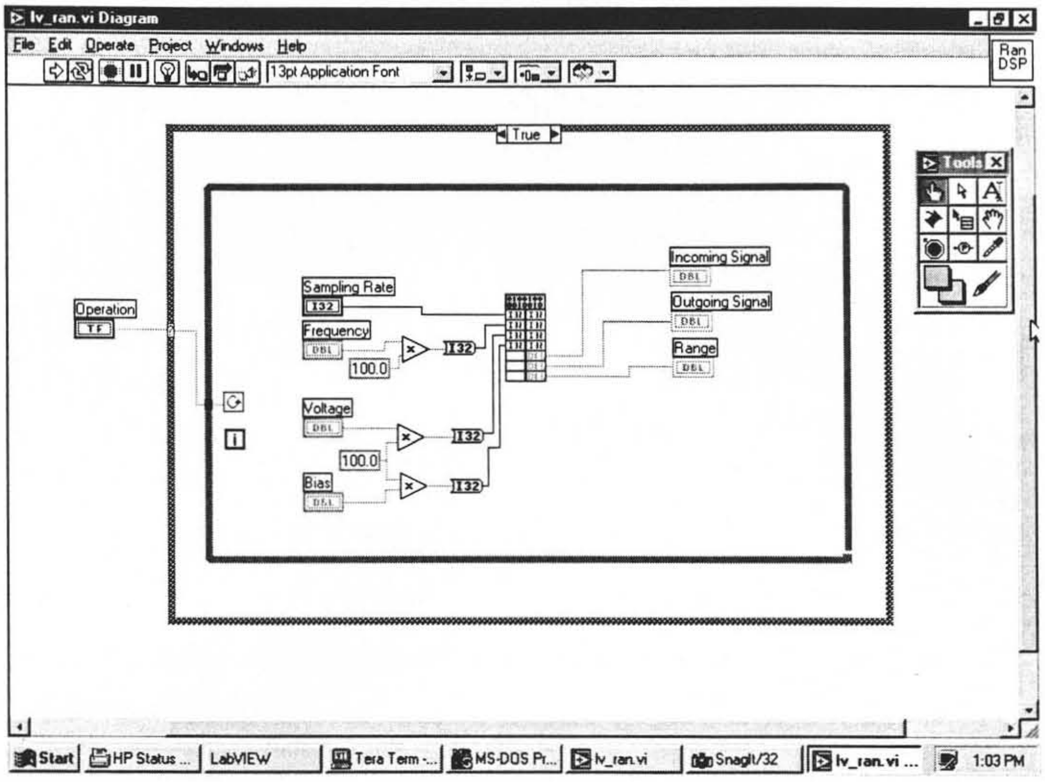


Figure A.5 The Block diagram of the case true range of displacement

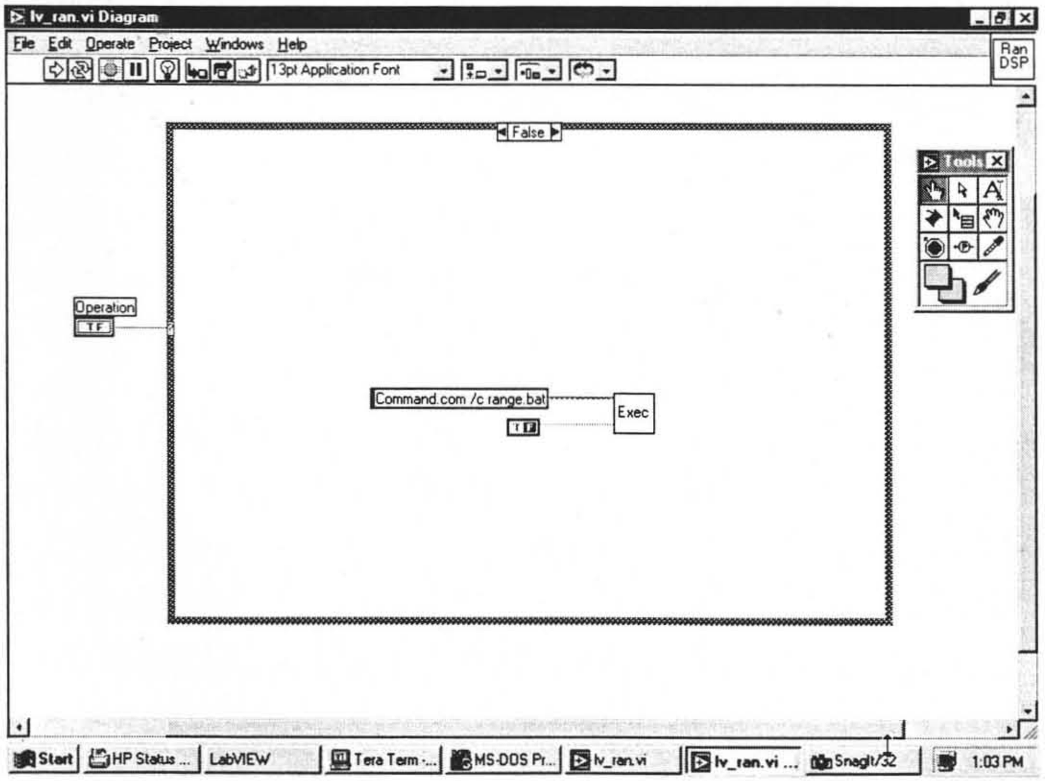


Figure A.6 The Block diagram of the case false range of displacement

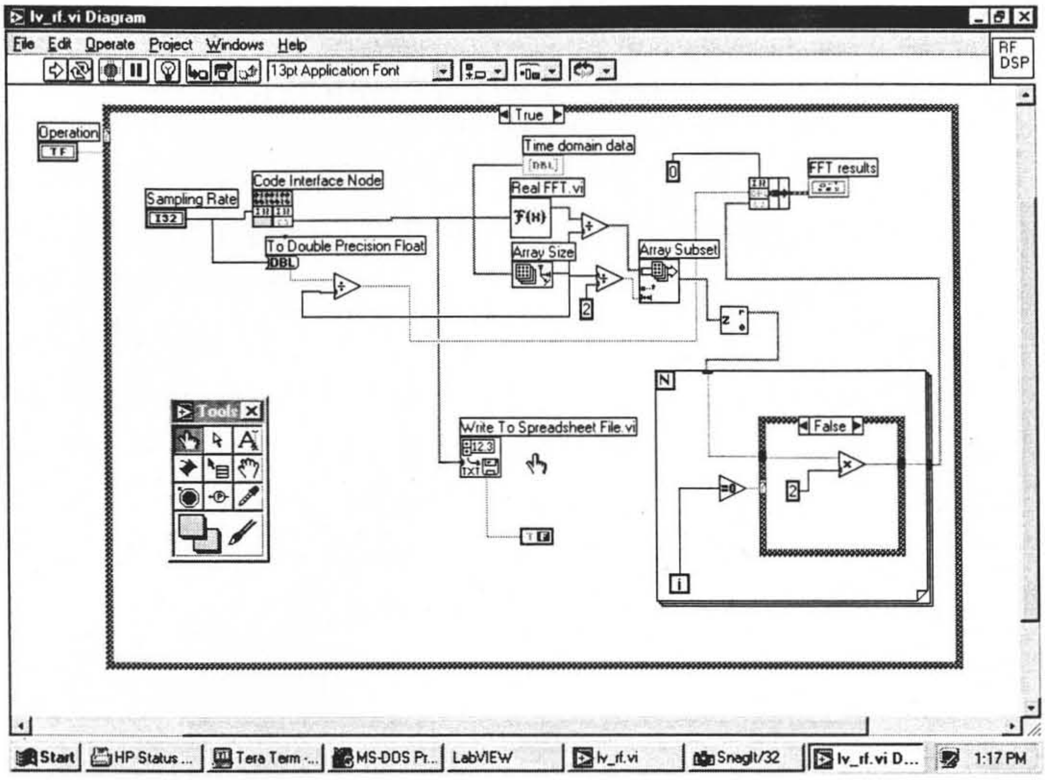


Figure A.7 The Block diagram of the case true Resonance Frequency

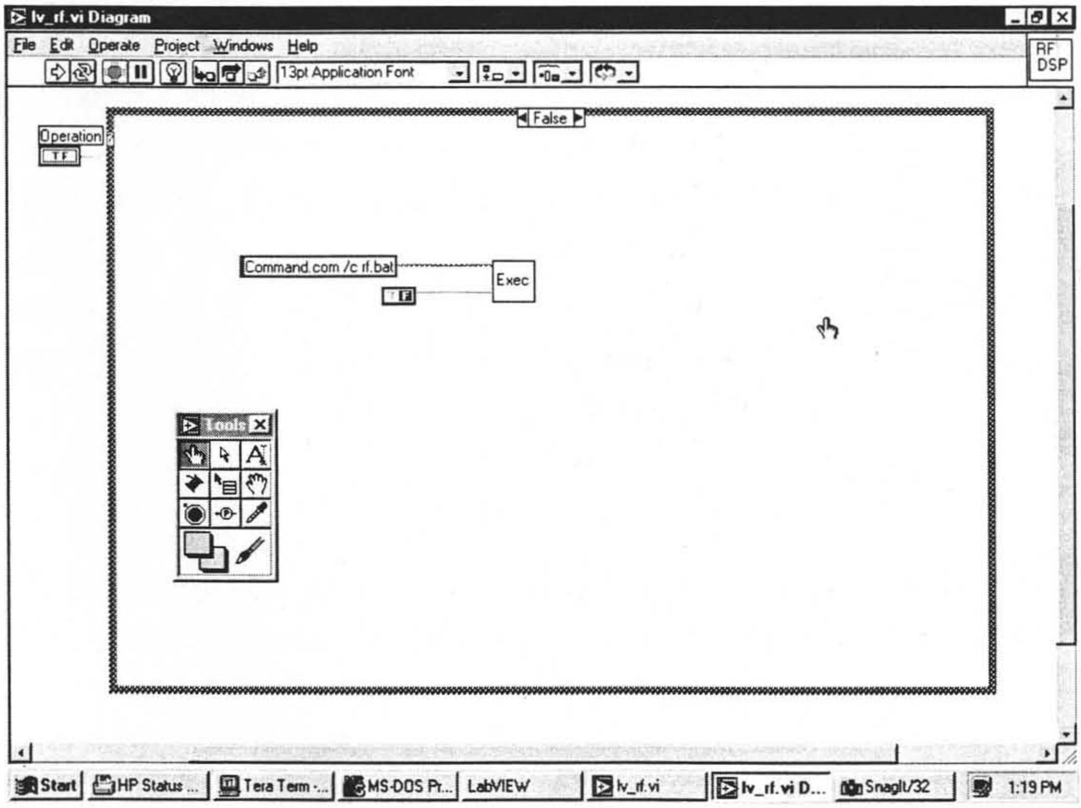


Figure A.8 The Block diagram of the case false Resonance Frequency

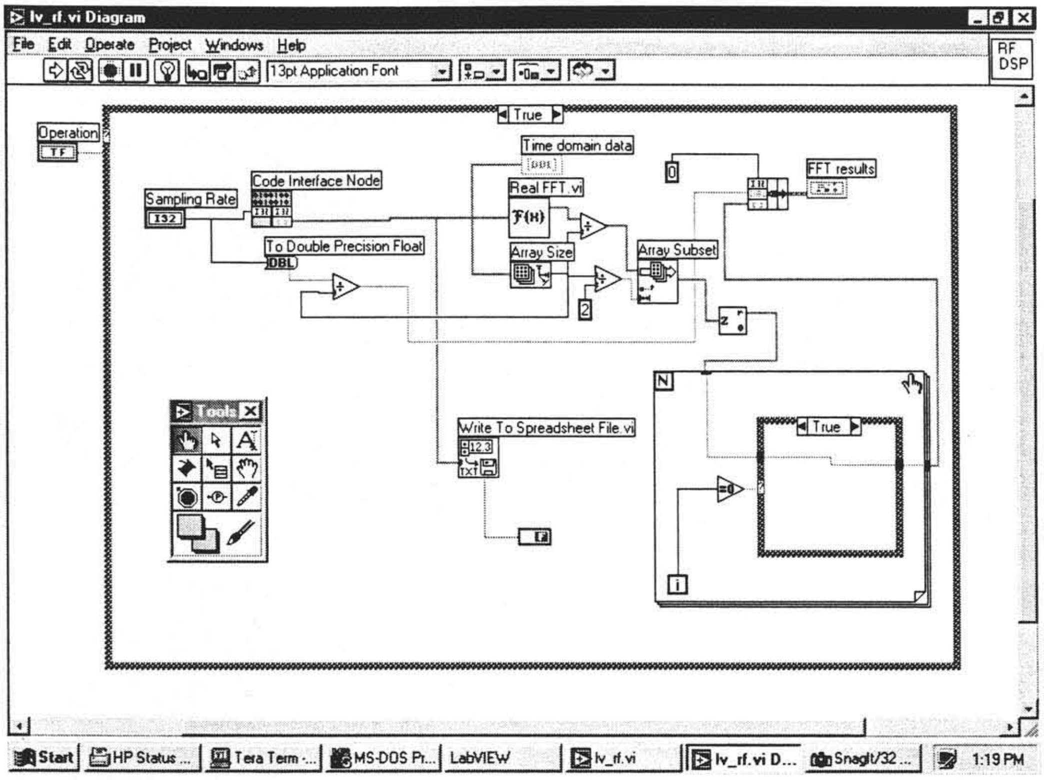


Figure A.9 The Second Block diagram of the case true Resonance Frequency

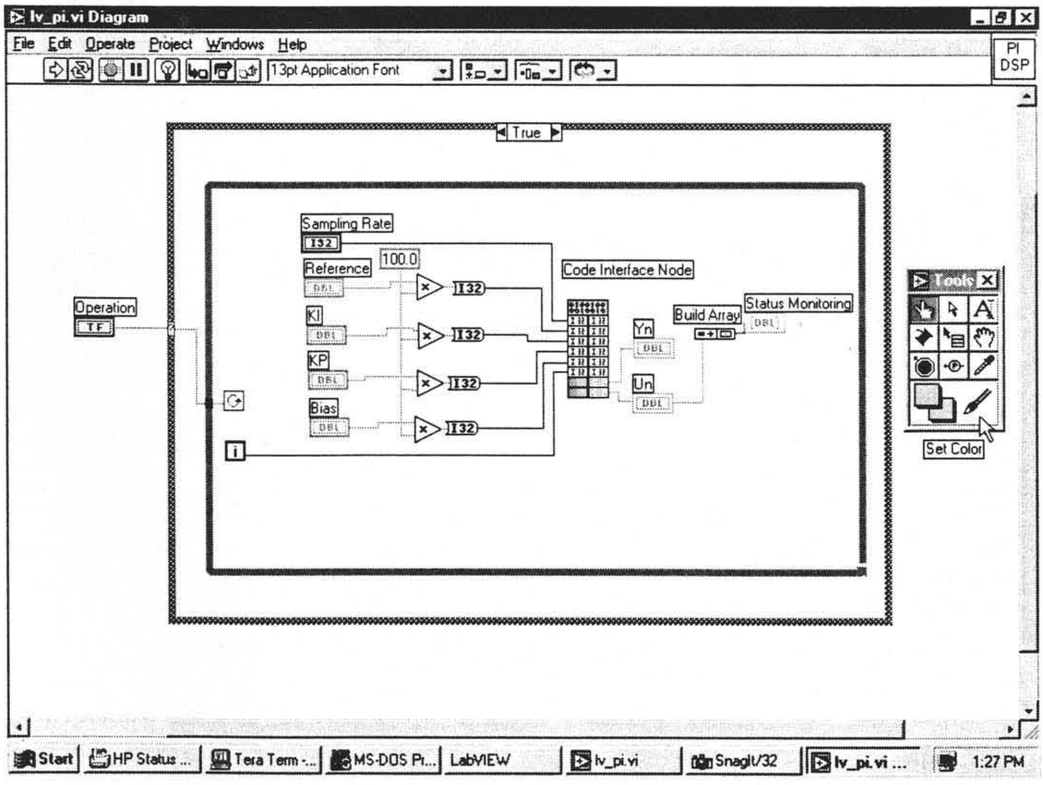


Figure A.10 The Block diagram of the case true Proportional Integral Control

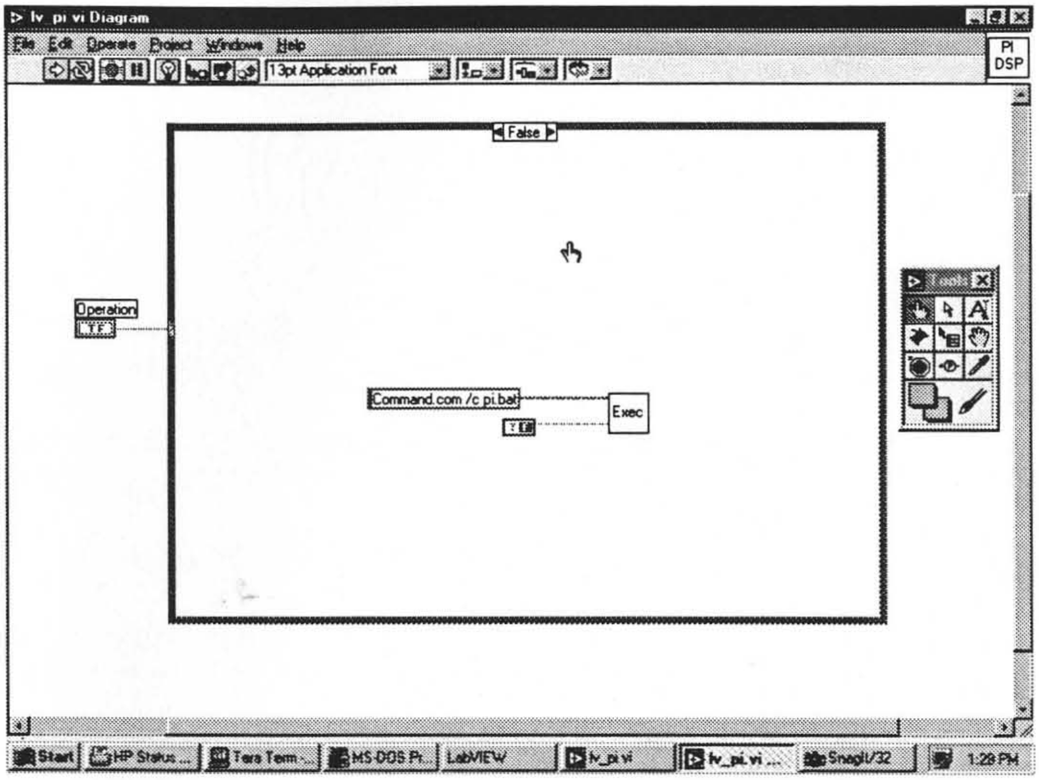


Figure A.11 The Block diagram of the case false Proportional Integral Control

APPENDIX B
THE CINS

B.1 The DSP Block CIN

```
/*
  CIN source file the DSP block. The DSP is set to go
  then the Sampling time and the desired signal are
  written to the DSP, DSP then writes out this value
  to the outside world reads a value which is then
  wrote back to LAbView.
 */

#include "extcode.h"
#include<stdio.h>
#include<math.h>
#include<conio.h>

CIN MgErr CINRun(int32 *Sampling_Rate, int32 *var2, float64
*Data_sent_by_DSP);

CIN MgErr CINRun(int32 *Sampling_Rate, int32 *var2, float64
*Data_sent_by_DSP) {

        /* ENTER YOUR CODE HERE */

        // All variables used in this function are declared.
        // ====================================================

        int sign, u16_bit, u12_bit;
//Data handling with signed numbers.
        int PAGE_VALUE=0x0, ADDRESSI=0x1388,ADDRESSO=0x1389,
Timer_Address=0x01387;
        int check, Check_Address=0x1386;

                // Start the DSP program execution.
                // ================================

                        inp(0x306);

        while (check != 1)
                {
```

```
            // The logic to set the sampling rate
            // ===================================

            outp(0x306,PAGE_VALUE); /*set the page value*/
            outpw(0x302,Timer_Address); //Sets address 0x1387
            outpw(0x300,((50000000)/(*Sampling_Rate*8*2)));

            // The logic to send the Output
            // ============================

            outp(0x306,PAGE_VALUE); /*set the page value*/
            outpw(0x302,ADDRESSO);  //Sets address 0x1389
            outpw(0x300,(*var2));  //sets the bias for sine wave

            // The logic to check if DSP is ready
            // ==================================

            outp(0x306,PAGE_VALUE); /*set the page value*/
            outpw(0x302,Check_Address); // Check address is set
            check=inpw(0x300); // wait for the DSP to
    finish its work
               } //endwhile

            // The Logic to read the Signal from DSP
            // =====================================

            outp(0x306,PAGE_VALUE); /*set the page value*/
            outpw(0x302,ADDRESSI); //Sets address ADDRESSI=0x1388
            u16_bit=inpw(0x300); // read 16 bits
            sign=u16_bit & 0x0800;
            u12_bit=u16_bit & 0x07ff;

            if(sign==0)
               {
                 *Data_sent_by_DSP= (float64) (u12_bit / 409.0);
                 if ((*Data_sent_by_DSP) > (5.0))
                     *Data_sent_by_DSP= 5.0;
                            }//endif

            else
               {
                  u16_bit=~u16_bit; /*desired negative output
 voltage (0-5)*/
                  u16_bit=u16_bit+1;
```

```
                        u12_bit=u16_bit&0x0fff; /*Stores 2's complement
value */
                        *Data_sent_by_DSP=(float64)(u12_bit/(-409.0));
                        if ((*Data_sent_by_DSP) < (-5.0))
                           *Data_sent_by_DSP= -5.0;
                                 }//endelse

                 // The Logic to reset the check
                 // ============================

                 outp(0x306,PAGE_VALUE); /*set the page value*/
                 outpw(0x302,Check_Address); // Check address is set
                 outpw(0x300,0);

         return noErr;
         }
```

B.2 The Hysteresis CIN

```
/*CIN source file for the hysteresis measurement. The
  DSP is set to go then the Sampling time and the desired
  voltage range are selected and PC waits for the DSP to
  finish and then loads all data into the LabView arrays.
 */

#include "extcode.h"
#include<stdio.h>
#include<math.h>
#include<conio.h>

/*
 * typedefs
 */

typedef struct {
        int32 dimSize;
        float64 arg1[1];
        } TD1;
typedef TD1 **TD1Hdl;

CIN MgErr CINRun(int32 *Sampling_Rate, TD1Hdl DSP_Input,
TD1Hdl DSP_Output, int32 *voltage);

CIN MgErr CINRun(int32 *Sampling_Rate, TD1Hdl DSP_Input,
TD1Hdl DSP_Output, int32 *voltage) {

        /* ENTER YOUR CODE HERE */

        // All variables used in this function are declared.
        // =================================================

        int sign,u16_bit,u12_bit, y16_bit,y12_bit,i,n;
//Data handling with signed numbers.
        int PAGE_VALUE=0x0,ADDRESSI=0x1388,ADDRESSO=0x2788,
    Timer_Address=0x01387;
        int check, Check_Address=0x1386, Voltage_Address =
0x1385;
        int32 numDims;
        MgErr err=bogusError;
```

```
                // Start the DSP program execution.
                // ==============================
                n=0;
                //Put the DSP to go
                inp(0x306);



                // Actual Data Acquisition is carried out.
                // =====================================

                numDims=1;    // This is a one dimensional
     array
                n=2047;       // The length or no of
elements of array
                if (err = NumericArrayResize(fD, numDims,
(UHandle *)&DSP_Input, n))
                goto out;       // Input array is adjusted.


                if (err = NumericArrayResize(fD, numDims,
(UHandle *)&DSP_Output, n))
                goto out;       // Output Array is adjusted.

                (*DSP_Input)->dimSize = n;  // Input array
                (*DSP_Output)->dimSize = n; // Output array

                check=0;

                while (check != 1)
                   {
                      // The logic to set the sampling rate
                      // ================================

                      outp(0x306,PAGE_VALUE); /*set the
page value*/
                      outpw(0x302,Timer_Address); //Sets
address
                      outpw(0x300,((50000000)/(*Sampling_Rate
*8*2)));
//sets the sampling rate

                      outp(0x306,PAGE_VALUE);
                      outpw(0x302, Voltage_Address);
                      outpw(0x300, *voltage);

                      outp(0x306,PAGE_VALUE);
                      outpw(0x302,Check_Address);
// Check address is set
                      check=inpw(0x300); // wait for
the DSP to finish its work
                   } //endwhile


                 for (i=0;i<2047;i++)
                     {
                       // Signal sent by the DSP is stored
 in Array DSP_Input
                       outp(0x306,PAGE_VALUE);
                       outpw(0x302,(ADDRESSI+i));
                       u16_bit=inpw(0x300);
                       sign=u16_bit & 0x0800;
                       u12_bit=u16_bit & 0x07ff;

                          if(sign==0)
                              {
                               (*DSP_Input)->arg1[i]=
(float64)(u12_bit /409.0);
                               }//endif

                            else
                               {
                               u16_bit=~u16_bit;
                               u16_bit=u16_bit+1;
                               u12_bit=u16_bit&0x0fff;

                               (*DSP_Input)->arg1[i] =(float64)
(u12_bit / (-409.0));
                               if (((*DSP_Input)->arg1[i]) <
    (-5.0))
                                  (*DSP_Input)->arg1[i]=-5.0;
                               }//endelse

                        // Signal sent to the DSP by the
     sensor is store in Array DSP_Output
                        outp(0x306,PAGE_VALUE);
                        outpw(0x302,ADDRESSO+i);
```

```
                              y16_bit=inpw(0x300);
                              sign=y16_bit & 0x0800;
                              y12_bit=y16_bit & 0x07ff;

                                 if(sign==0)
                                   {
                              (*DSP_Output)->arg1[i]= (float64)
    (y12_bit / 409.0);
                                     }//endif

                                 else
                                     {
                               y16_bit=~y16_bit; /*desired negative
   output voltage (0-5)*/
                               y16_bit=y16_bit+1;
                               y12_bit=y16_bit&0x0fff;
 (*DSP_Output)->arg1[i] = (float64)
 (y12_bit / (-409.0));
                                  if (((*DSP_Output)->arg1[i]) <
(-5.0))
                                 (*DSP_Output)->arg1[i_= -5.0;
                                   }//endelse

                            } //endfor

                         // Check is reset to 0.
                         outp(0x306,PAGE_VALUE);
                         outpw(0x302,Check_Address);
                         outpw(0x300,0);



                         // Halt the DSP program execution.
                         // ================================
                         inp(0x307);

                    return noErr;

                    out:
                    return err;
                    }// end CIN
```

B.3 The Displacement Measurement CIN

```
/*
   CIN source file for the PZT movement range measurement.
   The DSP is set to go then the Sampling time and the
   desired signal are written to the DSP, the DSP then
   writes out this value to the outside world reads a value
   which is displayed on the chart, it also calculates and
   transfers the range of the readings.
 */

#include "extcode.h"
#include<stdio.h>
#include<math.h>
#include<conio.h>

CIN MgErr CINRun(int32 *Sampling_Rate, int32 *Frequency,
int32 *Voltage, int32 *Bias,
                float64 *Incoming_Signal, float64
*Outgoing_Signal, float64 *Range);

CIN MgErr CINRun(int32 *Sampling_Rate, int32 *Frequency,
int32 *Voltage, int32 *Bias,
                float64 *Incoming_Signal, float64
*Outgoing_Signal, float64 *Range) {

        // All variables used in this function are declared.
        // ================================================

        int sign, u16_bit, u12_bit, y16_bit, y12_bit;
//Data handling with signed numbers.
        int PAGE_VALUE=0x0,ADDRESSI=0x1388,ADDRESSO=0x1389,
     Timer_Address=0x01387;
        int check, Check_Address=0x1386, Range_Address=0x138a;
        int freq_address=0x138b, bias_address=0x138c,
Voltage_address=0x138d;

                // Start the DSP program execution.
                // ================================

                     inp(0x306);

                // Check if the DSP is done
```

```
                    // =======================

                    while (check != 1)
                            {
                    // The logic to set the frequency
                    // =============================

                    outp(0x306,PAGE_VALUE);
                    outpw(0x302,freq_address);
                    outpw(0x300,(*Frequency));

                    // The logic to set the sampling rate
                    // =================================

                    outp(0x306,PAGE_VALUE);
                    outpw(0x302,Timer_Address);
                    outpw(0x300,((50000000)/(*Sampling_
Rate*8*2)));

                    // The logic to set the Voltage
                    // ===========================

                    outp(0x306,PAGE_VALUE);
            outpw(0x302,Voltage_address);
                    outpw(0x300,(*Voltage));

                    // The logic to set the Bias
                    // ========================

                    outp(0x306,PAGE_VALUE);
                    outpw(0x302,bias_address);
                    outpw(0x300,(*Bias));


                       outp(0x306,PAGE_VALUE);
                       outpw(0x302,Check_Address);
                       check=inpw(0x300);
                      } //endwhile

                    // The Logic to read the Signal going from DSP
                    // =========================================

                    outp(0x306,PAGE_VALUE);
                    outpw(0x302,ADDRESSI);
```

```
                 u16_bit=inpw(0x300);
                 sign=u16_bit & 0x0800;
                 u12_bit=u16_bit & 0x07ff;

                 if(sign==0)
                    {
                      *Incoming_Signal= (float64)
(u12_bit/409.0);
                                  }//endif

                 else
                    {
                       u16_bit=~u16_bit;
                       u16_bit=u16_bit+1;
                       u12_bit=u16_bit&0x0fff;
                       *Incoming_Signal = (float64)
    (u12_bit / (-409.0));
                       if ((*Incoming_Signal) < (-5.0))
                          *Incoming_Signal= -5.0;
                                 }//endelse

                 // The Logic to read the Signal coming to DSP
                 // ==========================================

                 outp(0x306,PAGE_VALUE);
                 outpw(0x302,ADDRESS0);
                 y16_bit=inpw(0x300);
                 sign=y16_bit & 0x0800;
                 y12_bit=y16_bit & 0x07ff;

                 if(sign==0)
                    {
                      *Outgoing_Signal= (float64)
(y12_bit / 409.0);
                                  }//endif

                 else
                    {
                       y16_bit=~y16_bit;
                       y16_bit=y16_bit+1;
                       y12_bit=y16_bit&0x0fff;
                       *Outgoing_Signal = (float64)
(y12_bit / (-409.0));
                       if ((*Outgoing_Signal) < (-5.0))
```

```
                        *Outgoing_Signal= -5.0;
                              }//endelse

               // The Logic to read the range of movement
               // ========================================

               outp(0x306,PAGE_VALUE);
               outpw(0x302,Range_Address);
               y16_bit=inpw(0x300);
               sign=y16_bit & 0x0800;
               y12_bit=y16_bit & 0x07ff;

               if(sign==0)
                  {
                    *Range= (float64) (y12_bit * 2.5
/ 100.0 );
                               }//endif

               else
                  {
                     y16_bit=~y16_bit;
                     y16_bit=y16_bit+1;
                     y12_bit=y16_bit&0x0fff;
                     *Range = (float64) (y12_bit
* 2.5 / (-100.0));
                     if ((*Range) < (-12.5))
                        *Range= -12.5;
                              }//endelse

              // The Logic to reset the check
              // ============================

              outp(0x306,PAGE_VALUE);
              outpw(0x302,Check_Address);
              outpw(0x300,0);


        return noErr;
        }
```

B.4 The Resonance Frequency Calculation CIN

```
/*
  CIN source file for the resonant frequency measurement.
  The DSP is set to go then the Sampling time is selected
  and PC waits for the DSP  to finish and then loads all
  data into the LabView arrays.
 */

#include "extcode.h"
#include<stdio.h>
#include<math.h>
#include<conio.h>

/*
 * typedefs
 */

typedef struct {
        int32 dimSize;
        float64 arg1[1];
        } TD1;
typedef TD1 **TD1Hdl;

CIN MgErr CINRun(int32 *Sampling_Rate, TD1Hdl DSP_Input);

CIN MgErr CINRun(int32 *Sampling_Rate, TD1Hdl DSP_Input) {

        /* ENTER YOUR CODE HERE */

        // All variables used in this function are declared.
        // ==================================================

        int sign,u16_bit,u12_bit,i,n;
        int PAGE_VALUE=0x0,ADDRESSI=0x1388,Timer_Address=0x01387;
        int check, Check_Address=0x1386;
        int32 numDims;
        MgErr err=bogusError;

                // Start the DSP program execution.
                // ================================
                n=0;
                //Put the DSP to go
```

```
            inp(0x306);

            // Actual Data Acquisition is carried out.
            // ========================================

            numDims=1;
            n=4095;
            if (err = NumericArrayResize(fD, numDims,
         (UHandle *) &DSP_Input, n))
            goto out;

            (*DSP_Input)->dimSize = n;

            check=0;

            while (check != 1)
               {
                  // The logic to set the sampling rate
                  // ==================================

                  outp(0x306,PAGE_VALUE);
                  outpw(0x302,Timer_Address);
                  outpw(0x300,((50000000)/(*Sampling_Rate
*8*2)));

                  outp(0x306,PAGE_VALUE);
                  outpw(0x302,Check_Address);
                  check=inpw(0x300);
               } //endwhile


            for (i=0;i<n;i++)
                 {
                    // Signal sent by the DSP
                    // ======================

                    outp(0x306,PAGE_VALUE);
                    outpw(0x302,(ADDRESSI+i));
                    u16_bit=inpw(0x300);
                    sign=u16_bit & 0x0800;
                    u12_bit=u16_bit & 0x07ff;

                         if(sign==0)
                           {
```

```
                        (*DSP_Input)->arg1[i]= (float64)
(u12_bit /409.0);
                               }//endif

                            else
                               {
                                  u16_bit=~u16_bit;
                                  u16_bit=u16_bit+1;
                                  u12_bit=u16_bit&0x0fff;
                                  (*DSP_Input)->arg1[i] =
(float64) (u12_bit / (-409.0));
                      if (((*DSP_Input)->arg1[i]) < (-5.0))
                            (*DSP_Input)->arg1[i]= -5.0;
                               }//endelse

                     } //endfor

                // Check is reset to 0.
                outp(0x306,PAGE_VALUE);
                outpw(0x302,Check_Address);
                outpw(0x300,0);



                // Halt the DSP program execution.
                // ================================
                inp(0x307);

        return noErr;

        out:
        return err;
        }// end CIN
```

B.5 The PI Control CIN

```
/*
  CIN source file for PI control. The DSP is set to go
  then the Sampling time, reference, KI, KP, and Bias
  are wriiten to the DSP, the DSP then writes out this
  value to the outside world reads a value which is
  displayed on the chart, it also calculates controls
  the plant with PI algorithm.
 */

#include "extcode.h"
#include<stdio.h>
#include<math.h>
#include<conio.h>

CIN MgErr CINRun(int32 *Sampling_Rate, int32 *Reference,
  int32 *KI, int32 *KP,
                        int32 *Bias, int32 *in,
float64 *Yn, float64 *Un);

CIN MgErr CINRun(int32 *Sampling_Rate, int32 *Reference,
int32 *KI, int32 *KP,
                        int32 *Bias, int32 *in,
float64 *Yn, float64 *Un) {

        /* ENTER YOUR CODE HERE */
        // All variables used in this function are declared.
        // ================================================

        int sign, u16_bit, u12_bit, y16_bit, y12_bit;
        int PAGE_VALUE=0x0,ADDRESSI=0x1388,ADDRESSO=0x1389,
Timer_Address=0x01387;
        int check, Check_Address=0x1386,
Reference_Address=0x138d;
        int KI_address=0x138c, KP_address=0x138b,
Bias_address=0x138a;

                // Start the DSP program execution.
                // ===============================

                        if (*in < 2)
                inp(0x306);

        // Check if the DSP is done
        // ========================

        while (check != 1)
                {

        // The logic to set the Reference
        // ==============================

        outp(0x306,PAGE_VALUE);
        outpw(0x302,Reference_Address);
        outpw(0x300,(*Reference));

        // The logic to set the sampling rate
        // ==================================

        outp(0x306,PAGE_VALUE);
        outpw(0x302,Timer_Address);
        outpw(0x300,((50000000)/(*Sampling_Rate
*8*2)));

        // The logic to set the KI
        // =======================

        outp(0x306,PAGE_VALUE);
        outpw(0x302,KI_address);
        outpw(0x300,(*KI));

        // The logic to set the Bias
        // =========================

        outp(0x306,PAGE_VALUE);
        outpw(0x302,Bias_address);
        outpw(0x300,(*Bias));


        // The logic to set the KP
        // =========================

        outp(0x306,PAGE_VALUE);
        outpw(0x302,KP_address);
        outpw(0x300,(*KP));
```

```
      // The Check is read
      // ================

      outp(0x306,PAGE_VALUE);
      outpw(0x302,Check_Address);
      check=inpw(0x300);

   } //endwhile

// The Logic to read the Signal going from DSP
// ===========================================

outp(0x306,PAGE_VALUE);
outpw(0x302,ADDRESSI);
u16_bit=inpw(0x300);
sign=u16_bit & 0x0800;
u12_bit=u16_bit & 0x07ff;

if(sign==0)
   {
     *Un= (float64) (u12_bit / 409.0);
                }//endif

else
   {
      u16_bit=~u16_bit;
      u16_bit=u16_bit+1;
      u12_bit=u16_bit&0x0fff;
      *Un = (float64) (u12_bit / (-409.0));
      if ((*Un) < (-5.0))
         *Un= -5.0;
               }//endelse

// The Logic to read Signal coming to DSP
// ======================================

outp(0x306,PAGE_VALUE);
outpw(0x302,ADDRESSO);
y16_bit=inpw(0x300);
sign=y16_bit & 0x0800;
y12_bit=y16_bit & 0x07ff;

if(sign==0)
```

```
              {
                *Yn= (float64) (y12_bit / 409.0);
                             }//endif

           else
              {
                 y16_bit=~y16_bit;
                 y16_bit=y16_bit+1;
                 y12_bit=y16_bit&0x0fff;
                 *Yn = (float64) (y12_bit / (-409.0));
                 if ((*Yn) < (-5.0))
                    *Yn= -5.0;
                           }//endelse

          // The Logic to reset the check
          // ============================

          outp(0x306,PAGE_VALUE);
          outpw(0x302,Check_Address);
          outpw(0x300,0);

 return noErr;
 } //endmain
```

APPENDIX C

THE DSP PROGRAMS

C.1 DSP Program for the DSP Block Program

```
#define TIMPER0 0x186A
#include "D310BIO.H"
void main()
{
        int *input_pointer,*output_pointer, *check, output;
        int *timer_pointer,desired_rate;
        timer_pointer=(int *)0x1387;
        *timer_pointer=TIMPER0;
        desired_rate=*timer_pointer;
        input_pointer=(int *)0x1388;
        output_pointer=(int *)0x1389;
        check=(int *)0x1386;
        InitDsp();
                while(1)   {
                 if (*timer_pointer != desired_rate)
                        {
                        int *p7;
                        p7=(int *)CTRL;
                        *(p7+0x28)=*timer_pointer;
                        *(p7+0x20)=TIMGB0START;
                        desired_rate=*timer_pointer;
                        }
                        if (*output_pointer > 2047)
                                        {
           *output_pointer = 65535 - (*output_pointer) + 1;
           *output_pointer = (*output_pointer * -1);
                                        }
                             if (*output_pointer < -2047)
           *output_pointer = *output_pointer & 0x0000ffff;
                *input_pointer=ReadAdc(0);
                output=*output_pointer;
                WriteDAC(output,0);
                *check=1;
                }//end while
//end main
```

C.2 The Hysteresis Program

```
#define TIMPER0 0x7a12
#include "D310BIO.H"
void main()
{
        int *input_pointer,*output_pointer;
        int *timer_pointer,desired_rate;
        int i,*check, *voltage, output;
        timer_pointer=(int *)0x1387;
        check=(int *) 0x1386;
        voltage=(int *) 0x1385;
        *timer_pointer=TIMPER0;
        desired_rate=*timer_pointer;
        input_pointer=(int *)0x1388;
        output_pointer=(int *)0x2788;
        InitDsp();
        WriteDAC (0,0);
        WriteDAC (0,1);
        *check=0;
        *voltage=(1 * 2047 / 5);
                while(1)
                {
                     for (i=0;i<2047;i++)
                           {
                  if (*timer_pointer != desired_rate)
                      {
                         int *p7;
                         p7=(int *)CTRL;
                         *(p7+0x28)=*timer_pointer;
                         *(p7+0x20)=TIMGB0START;
                         desired_rate=*timer_pointer;
                               }//endif

                 if (i<410)
                   *input_pointer=i; // Going upto 1 volt.

                 if (i>409 && i<1227)
                   *input_pointer=(*(input_pointer-1))-1;

                 if (i>1226 && i<2047)
                   *input_pointer=(*(input_pointer-1))+1;
                  output= (int) ((*input_pointer)
* (*voltage) / 409);
                  WriteDAC(output,0);
                  *output_pointer= ReadAdc(0);

                  input_pointer++;
                  output_pointer++;

                  if (i == 2046 )
                     {
                       input_pointer=(int *)0x1388;
                       output_pointer=(int *)0x2788;
                                        } // endif

                              }//endfor

                              *check=1;
              }// endwhile

}
```

C.3 The Displacement Calculation Program

```
#define TIMPER0 0x138
#include "D310BIO.H"
#include <math.h>
#define PI              3.14159265358979

void main()
{
        int *input_pointer,*output_pointer;
        int *timer_pointer,desired_rate;
        int *check, *range, max, min, n;
        int *frequency, *bias, *voltage;
        double theta, Ts;

        frequency=(int *)0x138b;
        bias=(int *)0x138c;
        voltage=(int *)0x138d;
        timer_pointer=(int *)0x1387;
        check=(int *) 0x1386;
        range=(int *) 0x138a;
        input_pointer=(int *)0x1388;
        output_pointer=(int *)0x1389;

        *timer_pointer=TIMPER0;
        desired_rate=*timer_pointer;
        InitDsp();
        WriteDAC (0,0);
        WriteDAC (0,1);
        *check=0;
        *range=0;
        *frequency=5;
        *bias=0;
        *voltage=1;

        WriteDAC(0,0);
        max=0;
        min=max;
        n=0;

                while(1)
                {
                   if (*timer_pointer != desired_rate)
```

```
                        {
                          int *p7;
                          p7=(int *)CTRL;
                          *(p7+0x28)=*timer_pointer;
                          *(p7+0x20)=TIMGB0START;
                          desired_rate=*timer_pointer;
                                 }//endif

                          Ts = (*timer_pointer) / 3125000.0;
                          theta = (double) (2 * PI *
    (*frequency / 100.0) * n * Ts);
                          *input_pointer= (int) (((*voltage
         *409 / 100 ) *
         sin (theta)) + (*bias * 409 / 100));
                          n++;
                          if (theta == 2* PI)
                          n=0;

                          WriteDAC(*input_pointer,0);
                          *output_pointer= ReadAdc(0);

                          if (theta > (PI/2) &&
(*output_pointer) > max)
                                    max=*output_pointer;

                          if (theta > (3 * PI / 2) &&
(*output_pointer) < min)
                                    min=*output_pointer;

                 if ((max - min) >0)
                         *range=(max-min) * 100 / 409;
                         *check=1;

           }// endwhile

} // endmain
```

C.4 The Program for Resonance Frequency

```
#define TIMPER0 0x7a12
#include "D310BIO.H"
void main()
{
        int *input_pointer;
        int *timer_pointer,desired_rate;
        int i,*check;
        timer_pointer=(int *)0x1387;
        check=(int *) 0x1386;
        *timer_pointer=TIMPER0;
        desired_rate=*timer_pointer;
        input_pointer=(int *)0x1388;
        InitDsp();
        WriteDAC (0,0);
        WriteDAC (0,1);
        *check=0;
        while(1)
           {
              for (i=0;i<5000;i++)
                 {
                   if (*timer_pointer != desired_rate)
                       {
                          int *p7;
                          p7=(int *)CTRL;
                          *(p7+0x28)=*timer_pointer;
                          *(p7+0x20)=TIMGB0START;
                          desired_rate=*timer_pointer;
                         }//endif

                        *input_pointer= ReadAdc(0);
                               WriteDAC(0,0);
                               input_pointer++;
                           }//endfor
                               *check=1;
             }// endwhile

 }//end main
```

C.5 The Proportional Integral Control Program

```
#define TIMPER0 0x138
#include "D310BIO.H"
#include <math.h>
#define PI            3.14159265358979

void main()
{
        // All variables are declared
        // =========================

        int *input_pointer,*output_pointer;
        int *timer_pointer,desired_rate;
        int *check;
        int *bias, *KP, *KI, *reference;
        double Ts, ref, KP_dbl, KI_dbl;
        double un, yn, yn_1, en, en_1;

        // All pointers are addressed
        // =========================

        bias=(int *)0x138a;
        timer_pointer=(int *)0x1387;
        check=(int *) 0x1386;
        input_pointer=(int *)0x1388;
        output_pointer=(int *)0x1389;
        KP=(int *) 0x138b;
        KI=(int *) 0x138c;
        reference=(int *) 0x138d;

        // All pointers are initialized
        // ===========================

        *timer_pointer=TIMPER0;
        desired_rate=*timer_pointer;
        *check=0;
        *bias=0;
        *KP=20;
        *KI=1000;
        *reference=100;
        en_1=0;
        yn_1=0;
        InitDsp();

        WriteDAC(0,0);
        WriteDAC(0,1);

                while(1)
                 {
                  if (*timer_pointer != desired_rate)
                    {
                      int *p7;
                      p7=(int *)CTRL;
                      *(p7+0x28)=*timer_pointer;
                      *(p7+0x20)=TIMGB0START;
                      desired_rate=*timer_pointer;
                    }//endif

                    Ts = (*timer_pointer) / 3125000.0 ;

                    if (*reference > 2047)
                        {
                        *reference = 65535-(*reference)+1;
                        *reference = (*reference * -1);
                                        }
                        if (*reference < -2047)
                           {
                            *reference = *reference &
0x0000ffff;
                           }

                         ref= (double) 0.01 * (*reference);
                         *input_pointer=ReadAdc(0);
                         un= 5.0 / 2047.0 * (*input_pointer);
                         en= ref - un;
                         KP_dbl=(*KP)*0.01;
                         KI_dbl=(*KI)*0.01;
                         yn = ( yn_1 + (KP_dbl + KI_dbl * Ts)
* en - KP_dbl * en_1 );

                                if (yn > 4.997)
                                        yn=4.997;
                                if (yn < -4.997)
                                        yn=-4.997;
```

```
                                    *output_pointer= (int) 2047.0
/ 4.9976 * yn;

                                    if (*output_pointer > 2047)
                                          *output_pointer = 2046;
                                    if (*output_pointer < -2047)
                                          *output_pointer = -2040;

                                    WriteDAC (((*output_pointer) +
(*bias * 409)),0);


                                    en_1=en;
                                    yn_1=yn;

                                    *check=1;

            }// endwhile

} // endmain
```

REFERENCES

1. Texas instruments *TMS320C31 Addendum to the TMS320C3x User's Guide*, 1990.
2. Texas instruments, *TMS320C3x User's Guide*, 1990.
3. Texas instruments *TMS320 Floating-point DSP optimizing C Compiler*, 1995.
4. Dalanco Spry, 89 Westland Ave, Rochester, NY. *TMS320 Floating-point DSP optimizing C Compiler*, 1995.
5. Geoff Lee. *Object Oriented GUI Application Development.* Prentice Hall Englewood Cliffs, NJ 1993.
6. Mark A. Krasnoselski, Aleksei V. Pokrovski. *Systems with Hysteresis*, Springer-Verlag, NY 1989.
7. Karl J. Astrom, Bjorn Wittenmark. *Computer Controlled Systems Theory And Design*, Prentice Hall, Upper Saddle River, NJ 1997
8. Tian Hong *Control of Smart Structure using adaptive dither* Masters Thesis Department of Electrical and Computer Engineering New Jersey Institute of Technology, Newark, NJ , 1994
9. http://www.lassp.cornell.edu/sethna/hyteresis/WhatIsHysteresis.html *What is Hysteresis.*, 12/22/98.
10. National Instruments *LabVIEW User Manual*, Jan 1998.
11. National Instruments *G programming Reference Manual*, Jan 1998.
12. National Instruments *LabVIEW Function and VI Reference Manual*, Jan 1998.
13. R.M. Evan-Iwanowski. In R. Cooper, editor, *Resonance Oscillations in Mechanical Systems*, Elsevier Scientific publishing company, New York, 1976.